Exhibit 1

STATE OF COLORADO

Colorado Water Conservation Board
Department of Natural Resources
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Denver, Colorado 80203
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John W. Hickenlooper
Governor

Mike King
DNR Executive Director

James Eklund
CWCB Director

TO: Colorado Water Conservation Board Members

FROM: Linda Bassi, Chief
Jeff Baessler, Deputy Chief
Stream and Lake Protection Section

DATE: January 15, 2014

SUBJECT: **Agenda Item 29, January 27-28, 2014 Board Meeting**
Stream and Lake Protection Section – New Appropriation Recommendations in Water Divisions 1, 4 and 5

Introduction

This memo provides an overview of the technical analyses that were performed by both the recommending entities and CWCB staff to provide the Board with sufficient information to declare its intent to appropriate in accordance with the Rules Concerning the Colorado Instream Flow and Natural Lake Level Program ("ISF Rules"). Staff's detailed analysis of each stream contained in the "Instream Flow Recommendation Notebook," which was mailed to the Board separately, provides the technical basis for each appropriation.

Staff Recommendation

Staff recommends that, pursuant to ISF Rule 5d., the Board declare its intent to appropriate an instream flow ("ISF") water right on each stream segment listed on the attached Tabulation of Instream Flow and Natural Lake Level Recommendations, and direct Staff to publicly notice the Board's declaration of its intent to appropriate.

Background

Pursuant to ISF Rule 5d., staff is requesting the Board to declare its intent to appropriate ISF water rights on the stream segments identified in the attached table. Staff has reviewed each proposed stream segment to ensure that for each ISF recommendation, the data set is complete and standard methods and procedures were followed. In addition, staff has completed its water availability studies. Staff has identified 18 stream segments in Water Divisions 1, 4, and 5 for which sufficient information has been compiled and analyses performed upon which the Board can base its intent to appropriate. These segments are located in Larimer, Gunnison, Mesa, Montrose, and Garfield Counties.

Technical Investigations

Staff's executive summary and technical analysis of each stream are contained in the Instream Flow Recommendation Reports and form the basis for staff's recommendations. In addition to the reports, the scientific data and technical analyses performed by the recommending entity are accessible on

the Board's web site at http://cwcb.state.co.us/environment/instream-flow-program/Pages/2013ProposedInstreamFlowAppropriations.aspx.

Natural Environment Studies

The Bureau of Land Management (BLM) and Colorado Parks and Wildlife (CPW) have conducted field surveys of the natural environment resources on these streams and have found natural environments that can be preserved. To quantify the resources and to evaluate instream flow requirements, the BLM and CPW collected biologic and hydraulic data and performed R2CROSS modeling on all segments, and PHABSIM modeling on the Dolores River segment. All of the data and models used to support the recommendation were analyzed and/or reviewed by CWCB staff. Based on the results of these analyses, staff prepared recommendations of the amount of water necessary to preserve the natural environment to a reasonable degree for each of the streams listed on the attached Tabulation of Instream Flow and Natural Lake Level Recommendations.

Water Availability Studies

Staff has conducted an evaluation of water availability for the streams listed. To determine the amount of water physically available for the Board's appropriations, staff analyzed available USGS gage records, available streamflow models, and/or utilized appropriate standard methods to develop a hydrograph of median daily and/or mean monthly flows for each stream flow recommendation. In addition, staff analyzed the water rights tabulation for each stream and consulted with the Division Engineer's Office in the relevant water division to identify any potential water availability problems. Based upon its analyses, staff has determined that water is available for appropriation on each stream to preserve the natural environment to a reasonable degree without limiting or foreclosing the exercise of valid water rights.

Stakeholder Outreach

Staff provided public notice of the recommendations in both March and November of 2013 and met with the County Commissioners for each county where the stream segments were located. In addition, water commissioners and local land owners were contacted when possible to further discuss the recommendations.

For the Dolores River ISF recommendation, staff also met with and gave presentations to the Southwest Colorado Water Conservancy District Board and the Southwest Basin Roundtable. In addition, Staff, BLM and CPW presented information on the Dolores River ISF recommendation and answered questions at the Dolores River Management Coordination Workshop held in Cortez on January 10, 2014. Numerous issues were identified during these meetings, including: 1) the proximity of the ISF reach to the state line; 2) concerns over interstate compacts and the potential effect of an ISF water right during a period of compact curtailment; 3) concerns that an ISF water right could deprive the people of the State of Colorado the beneficial use of waters available by law and interstate compact; 4) concerns that the ISF water right could interfere with future changes of existing uses, or the development of new future water rights; 5) whether the Board intends to include a "future use allocation" as part of the ISF water right; 6) concerns that dry years are not adequately addressed in Staff's water availability analysis; and 7) concerns that the flows quantified to preserve the natural environment are excessive. Although multiple concerns were voiced, staff is confident that sufficient information and analyses have been compiled and performed to support findings that a natural environment exists; that water is available for the appropriation to be made, and that no material injury will occur to water rights. Further, staff intends to continue discussions with stakeholders on these issues.

Numerous stakeholders have also expressed support for the appropriation of Dolores River ISF recommendation. Letters from stakeholders received to date are attached.

Instream Flow Rule 5d.

Rule 5d. provides that the Board may declare its intent to appropriate ISF water rights after reviewing Staff's recommendations for the proposed appropriations. Rule 5d. also sets forth the activities that take place after the Board declares its intent that initiate the public notice and comment procedure for the ISF appropriations. Specifically,

5d. Board's Intent to Appropriate. Notice of the Board's potential action to declare its intent to appropriate shall be given in the January Board meeting agenda and the Board will take public comment regarding its intent to appropriate at the January meeting.

(1) After reviewing Staff's ISF recommendations for proposed ISF appropriations, the Board may declare its intent to appropriate specific ISF water rights. At that time, the Board shall direct the Staff to publicly notice the Board's declaration of its intent to appropriate.

(2) After the Board declares its intent to appropriate, notice shall be published in a mailing to the ISF Subscription Mailing Lists for the relevant water divisions and shall include:

- (a) A description of the appropriation (e.g. stream reach, lake location, amounts, etc.);
- (b) Availability (time and place) for review of Summary Reports and Investigations Files for each recommendation; and,
- (c) Summary identification of any data, exhibits, testimony or other information in addition to the Summary Reports and Investigations Files supporting the appropriation.

(3) Published notice shall also contain the following information:

- (a) The Board may change flow amounts of contested ISF appropriations based on information received during the public notice and comment period.
- (b) Staff will maintain, pursuant to Rule 5e.(3), an ISF Subscription Mailing List for each water division composed of the names of all persons who have sent notice to the Board Office that they wish to be included on such list for a particular water division. Any person desiring to be on the ISF Subscription Mailing List(s) must send notice to the Board Office.
- (c) Any meetings held between Staff and members of the public will be open to the public. Staff may provide Proper Notice prior to any such meetings and may provide notice to persons on the ISF Subscription Mailing List(s).
- (d) Any Notice to Contest must be received at the Board office no later than March 31st, or the first business day thereafter. All Notices of Party status and Contested Hearing Participant status must be received at the Board office no later than April 30th, or the first business day thereafter.
- (e) Staff will announce its Final Staff ISF Recommendation concerning contested appropriations at the September Board meeting and will send notice of the Final Staff Recommendation to all persons on the Contested Hearing Mailing List.
- (f) The Board may take final action on any uncontested ISF appropriations at the May Board meeting.

(4) After the Board declares its intent to appropriate, notice of the Board's action shall be mailed within five working days to the County Commissioners of the county(ies) in which the proposed reach or lake is located.

Attachment

Colorado Water Conservation Board

Instream Flow Tabulation - Streams

Water Division 1

Case Number	Stream	Watershed	County	Upper Terminus	Lower Terminus	Length (miles)	USGS QUADS	Amount(dates) (CFS)	Approp Date
13/1/A-002	Shell Creek	Upper Laramie	Larimer	headwaters in the vicinity of lat 40 55 11N long 105 51 03W	BLM boundary at lat 40 58 53N long 105 52 49W	6.25	Crazy Mountain Sand Creek Pass	1 (11/1 - 3/31) 1.1 (4/1 - 10/31)	

Totals for Water Division 1

Total # of Stream Miles = 6.25

Total # of Appropriations = 1

(Totals do not include donated/acquired water rights)

Instream Flow Tabulation - Water Division 4

Case Number	Stream	Watershed	County	Upper Terminus	Lower Terminus	Length (miles)	USGS QUADS	Amount(dates) (CFS)	Approp Date
14/4/A-006	Dolores River	Lower Dolores	Montrose Mesa	confl San Miguel River at lat 38 22 47N long 108 48 13W	confl West Creek at lat 38 40 39N long 108 58 34W	34.21	Gateway Juanita Arch Red Canyon Roc Creek	200 (3/16 - 4/14) 900 (4/15 - 6/14) 400 (6/15 - 7/15) 200 (7/16 - 8/14) 100 (8/15 - 3/15)	
14/4/A-004	East Creek	Lower Gunnison	Mesa	confl North East Creek at lat 38 55 06N long 108 29 57W	hdgt East Creek Ditch at lat 38 58 27N long 108 27 27W	4.94	Whitewater	1.6 (3/15 - 6/30) 0.25 (7/1 - 3/14)	
14/4/A-007	East Creek	Lower Gunnison	Mesa	East Creek Ditch hdgt at lat 38 58 27N long 108 27 39W	confl Gunnison River at lat 38 58 35N long 108 27 16W	0.37	Whitewater	1.6 (3/15 - 5/31)	
13/4/A-001	Granite Creek	Lower Dolores	Mesa	confl two unnamed tributaries at lat 38 50 57N long 108 57 43W	Colorado-Utah border at lat 38 49 49N long 109 03 21W	5.79	Steamboat Mesa Two V Basin	2.7 (4/1 - 6/30) 0.5 (7/1 - 3/31)	
14/4/A-005 (increase)	Hot Springs Creek	Tomichi Creek	Gunnison	outlet Hot Springs Reservoir at lat 38 30 47N long 106 32 29W	LL Bush Ditch No. 4 hdgt at lat 38 29 23N long 106 35 09W	3.46	Doyleville Pitkin	2.4 (5/1 - 7/21)	
14/4/A-001 (increase)	Oh-Be-Joyful Creek	East-Taylor	Gunnison	confl unnamed tributary at lat 38 54 25N long 107 03 21W	confl Slate River at lat 38 54 37N long 107 01 49W	1.66	Oh-Be-Joyful	3 (4/1 - 4/30) 14 (5/1 - 7/15) 3 (7/16 - 8/15)	
14/4/A-002 (increase)	Slate River	East-Taylor	Gunnison	confl Poverty Gulch at lat 38 56 46N long 107 03 40W	confl Oh-Be-Joyful Creek at lat 38 54 37N long 107 01 49W	3.69	Oh-Be-Joyful	30 (5/1 - 7/15)	
14/4/A-003 (increase)	Slate River	East-Taylor	Gunnison	confl Oh-Be-Joyful Creek at lat 38 54 37N long 107 01 49W	confl Coal Creek at lat 38 52 38N long 106 58 39W	5.63	Gothic Oh-Be-Joyful	45 (5/1 - 7/15)	
12/4/A-001	Ute Creek	Lower Dolores	Mesa	headwaters in the vicinity of lat 38 42 23N long 108 47 16W	confl West Creek at lat 38 43 29N long 108 54 36W	7.87	Gateway Pine Mountain	2 (4/1 - 6/15) 0.3 (6/16 - 3/31)	

Instream Flow Tabulation - Water Division 4

Case Number	Stream	Watershed	County	Upper Terminus	Lower Terminus	Length (miles)	USGS QUADS	Amount(dates) (CFS)	Approp Date

Totals for Water Division 4

Total # of Stream Miles = 67.62

Total # of Appropriations = 9

(Totals do not include donated/acquired water rights)

Instream Flow Tabulation - Water Division 5

Case Number	Stream	Watershed	County	Upper Terminus	Lower Terminus	Length (miles)	USGS QUADS	Amount(dates) (CFS)	Approp Date
12/5/A-001	Beaver Creek	Colorado Headwaters-Plateau	Garfield	headwaters in the vicinity of lat 39 22 48N long 107 51 58W	Dame Ditch hdgt at lat 39 28 06N long 107 49 06W	8.11	North Mamm Peak	0.7 (12/1 - 4/30) 4.75 (5/1 - 6/30) 2.85 (7/1 - 7/31) 1 (8/1 - 11/30)	
12/5/A-002	Beaver Dam Creek	Colorado Headwaters-Plateau	Mesa	headwaters in the vicinity of lat 39 21 29N long 107 26 55W	confl East Divide Creek at lat 39 21 52N long 107 28 22W	1.60	Quaker Mesa	0.14 (11/1 - 4/30) 0.9 (5/1 - 8/31) 0.35 (9/1 - 10/31)	
12/5/A-003	East Divide Creek	Colorado Headwaters-Plateau	Mesa Garfield	confl Gennings Creek at lat 39 20 25N long 107 28 24W	confl Camp Creek at lat 39 23 03N long 107 28 32W	3.49	Center Mountain Quaker Mesa	1.4 (4/1 - 4/15) 4.8 (4/16 - 6/30) 1.5 (7/1 - 7/15) 1.2 (7/16 - 7/30) 0.3 (8/1 - 3/31)	
12/5/A-004	East Divide Creek	Colorado Headwaters-Plateau	Garfield	confl Camp Creek at lat 39 23 03N long 107 28 32W	confl June Creek at lat 39 26 03N long 107 34 51W	9.45	Center Mountain Gibson Gulch	3 (4/1 - 4/15) 7.2 (4/16 - 6/30) 3 (7/1 - 7/31) 1.1 (8/1 - 3/31)	
14/5/A-003	East Fork Parachute Creek	Parachute Creek-Roan Creek	Garfield	confl Bull Gulch at lat 39 33 48N long 108 00 53W	BLM boundary at lat 39 34 34N long 108 01 52W	1.28	Forked Gulch	5 (4/15 - 6/30) 0.65 (7/1 - 4/14)	
14/5/A-004	Left Fork Carr Creek	Parachute Creek-Roan Creek	Garfield	headwaters in the vicinity of lat 39 35 26N long 108 36 52W	Franklin Ditch # 2 hdgt at lat 39 33 25N long 108 30 32W	6.43	Henderson Ridge	0.75 (11/1 - 3/31) 2 (4/1 - 8/31) 1 (9/1 - 10/31)	
12/5/A-006	Meadow Creek	Colorado Headwaters-Plateau	Garfield	outlet of Meadow Creek Reservoir at lat 39 48 25N long 107 32 44W	confl Main Elk Creeek at lat 39 42 19N long 107 34 05W	8.21	Deep Creek Point Meadow Creek Lake	1.3 (10/1 - 3/31) 2.1 (4/1 - 9/30)	

Instream Flow Tabulation - Water Division 5

Case Number	Stream	Watershed	County	Upper Terminus	Lower Terminus	Length (miles)	USGS QUADS	Amount(dates) (CFS)	Approp Date
12/5/A-005	West Divide Creek	Colorado Headwaters-Plateau	Mesa	confl Little Beaver Creek at lat 39 16 14N long 107 27 31W	confl Mosquito Creek at lat 39 18 26N long 107 33 43W	8.11	Quaker Mesa Flatiron Mountain	4.2 (3/15 - 4/15) 14.1 (4/16 - 7/15) 4.2 (7/16 - 7/31) 1.14 (8/1 - 3/14)	

Totals for Water Division 5

Total # of Stream Miles = 46.68

Total # of Appropriations = 8

(Totals do not include donated/acquired water rights)

Report Totals

Total # of Stream Miles = 120.55

Total # of Appropriations = 18

(Totals do not include donated/acquired water rights)

Exhibit 2

United States Department of the Interior

BUREAU OF LAND MANAGEMENT
Colorado State Office
2850 Youngfield Street
Lakewood, Colorado 80215-7210
www.co.blm.gov

In Reply Refer To:
7250 (CO-930)

DEC 2 4 2013

Ms. Linda Bassi
Colorado Water Conservation Board
1313 Sherman Street, Room 721
Denver, Colorado 80203

Dear Ms. Bassi:

The Bureau of Land Management (BLM) is writing this letter to formally communicate its instream flow recommendation for the lower Dolores River, between the confluence with the San Miguel River and the confluence with West Creek near the town of Gateway. The importance of this stream reach has led to cooperation between the BLM and the Colorado Parks and Wildlife (CPW) to document the natural environment and implement cooperative studies to determine the flow rates needed to support the natural environment.

This portion of the river is known to provide habitat for flannelmouth sucker, bluehead sucker and roundtail chub, large-bodied native fish endemic to rivers and streams of the Colorado Plateau. The BLM and the CPW are signatories to a multi-state conservation agreement designed to protect and enhance habitat for these species, with the objective of preventing a listing of these species under the Endangered Species Act. This agreement is entitled "*Range-Wide Conservation Agreement and Strategy for Roundtail Chub (*Gila robusta*), Bluehead Sucker (*Catostomus discobolus*) and Flannelmouth Sucker (*Catostomus latipinnis*) 2006*" and is also known as the "Three Species Agreement." Establishment of instream flow protection for streams known to provide habitat for the species is identified as a priority conservation action under this agreement. In addition, the BLM has identified habitat for the three species as an "outstandingly remarkable value" as part of the BLM's evaluation of this river pursuant to the Wild and Scenic Rivers Act. Appropriation of an instream flow water right is a crucial component of protecting the habitat for these species that occurs on BLM lands.

Broadly-based stakeholder groups have also recommended to the BLM that water-dependent values be protected on this stream reach. An independently-formed stakeholder group, which analyzed streams in the Grand Junction Field Office planning area, recommended that the portion of the Dolores River in Mesa County be protected by a state-based instream flow water right. A broad-based stakeholder group convened by the BLM's Resource Advisory Council, which analyzed streams in Montrose County, recommended that 4.2 miles of this stream reach in Montrose County be determined as "suitable" for designation into the National Wild and Scenic Rivers System.

Protection of instream flows on this section of the Dolores River will also support a major partnership effort to restore riparian habitat along the river. The Dolores River Restoration Partnership has treated more than 415 acres of tamarisk, Siberian elm and weeds along this reach of the river. In addition to the BLM, the partnership includes the CPW, The Nature Conservancy, The Walton Foundation, the Tamarisk Coalition, Colorado Department of Transportation, Montrose County, Mesa County and multiple youth conservation corps. To date, the partnership has invested more than $2.2 million of state, federal, foundation, and non-government organization funds in restoring this reach of the river. The partnership predicts that an additional $575,000 will be expended within this reach in future years on follow-up treatments, monitoring, and long-term maintenance of treated lands. These future expenditures include a $100,000 grant from the Colorado Water Conservation Board (CWCB).

The BLM believes that instream flow protection for these values can be achieved while allowing water to be developed for current and future needs, including municipal, industrial and agricultural uses. The BLM is willing to meet with water users and stakeholders within the watershed to discuss any concerns they may have about the impact of the proposed appropriation on future water uses and development. The BLM is also willing to provide all of the supporting data to interested parties for their review. The BLM requests the CWCB proceed with its appropriation process at the regularly scheduled board meeting in January 2014, given that meetings to date with stakeholders in the Dolores River watershed have not revealed any significant reasons for a delay.

Enclosures to this letter provide specific information with regard to recommended flow rates, habitat analysis, biological characteristics, and water availability.

If you have any questions regarding this formal recommendation, please contact Roy Smith, BLM Water Rights Specialist, at (303) 239-3940.

Sincerely,

John Mehlhoff
Acting State Director

Enclosures

cc: Barbara Sharrow, Uncompahgre Field Office
Jedd Sondergard, Uncompahgre Field Office
Valori Armstrong, Southwest District
Katie Stevens, Grand Junction Field Office
Nate Dieterich, Grand Junction Field Office
Jim Cagney, Northwest District

Enclosure 1 – Dolores River Instream Flow Recommendation

Biological Summary

Fisheries

Fishery surveys taken during 2007, 2009 and 2010 by the Colorado Parks and Wildlife (CPW) indicate that the stream environment supports bluehead sucker (*Catostomus discobolus*), flannelmouth sucker (*Catostomus latipinnis)*, roundtail chub (*Gila robusta*) and speckled dace (*Rhinichthys osculus*). The surveys indicated that, depending upon the location with the reach, 76% to 89% of the fish captured were native species. All three species that are subject to the "Three Species Agreement" were present in all of the sampled locations, and all three species were represented by individuals of multiple age classes. Based upon the data currently available, this reach of the Dolores River appears to be one of the best populations of the three native fishes within the Dolores River watershed, and represents an intact and functional assemblage of native warm water fish. In addition, phenology of the two sucker species do not indicate any hybridization with non-native white suckers, which occurs within the other major river basin in western Colorado (Colorado, White and Yampa Rivers). Accordingly, the CPW manages this reach as a Category 204 Native Fish Conservation Stream.

Roundtail chub is recognized by the State of Colorado as a species of special concern. The roundtail chub, flannelmouth sucker and bluehead sucker are considered sensitive species by the Bureau of Land Management (BLM). Criteria that apply to the BLM sensitive species include the following: 1) species under status review by the U.S. Fish and Wildlife Service; or 2) species with numbers declining so rapidly that federal listing may become necessary; or 3) species with typically small and widely dispersed populations; or 4) species inhabiting ecological refugia or other specialized or unique habits. The three species meet the first two of the criteria listed above, qualifying them as "sensitive species."

The BLM, the CPW and others have developed the "Range-Wide Conservation Agreement and Strategy" described earlier to direct management for these species. These species are not currently federally listed under the Endangered Species Act. The range-wide plan provides direction and goals for research and management of projects. The success of management strategies will depend upon the voluntary implementation of these strategies by the signatories. Special attention will need to be given to habitat degradation and influence of non-native species interactions within the native range of these species. The intention of these plans is to increase populations and distribution of the identified species, thereby assisting in the long-term persistence of the species.

The success of such plans could potentially curtail the need for federal listing of these species under the Endangered Species Act (ESA). Specifically, when the U.S. Fish and Wildlife Service found the roundtail chub "warranted, but precluded" for listing under the ESA, it noted "Addressing the needs of candidate species before the regulatory requirements of the Endangered Species Act come into play often allows greater flexibility to stabilize or restore these species and their habitats."

Macroinvertebrates

The BLM collected macroinvertebrate surveys during July 2013. The BLM utilized a sampling protocol developed by the National Aquatic Monitoring Center (NAMC), designed to generate data sufficient to characterize the status and trend of aquatic macroinvertebrate assemblages, including quantifying the effects of human disturbances and/or restoration actions. The results of this survey will be available by January 2014. The BLM will provide these results to the Colorado Water Conservation Board, along with our analysis of health and status of the macroinvertebrate community.

Riparian Community

The Dolores River riparian community has been heavily impacted by invasion of non-native tamarisk. Depending upon the location, the tamarisk component of the riparian community can range from 10 to 80% of vegetation cover. However, there are still extensive occurrences of native species, including Rio Grande cottonwood, narrow-leaf cottonwood, box elder, coyote willow, skunkbrush and New Mexico privet. In many locations, tamarisk dominates the zone immediately adjacent to the river channel and native species dominate the first terrace that is slightly elevated above the river channel. Even with the tamarisk impact, the river banks are in stable condition and excessive erosion does not appear to be impacting the aquatic community.

As mentioned previously, the Dolores River Restoration Partnership is making a major investment in treating the invasive species along the river. The Partnership's objective is to increase the vigor and extent of native riparian species, including Rio Grande cottonwood, narrow-leaf cottonwood, box elder, coyote willow, New Mexico privet, skunkbrush, and an understory of native grasses and forbs For the river corridor to successfully transition back to a vegetation community dominated by native species, a supporting hydrologic regime will be required that provides periodic flooding and maintains groundwater levels within the root zone of the riparian community.

While the proposed instream flow water right doesn't protect the highest flood flows, the BLM and the CPW believe that the proposed seasonal variations in flow rates will provide good support for groundwater levels in near-stream alluvial deposits. This support is accomplished by protecting stream flow during the snowmelt runoff period, the flows that recharge near-stream alluvium deposits. In addition, by protecting base flows during seasonally dry periods, alluvial groundwater can be maintained during high temperature and high evapotranspiration periods. Maintenance of groundwater levels in near-stream alluvial deposits during both periods will sustain the health and vigor of the riparian community.

Enclosure 2 – Dolores River Instream Flow Recommendation

Flow Quantification Methodology

PHABSIM and R2CROSS Methodology

The Colorado Parks and Wildlife (CPW) and the Bureau of Land Management (BLM) evaluated all of the data collected to date and determined that best flow recommendation would be derived from a combination of methods. PHABSIM (Physical Habitat Simulation) is a widely accepted method for quantifying the suitable versus unsuitable hydraulic habitat attributes of selected species and life stages as a function of discharge. R2CROSS is best suited for identifying flows with specific hydraulic criteria across riffle type habitats. The State of Colorado has used R2CROSS extensively in the past to appropriate instream flow water rights. PHABSIM is widely used in North America to quantify instream flow requirements, and it has been utilized previously by the Colorado Water Conservation Board to quantify instream flow appropriations.

The CPW and the BLM determined that exclusive use of the standard R2CROSS method would not be appropriate for this reach of the Dolores River. Historically, R2CROSS has been used in small to medium-sized streams with a high percentage of riffle habitat. In contrast, the Dolores River has a wide channel (over 100 feet wide in most places), supports different types of fish species than are typically found in smaller streams in Colorado (warm/cool water species) and exhibits big river channel hydraulics that include extensive run, pool and glide habitat and very low gradient. In addition, only a very small percentage of the fish habitat in this reach is comprised of riffles. For these reasons, the CPW and the BLM decided to utilize PHABSIM results to develop flow recommendation for the snowmelt runoff months between March and August. This is the portion of the year when the three sensitive species are using run, pool, glide and riffle habitat to complete important parts of their life cycles, such as spawning and recruitment of young-of-the -year. A diversity of habitat availability is critical during this period for maintaining the biomass and age class structure of the three sensitive fish species.

The CPW and the BLM decided to use the R2CROSS methodology to develop flow recommendations during the base flow portions of the year from August through March. This is the period when there is substantial competition between individuals for physical habitat space, foraging areas and limited food supplies. During this period, it is critical for the three species to be able to move between habitat areas to make full use of the limited physical habitat. Riffles are the first location where low flows can limit passage between habitat types, so it as appropriate to develop flow recommendations that focus on the fish passage function.

To select an appropriate location for PHABSIM modeling, the CPW and the BLM staff conducted reconnaissance throughout the 34-mile reach to identify its typical habitat characteristics, including channel widths, substrate types, depths and velocities. The CPW and the BLM staff then selected an 1800-foot reach of stream, located approximately seven miles upstream from the town of Gateway, as a location that could represent the full variety of habitat types found within the 34-mile reach. The CPW and the BLM staff established and monumented seven transects that incorporate different mesohabitat types including riffles, runs, pools and

glides. These seven different cross-sections formed the basis for the PHABSIM/River Habitat Simulation (RHABSIM) study conducted by the CPW and the BLM.

The CPW and the BLM staff also ran data from the seven cross sections through the R2CROSS model. Since the seven cross sections include only one cross section of riffle habitat, the CPW and the BLM staff also collected data from four additional representative riffle cross sections at other locations on the river. The additional cross section data collection was designed to increase the reliability of the R2CROSS model in predicting hydraulic characteristics that would be experienced at various flow rates within the 34-mile reach.

The initial recommendations based on the PHABSIM and R2CROSS modeling are designed to address the unique biologic requirements of this stream reach without regard to water availability. In addition to the criteria developed using the PHABSIM Methodology and RHABSIM Software, the three standard instream flow hydraulic parameters used in R2CROSS (average depth, percent wetted perimeter and average velocity) were also used to calculate and inform the biologic instream flow recommendations.

Relationship Between Life History of The Three Fish Species and Use of PHABSIM and R2CROSS Methodologies

The decision by the CPW and the BLM to utilize both the PHABSIM and R2CROSS methodologies is directly related to the life history of flannelmouth sucker, bluehead sucker and roundtail chub. Specifically, snowmelt runoff flows are critically important during certain life stages of this fish, and maintenance of base flows is critically important for other life stages. A summary of the life history of these three species is as follows:

- Late winter - early spring (pre-peak snowmelt period), March - April: low elevation streams in western Colorado often surge in response to melt of low elevation snowmelt, spring storms and early ripening of the snowpack in higher terrain, and water begins warming in response to longer days and warmer air temperatures. Along with an increasing photo-period, these hydrologic cues signal native fish to navigate toward likely spawning sites. Flannelmouth suckers and bluehead suckers have been known to travel long distances toward habitual spawning areas. In addition, increased flows during this period also mobilize fine sediments that may have settled during localized late-summer or fall monsoon storms, improving conditions in cobbles for spawning.

- Peak snowmelt runoff: In the Lower Dolores River, peak runoff occurs anywhere from mid-April thru mid-June, and has multiple benefits for native species. First, peak flows clear riffles of sediment and often re-set bed sediments to provide optimal aeration for deposited eggs. Second, peak flows are critical for maintaining habitat diversity within the stream channel, critical for support of all life stages of native fish. Especially important for emerging fry are side-channel and backwater sites that become refugia for young fish. Third, peak flows are critical for redistributing sediments, creating new instream and near-stream habitat and invigorating riparian processes (recall prior note about the importance of alluvial groundwater). Ramping flows on the descending side of the hydrograph are important so that fish have time to move to habitats where they will

spend most of the next 8 months of their lives. Spawning for bluehead suckers and flannelmouth suckers may occur during pre-peak or post-peak periods of the hydrograph, and fry emergence and dispersal shortly thereafter (7-10 days) is aided by continuing high flows and subsequent drift to side-channel, low velocity sites. Roundtail chub generally spawn at higher water temperatures than the sucker species, but soon after peak snowmelt runoff to allow for proper growth prior to winter.

- Baseflow: July - February: Adequate baseflow conditions are critical for survival of native fish for a few reasons. First, as young-of-the-year fish mature during summer, they venture from refugia into the main channel where larger adult and juvenile fish also survive. They need enough wetted perimeter and available habitats to survive predation and competition from both native (roundtail) and non-native fish. Second, native suckers, particularly bluehead suckers, are primarily foraging fish that feed on algae and detritus within the main channel, and incidental to consumption of vegetation by these fish, is the consumption of a number of high-protein macroinvertebrates that also feed on or inhabit riverine plants. This primary production within the channel is highly dependent on riffles that have both good aeration and available sunlight. Growth during summer baseflow months is critical to provide fish the resiliency needed to survive the winter, when forage is scarce. Baseflow during winter months is necessary to provide enough habitat variety to overwinter both young-of-the-year, juvenile, and adult fish and to provide enough mobility so that fish can escape predation or find more advantageous habitats as seasonal conditions evolve.

It is important also to recognize that these native fish evolved within the Colorado Plateau, a region that is hydrologically diverse and variable. Optimal conditions for spawning, growth, and survival were typically unpredictable. Adaptations of these fishes to accommodate this variability include their relatively large body sizes and longevity, as well as their egg-dispersal mechanisms, which favored high volume and low 'investment' in terms of energy required to nurture and care for emerging fry. In essence, these adaptions mimic the hydrologic landscape from which they evolved. This instream flow proposal should maintain, on a minimum basis, the seasonal variations in conditions required for these native fish to persist in the Lower Dolores River.

Application of Habitat Suitability Criteria

Habitat suitability criteria (HSC) were developed from the 2003 Riverine Fish Flow Investigation Study Report (Federal Aid Project F-289-R6) written and performed by Richard Anderson, the CPW Aquatic Researcher, and Gregory Stewart, Department of Geosciences Oregon State University[1]. The basis for this study was a 1999 request from the Colorado Water Conservation Board for the CPW to provide biologically justified instream flow recommendations for the Yampa and Colorado Rivers based on habitat and flow requirements for non-endangered native fish. Anderson and Stewart used two-dimensional (2D) modeling to develop habitat suitability criteria for bluehead and flannelmouth suckers, two native species.

[1] See "Impacts of stream flow alterations on native fish abundance and native fish habitat and the use of native fish population data to support instream flow recommendations made using a 2D instream flow methodology."

Their methods and results are more fully described in Anderson and Stewart (2003) and Stewart and Anderson (2005) and (2006).

The bluehead and flannelmouth sucker habitat suitability criteria were used to develop specific hydraulic criteria that were incorporated into a PHABSIM/RHABSIM analysis. Stewart and Anderson determined that "Abundance of bluehead sucker was a reliable indicator for instream flows and habitat maintenance for the native fish assemblage. In the Colorado, Gunnison and Yampa Rivers bluehead sucker habitat peaked at flows of 600 to 1,200 cfs. This flow range also resulted in high habitat diversity and high native fish biomass." Their assumption that flows that maintained adequate bluehead sucker abundance (about 25% of fish over 15 cm) would also maintain adequate flannelmouth sucker and roundtail chub habitat was validated by this study.

The CPW and the BLM determined that the flannelmouth sucker and bluehead sucker would be the primary indicator species for the biologically based instream flow recommendation. The reason for considering the needs of both species is that they have somewhat different habitat preferences. Flannelmouth sucker have stronger preference for pool, glide and run habitats, while bluehead sucker abundance is directly related to availability and quality of riffle habitats. Roundtail chub primarily utilize habitats with slower velocities, typically found in pools. The CPW and the BLM determined that if sufficient flows were protected for flannelmouth sucker and bluehead sucker needs, there would also be sufficient water to maintain pool habitats relied upon by roundtail chub.

When developing recommendations for flow rates to support flannelmouth sucker and bluehead sucker, The CPW and the BLM personnel examined tables and graphs produced by the PHABSIM model that show amounts of "weighted usable area" (suitable habitat) available at various flow rates for each of the two species. The CPW and the BLM personnel then identified the most efficient flow rate for providing habitat protection. In this case, the most efficient flow rate is defined as the minimum flow rate that protects at least 90 percent of the habitat that is potentially available within the stream channel for both species. For example, if a PHABSIM modeling run showed that an equal amount of weighted usable area was available at either of two different flow rates, then lower flow rate was identified for protection because it is more efficient.

When identifying minimum flow rates, the CPW and the BLM personnel also considered the amount of time weighted usable area is available in the Dolores River channel, specifically the number of days within a calendar year. The CPW and the BLM considered this factor because much of the potential habitat in the Dolores River is typically available during a 2-month period during the peak of snowmelt runoff between April 15 and June 14. This peak snowmelt period comprises only 16.7% of the calendar year. There are certain life functions of the species that can only occur during this very short period, so protecting the high flow rates associated with snowmelt runoff is essential if the long-term viability of these conservation populations is to be ensured.

Application of R2CROSS Criteria

The primary objective of most cross section methodologies, including R2CROSS, is to maintain quality riffles. Riffles are the most vulnerable habitat to dewatering and riffles are important for

invertebrate productivity. As noted previously, riffles comprise only a very small portion of the total habitat area in this stream reach, so the importance of maintaining riffle habitats is magnified even further. The CPW and the BLM performed a reconnaissance to identify the various types of riffles within this stream reach, based upon width, substrate, and average water velocity. The two agencies then selected four representative riffles for further R2CROSS analysis.

The CPW and the BLM personnel applied the following R2CROSS criteria in evaluating the R2CROSS modeling runs:

- Maintain 70% of wetted perimeter, given that the channel width typically exceeds 60 feet. These criteria are taken from Nehring, R.B., 1979, "Evaluation of instream flow methods and determination of water quanity needs for streams in the State of Colorado."
- Maintain 1.3 feet per second average velocity and maintain 1.0 average depth, which creates at least marginally suitable habitat for flannelmouth sucker and bluehead sucker. These criteria are taken from the 2003 Riverine Fish Flow Investigation Study Report referenced earlier in this letter.

The R2CROSS model provides reliable predictive results for flows that are up to 250% of the flow measured during the data collection effort. It also provides reliable predictive results for flows down to 40% of the flow measured during the data collection effort. This range, from 40% to 250% of flows measured during the data collection, is referred to as the "confidence interval" for R2CROSS modeling. When the flow rate that meets the instream flow criteria fell outside of this confidence interval, data from that cross section were not used to develop instream flow recommendations. The results from cross sections with usable results (inside the confidence interval) were averaged to develop the recommended flow rates.

Enclosure 3 - Dolores River Instream Flow Recommendation

Biological Flow Recommendations

Overview of Recommended Flow Rates

The recommended flow values were determined using the best professional judgment of Colorado Parks and Wildlife (CPW) and the Bureau of Land Management (BLM) biologists and hydrologists. The CPW and the BLM professionals reviewed and evaluated the results of the Physical Habitat Simulation (PHABSIM) Methodology and Habitat Simulation (RHABSIM) software PHABSIM/RHABSIM analysis. They also reviewed the R2CROSS analysis, using the criteria set forth in the previous section of this letter. These initial flow recommendations were based on the physical and biological data collected to date and were adjusted to accommodate the CPW and BLM initial analysis of water availability, as described in the following sections of this letter.

The PHABSIM/RHABSIM data analysis shows that the maximum amount of usable habitat for bluehead suckers is produced at a flow of 1200 cfs and for flannelmouth suckers at a flow of 875 cfs. The CPW and the BLM staff determined that a flow rate of 900 cfs would adequately protect the flannelmouth sucker habitat while protecting more than 90% of the usable habitat for bluehead sucker. The CPW and the BLM staff also noted that this usable habitat is typically available for only two months of the year. Accordingly, the initial biological recommendation for the snowmelt period between March 15 and August 14 is 900 cfs.

The R2CROSS analysis indicated that a fall/winter flow rate of approximately 100 cfs was necessary to meet two out of the three of the critical hydraulic criteria in the cross section selected by the CPW and the BLM. This flow rate is an average of the R2CROSS results collected in five different riffles. The CPW and the BLM personnel also determined that a flow of 100 cfs would also protect other habitat types, such as pools and glides, during the base flow period. According, the initial biological recommendation for the base flow period between August 15 and March 14 is 100 cfs.

Consideration of Water Availability

After developing initial flow recommendations based exclusively upon maintenance of usable habitat and hydraulic characteristics, The CPW and the BLM reviewed the initial recommendations in light of water available during various times of the year. The CPW and the BLM consideration of water availability was based upon an initial water availability analysis conducted jointly by the Colorado Water Conservation Board (CWCB), the CPW and the BLM staff. The initial water availability analysis is described in a separate enclosure. Consideration of water availability is very important for this recommendation because the amount of time (number of days in a calendar year) that habitat is available for the critical life functions of fish directly affects the health and viability of those populations.

After considering water availability, the original flow recommendations were modified as follows:

Time Period	% of 365-day year	Recommended Flow Rate	% of Weighted Usable Area Protected		Number of R2Cross Criteria Met
			Bluehead Sucker	Flannel-mouth Sucker	
April 15 to June 14 (61 days)	16.7%	900 cfs	94%	100%	3 of 3
June 15 to July 14 (30 days)	8.2 %	400 cfs	59%	66%	3 of 3
July 15 to August 14 (31 days)	8.5 %	200 cfs	30%	38%	3 of 3
August 15 to March 14 (212 days)	58%	100 cfs	8%	12%	2 of 3
March 15 to April 14 (31 days)	8.5%	200 cfs	30%	38%	3 of 3

The initial water availability analysis demonstrated that 900 cfs is available at least 50% of the time between April 15 and June 14, so no water availability adjustment was required during that time period. The biological flow recommendation of 900 cfs was reduced to 400 cfs for the June 15 through July 14 time period because of water availability concerns. The biological flow recommendation of 900 cfs flow was further reduced to 200 cfs during the July 15 to August 14 period because of water availability concerns. The recommendation for the June 15-July 14 and July 15-August 14 time periods are designed to maintain as much as possible bluehead sucker and flannelmouth sucker habitat during a period of the year when flows are rapidly declining. The descending limb of the hydrograph occurs at the warmest time of the year when the species are most active, and when the species are attempting to put on weight to survive limited food availability during winter.

The biological flow recommendation of 900 cfs was also reduced to 200 cfs for the March 15 to April 14 period because of water availability concerns. Protection of higher flows associated with the beginning of snowmelt runoff is warranted during this period because it is the beginning of the portion of the year when the sensitive fishes complete critical parts of their life cycles, including the commencement of spawning activities in early spring.

The R2CROSS Method suggests that fall/winter flows should be maintained at 100 cfs, which meets two of the three of the identified critical hydraulic criteria. The flow rate of 100 cfs was not reduced to address water availability concerns, because the initial water availability analysis performed jointly by the CWCB, the CPW, and the BLM suggested that 100 cfs is available at least 50% of the time during the time period between August 15 and March 14.

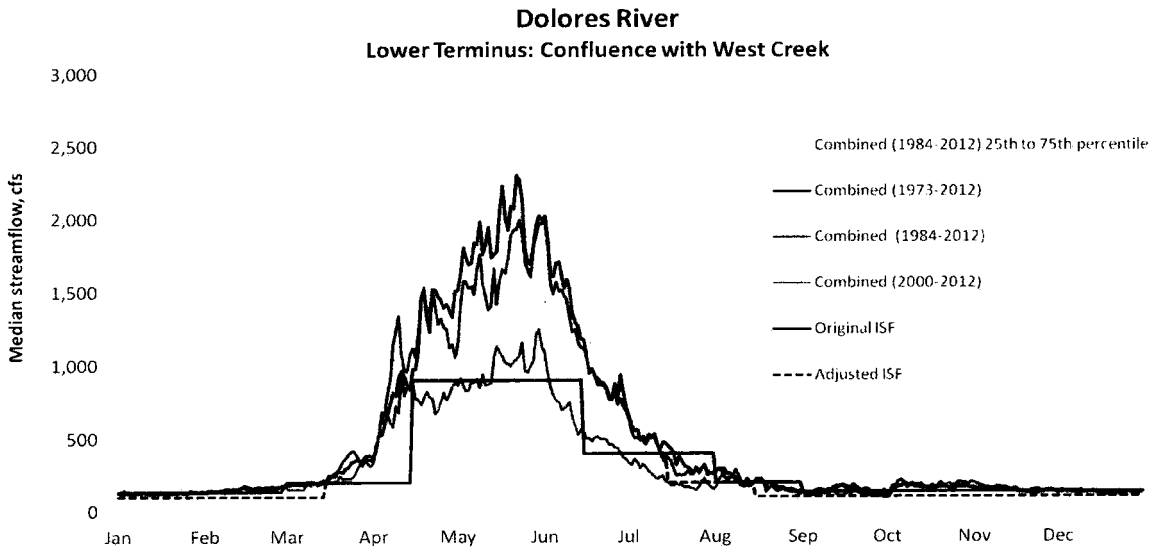
Enclosure 4 - Dolores River Instream Flow Recommendation

Water Availability

The Bureau of Land Management (BLM) and the Colorado Parks and Wildlife (CPW) staff cooperated with the Colorado Water Conservation Board (CWCB) staff to conduct an initial evaluation of the stream hydrology to determine if water was physically available for the instream flow recommendation. The hydrograph below was derived from data collected by the U.S Geological Survey (USGS) stream gage for the San Miguel River at Uravan, CO (#09177000), which has a drainage area of 1,500 square miles and from the USGS stream gage for the Dolores River at Bedrock, CO, which has a drainage area of 2,025 square miles. The period of record for the San Miguel River at Uravan gage was 1954 to 2004, and the period of record for the Dolores River at Bedrock gage is 1917 to 2013. The analysis focused on an overlapping period of record between 1973 and 2012, or 40 years.

The BLM and the CPW staff determined that combining the mean monthly flow from these two gages would provide a conservative estimate of water availability. The reason the estimate is conservative is that there is some limited tributary inflow to the Dolores River from Mesa Creek, Roc Creek and Blue Creek below these two gages. In addition, the estimate is believed to be accurate because there are no known diversions between the two gages and the upper terminus of the proposed instream flow reach at the confluence of the Dolores River and San Miguel River. Water availability for the lowest six miles of the proposed instream flow reach may have to be slightly adjusted for a handful of irrigation diversions that divert water upstream from Gateway. The initial water availability analysis may also have to be adjusted for channel losses or gains that occur through the 34-mile reach.

The cooperative analysis also examined subsets of the 40-year data set. In 1984, the Dolores Project on the Dolores River came on line and substantially altered the hydrology of the river. In 2000, two major events occurred. First, additional water delivery service areas were brought on line under the Dolores Project, increasing demand for project water. Second, a period of extended drought began. In the Dolores River watershed that feeds the Dolores Project, 11 of 13 years between 2000 and 2012 were below average water yield years. In the San Miguel River basin, 10 of 13 years between 2000 and 2012 were below average water yield years. The hydrograph below displays the results of the cooperative analysis.



The initial analysis of water availability revealed that proposed instream flow rates are conservative, when viewed from the perspective of water availability:

- The proposed flow rates are available at least 50% of the time, when viewed from the perspective of median flows over a wide range hydrologic conditions between 1984 and 2012, since the Dolores Project has been constructed.
- The proposed flow rates leave a substantial volume of water available in the river for future development, when viewed from the perspective of median flows. During the peak snowmelt period from April 15 to June 15, it is preliminarily estimated that the proposed flow rates would leave more than 66,000 acre feet annually available for development. During the baseflow period from August 15 through March 14, it preliminarily estimated that the proposed flow rates would leave approximately 23,000 acre feet available for development. It is important to note that these figures were derived using median hydrology and that more or less water could be available in high runoff or drought years.
- Even when viewed through the perspective of the recent drought period from 2000-2012, the proposed flow rates are generally aligned with water availability. There are certain short periods during drought years, such as late April and early June, when there would not be sufficient flow available to meet the recommended flow rates. However, the BLM and CPW believe that the opportunity to protect flow during the critical April 15 to June 14 period during average and above average years is important to long-term health and viability of this population of the three sensitive species.
- During drought years, it is likely that the proposed junior instream flow water right would not be in priority during the entire April 15 to June 14 period. Accordingly, the instream flow water right would not prevent diversions by established, senior water uses during drought periods. In addition, the instream flow water right would be junior to a large number of existing conditional water rights that have not yet been developed.

- If the period from 2000 through 2012 is viewed as a representative drought period, the proposed flow rates still allow for future water development by new junior water rights that could be established after an instream flow right is decreed. During the base flow period from August 15 through March 14, an average of 16,000 acre feet of water would still be available for future development during this representative drought period.

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30 December 2013

Ms. Linda Bassi
Colorado Water Conservation Board
Stream and Lake Protection Section
1313 Sherman Street, Room 723
Denver, Colorado 80203

Re: Colorado Parks and Wildlife Instream Flow Recommendations for the Dolores River – Montrose and Mesa Counties

Dear Linda:

The purpose of this letter is to formally transmit Colorado Parks and Wildlife's (CPW) instream flow (ISF) recommendations for the Dolores River (Water Division 4). This ISF recommendation is a joint recommendation from CPW and the Bureau of Land Management (BLM). CPW and BLM have collaborated on this effort from the start – jointly collecting stream habitat data, cross section data, natural environment data and then a coordinated review of the data, habitat modeling, and recommendation formulation. This effort started in 2010 and continued during the following three field seasons.

CPW is recommending ISFs for the reach of the Dolores River from its confluence with the San Miguel River near Uravan, Colorado to the confluence with West Creek near the town of Gateway, Colorado. This segment of the Dolores River is approximately 34 miles long and starts in Montrose County and ends in Mesa County. The lower terminus is approximately 7 miles from the Utah-Colorado border. Upstream of the upper terminus, there are existing decreed ISF water rights on the upper Dolores River (a 1975 ISF water right for 78 cfs) and on the Sam Miguel River (a 2011 ISF water right for flows ranging from 80 cfs to 325 cfs); within the reach that is the subject of this ISF recommendation there are several small tributary streams with ISF water rights in place (Mesa Creek and Rock Creek).

This segment of the Dolores River is important to CPW for a number of reasons, most importantly it is known to provide habitat for three native fish species of concern (both in Colorado and throughout the six state region) - flannelmouth sucker, bluehead sucker, and roundtail chub; these large-bodied fish are

STATE OF COLORADO
John W. Hickenlooper, Governor • Mike King, Executive Director, Department of Natural Resources
Bob D. Broscheid, Director, Colorado Parks and Wildlife
Parks and Wildlife Commission: Robert W. Bray • Chris Castilian, Secretary • Jeanne Horne
Bill Kane, Chair • Gaspar Perricone • James Pribyl • John Singletary
Mark Smith, Vice-Chair • James Vigil • Dean Wingfield • Michelle Zimmerman
Ex Officio Members: Mike King and John Salazar

endemic to rivers and streams of the Colorado Plateau. More importantly, these three species of fish are the subject of a range-wide conservation agreement and strategy that is signed by all six states' fish and wildlife management agencies, several Native American tribes, and federal agencies including the BLM and Bureau of Reclamation. This agreement is commonly referred to as the "Three Species Agreement" but is more accurately entitled "Range-Wide Conservation Agreement and Strategy for Roundtail Chub (*Gila robusta*), Bluehead Sucker (*Catostomus discobolus*), and Flannelmouth Sucker (*Catostomus latipinnis*) 2006"; both CPW and the BLM's Colorado State Office are signatories to this agreement. In essence, the Three Species Agreement is an agreement amongst state, federal and tribal entities who collectively agreed to take affirmative management steps toward protecting populations of, and habitats for, these fish species throughout their historic range. The overall goal of this agreement is to prevent listing of these fish species under the Endangered Species Act. In Colorado, one of the most critical and effective tools for the protection of fish habitat is the CWCB's ISF Water Right Program. It is for this reason that CPW is requesting that the CWCB consider the Dolores River segment as described above for inclusion in its ISF Protection Program.

CPW, and its predecessor agencies (the Colorado Division of Wildlife and the Colorado Division of Parks and Outdoor Recreation) have long been partners with the CWCB for the protection of ISFs in Colorado. Since its passage in 1973, CPW has been one of the primary sources for ISF recommendations; since the late 1980s, BLM has also provided the CWCB with many ISF recommendations. Over the course of those years, CPW and BLM have worked closely on dozens of ISF projects – the most recent being the San Miguel River ISF appropriations upstream of this Dolores River Segment. CPW's legislative and strategic mission and the stated purpose of the ISF Program in its legislative declaration are complementary to one another in many ways – CPW is directed by the following language:

- "… that the wildlife and their environment are to be protected, preserved, enhanced, and managed for the use, benefit, and enjoyment of the people of this state and its visitors … and that, to carry out such a program and policy, there shall be a continuous operation of planning, acquisition, and development of wildlife habitats and facilities for wildlife-related opportunities" (See §33-1-101 (1) C.R.S.)
- "[h]ealthy aquatic environments are essential to maintain healthy and viable fisheries, and critical for self-sustaining populations… by protecting and enhancing the quality and quantity of aquatic habitats." (CPW Strategic Plan)

And CWCB's ISF Program is guided by this simple statement:

- "Further recognizing the need to correlate the activities of mankind with some reasonable preservation of the natural environment" (See §37-92-102 (3) C.R.S.).

CPW reads these statements together as an affirmation that the CWCB's ISF Program is a critical habitat and species protection program that assists CPW in accomplishing its mission. In a similar way, one of CWCB's primary purposes is to foster the development and use of the state's water resources. In the case of

the Dolores River and in the context provided by the Three Species Agreement, CPW is of the belief that securing ISF protection for the Dolores River fishery is critical to the state's commitment to taking affirmative steps to prevent an ESA listing. We also believe from lessons learned elsewhere in the Colorado River basin, that the prevention of an ESA listing is critical to the future of water use and development in the state.

Natural Environment

This 34 mile reach of the Dolores River has the following physical characteristics:

- A very gentle gradient that averages about 0.2%.
- Mostly pool and run habitat types, riffle habitat is very limited.
- The dominant substrate type is sand and mud; some small cobble in isolated areas.
- Due to the general lack of significant tributary infow, the width and depth of the active channel is relatively uniform throughout the 34 mile reach.
- The riparian zone consists of a mixture of native and non-native trees, shrubs, and plants. There is a significant Tamarisk component to the riparian canapy.

CPW personnel has sampled the Dolores River quite intensively over the last decade with sampling events in 2007, 2009, and 2010. The river supports populations of bluehead sucker (*Catostomus discobolus*), flannelmouth sucker *Catostomus latipinnis*, roundtail chub (*Gila robusta*), and speckled dace (*Rhinichthys osculus*). These samples indicated that, depending upon the location with the reach, 76% to 89% of the fish captured were native species. All three of "Three Species Agreement" species were present in all locations. Further, the samples indicate that all three species were represented by individuals of multiple age classes. According to CPW biologists, this reach of the Dolores River appears to be one of the best populations of the three native fishes within the Dolores River watershed, and represents an intact and functional assemblage of native warm water fish. In addition, genetic testing of the two sucker species do not indicate any hybridization with non-native white suckers, which is known to occur in other major western Colorado rivers. CPW manages this reach as a Category 204 – Native Fish Conservation Stream.

The roundtail chub is classified as a "species of special concern" by CPW. BLM lists all three species as "sensitive species". The "Three Species Agreement" and Colorado's Species Conservation Plan (DRAFT) are designed to outline management measures to prevent a federal listing under the Endangered Species Act. Protection of the Dolores River native fishery with an ISF water right will go a long way toward Colorado's overall action to protect these species. As stated above, since the Dolores River does not have large numbers of non-natives (particularly predators and non-native suckers), this river reach presents a rather unique opportunity for Colorado to protect a healthy reproducing

assemblage of these native fish. Further, the occupied habitat in the Dolores River is dominated by public lands (BLM) thus providing some land use protection for the habitat. There have been recent efforts to list the roundtail chub throughout its range and these efforts have not succeeded due to state and federal land management agency efforts to conserve existing populations.

Below is a table which shows the habitat requirements and life stage periodicity for the three primary Dolores River fish species.

	SPAWN	FRY-EMERGENCE	YOUNG OF YEAR - JUVENILE	ADULT
Roundtail Chub	Need relatively clean cobbles/ interstitial space for eggs to settle; can be runs and glides; temps 14.4 - 18.3 C Season: After Peak Runoff	Structure/ complexity to avoid immediate predation Season: Late Summer	Quiet shallow channel margins, backwaters Season: Fall, Winter, and Spring	Deeper water/ slow-velocity eddies with access to good flow/ runs. In-channel structure. Carniverous, opportunistic feeder Season: All Year
Flannelmouth Sucker	Spawn over gravel, eggs adhere or fall into interstitial spaces. Needs clean substrate and flowing water to aerate eggs. Season: March - July	Near-shore, slow velocity habitats with cover Season: Late Summer	Utilizes wider variety of habitat types; deep runs, riffles and pools Season: Fall, Winter, and Spring	Utilizes multiple habitat types; feeds in riffles and deep runs on detritus, algae, invertebrates; have been known to move long distances (documented to ~150 miles) Season: All Year
Bluehead Sucker	Shallow areas with clean cobbles and interstitial space for egg incubation; 15.6 - (18-21) C Season: April - May	Near-shore, slow velocity habitats and trending toward deeper water and higher velocity with age Season: After Peak Runoff	Extends habitat used into faster moving water; begins feeding exclusively in riffles and deep runs Season: Fall, Winter, and Spring	Swifter velocity, higher-gradient riffles and runs. Opportunistic feeders of detritus, algae, and macro-invertebrates Season: All Year

More specifically to the lower Dolores River and the subject of ISFs, the following represents how these native species react to different stream flow conditions, air and water temperatures, etc. Also included in the following are geomorphic and fluvial processes associated with different stream flow conditions with an emphasis on how these factors affect habitat conditions for fish.

- Late winter - early spring (pre-peak snowmelt period), March - April: low elevation streams in western Colorado often surge in response to melt of

low elevation snowmelt, spring storms, and early ripening of the snowpack in higher terrain, and water begins warming in response to longer days and warmer air temperatures. Along with an increasing photo-period, these hydrologic cues signal native fish to navigate toward likely spawning sites. Flannelmouth suckers and bluehead suckers have been known to travel long distances toward habitual spawning areas. In addition, increased flows during this period also mobilize fine sediments that may have settled during localized late-summer or fall monsoon storms, improving conditions in cobbles for spawning.

- Peak snowmelt runoff: In the Lower Dolores River, peak runoff occurs anywhere from mid-April thru mid-June, and has multiple benefits for native species. First, peak flows clear riffles of sediment and often re-set bed sediments to provide optimal aeration for deposited eggs. Second, peak flows are critical for maintaining habitat diversity within the stream channel, critical for support of all life stages of native fish. Especially important for emerging fry are side-channel and backwater sites that become refugia for young fish. Third, peak flows are critical for redistributing sediments, creating new instream and near-stream habitat, and invigorating riparian processes (recall prior note about the importance of alluvial groundwater). Ramping flows on the descending side of the hydrograph are important so that fish have time to move to habitats where they will spend most of the next 8 months of their lives. Spawning for bluehead suckers and flannelmouth suckers may occur during pre-peak or post-peak periods of the hydrograph, and fry emergence and dispersal shortly thereafter (7-10 days) is aided by continuing high flows and subsequent drift to side-channel, low velocity sites. Roundtail chub generally spawn at higher water temperatures than the sucker species, but soon after peak snowmelt runoff to allow for proper growth prior to winter.

- Baseflow: July - February: Adequate baseflow conditions are critical for survival of native fish for a few reasons. First, as young-of-year fish mature during summer, they venture from refugia into the main channel where larger adult and juvenile fish also survive. They need enough wetted perimeter and available habitats to survive predation and competition from both native (roundtail) and non-native fish. Second, native suckers, particularly bluehead suckers, are primarily foraging fish that feed on algae and detritus within the main channel, and incidental to consumption of vegetation by these fish is the consumption of a number of high-protein macroinvertebrates that also feed on or inhabit riverine plants. This primary production within the channel is highly dependent on riffles that have both good aeration and available sunlight. Growth during summer baseflow months is critical to provide fish the resiliency needed to survive the winter, when forage is scarce. Baseflow during winter months is necessary to provide enough habitat variety to overwinter both

young-of-year, juvenile, and adult fish, and to provide enough mobility so that fish can escape predation or find more advantageous habitats as seasonal conditions evolve.

In summary, CPW is of the opinion that an important natural environment exists in the Dolores River; for the reasons described above, we believe that the Dolores River fishery is one of statewide interest and significance. We further believe that this natural environment can be preserved to a reasonable degree with the appropriation of an ISF water right in the amounts discussed below.

ISF Quantification

Methodologies – PHABSIM and R2CROSS

The recommending agencies for the Dolores River (CPW and BLM) utilized their collective professional judgement and past experiences with large river ISF recommendations and evaluated all of the data collected to date and determined that as was the case with the 2011 San Miguel ISF effort, the best flow recommendation would be derived from a combination of methods. PHABSIM (Physical Habitat Simulation) is a widely accepted method for quantifying the suitable versus unsuitable hydraulic habitat attributes of selected species and life stages as a function of discharge. R2CROSS is best suited for identifying flows with specific hydraulic criteria in a riffle habitat type. CWCB has used the R2CROSS method extensively in the past to appropriate ISF water rights. PHABSIM is a method that has been widely used and accepted to quantify ISF requirements. CWCB has previously used PHABSIM data to appropriate ISF water rights. In addition, CWCB has on numerous occasions, accepted ISF recommendations quantified with a combination of both R2CROSS and PHABSIM.

CPW and BLM determined that exclusive use of the standard R2CROSS method would not be appropriate for this reach of the Dolores River. Historically, R2CROSS has been used in small to medium-sized streams with a high percentage of riffle habitat. In contrast, the Dolores River has a wide channel (over 100 feet wide in most places), supports different types of fish species than are typically found in smaller streams in Colorado (warm/cool water species vs. cold water species such as salmonids). Further, the Dolores exhibits big river channel hydraulics with extensive run, pool, and glide habitats as well as a very low gradient. In addition, as noted above, the Dolores has a very small percentage of the total fish habitat as riffles. For these reasons, CPW and BLM decided to utilize PHABSIM to develop flow recommendation for the snowmelt runoff months between March and August. This is the portion of the year when the three sensitive species are using run, pool, glide, and riffle habitat to

complete important parts of their life cycles, such as spawning and recruitment of young of the year. Maintaining a diversity of habitat availability is critical during the higher stream flow period for the maintenance of population biomass and age class structure.

CPW and BLM decided to use the R2CROSS methodology to develop flow recommendations during the base flow portions of the year from August through March. This is the period when there is substantial competition between individuals for physical habitat space, foraging areas, and limited food supplies. During this period, it is critical for the three species to be able to move between habitat areas to make full use of the limited physical habitat. Riffles are the first location where low flows can limit passage between habitat types, so it as appropriate to develop flow recommendations that focus on the fish passage function of riffles and hydraulic controls.

To select an appropriate location for PHABSIM modeling, CPW and BLM staff conducted reconnaissance throughout the 34-mile reach to identify the typical habitat characteristics for the reach paying attention to factors such as channel width, substrate, depths, and velocities. The CPW and BLM staff then selected an 1800-foot reach of stream, located approximately seven miles upstream from the town of Gateway, as a location that could represent the full variety of habitat types found within the 34-mile reach. The CPW and BLM staff utilized standard PHABSIM field methods to establish and monument seven transects that incorporate the full variety of habitat types found in the Dolores River ISF segment. The transects were selected to describe the overall variety of riffles, runs, pools and glides. These seven cross-sections formed the basis for the data set that was input for the PHABSIM modeling programs.

BLM and CPW staff also ran the seven PHABSIM cross sections through the R2CROSS model. Since there was only one PHABSIM cross section placed in a riffle, in early 2013 CPW and BLM staff collected data from four additional representative riffle cross sections from other locations within the ISF segment. This additional cross section data was collected to increase the reliability of the R2CROSS modeling for the base flow period. We were of the opinion that since a large portion of the ISF recommendation hydrograph was going to be relying on R2CROSS modeling, the R2CROSS data set should be as robust as possible.

The initial recommendations based on the PHABSIM and R2CROSS modeling are designed to address the unique biologic requirements of this stream reach without regard to water availability. CPW and BLM utilized the same criteria as was used in the San Miguel ISF quantification when evaluating the PHABSIM output. The three standard hydraulic parameters (average depth, percent wetted perimeter and average velocity) were modified slightly and applied to the R2CROSS output to calculate the initial biologic ISF recommendations not constrained by water availability considerations.

PHABSIM Habitat Suitability Criteria (HSC)

PHABSIM HSC for the Dolores River ISF segment were developed from the 2003 Riverine Fish Flow Investigation Study Report (Federal Aid Project F-289-R6) written and performed by Richard Anderson, CPW Aquatic Researcher, and Gregory Stewart, Department of Geosciences, Oregon State University[1]. The basis for this study was a 1999 request from the CWCB for CPW to provide biologically justified ISF recommendations for the Yampa and Colorado Rivers based on habitat and flow requirements for non-endangered native fish. Anderson and Stewart used two–dimensional (2D) modeling to develop HSC for bluehead and flannelmouth suckers. Their methods and results are more fully described in Anderson and Stewart (2003) and Stewart and Anderson (2005) and (2006).

Stewart and Anderson determined that "Abundance of bluehead sucker was a reliable indicator for instream flows and habitat maintenance for the native fish assemblage. In the Colorado, Gunnison and Yampa Rivers bluehead sucker habitat peaked at flows of 600 to 1,200 cfs. This flow range also resulted in high habitat diversity and high native fish biomass." Their assumption that flows that maintained adequate bluehead sucker abundance (about 25% of fish over 15 cm) would also maintain adequate flannelmouth sucker and roundtail chub habitat was validated by this study. The bluehead and flannelmouth sucker habitat suitability criteria were used to develop specific hydraulic criteria that were incorporated into the PHABSIM analysis for the Dolores River.

As was the case on the San Miguel, CPW and BLM determined that the flannelmouth sucker and bluehead sucker would be the primary indicator species for the biologically based ISF recommendation. The reason for the focus on these two species is that they have somewhat different habitat preferences. Flannelmouth sucker have stronger preference for pool, glide, and run habitats, while bluehead sucker abundance is directly related to availability and quality of riffle habitats. Roundtail chub primarily utilize habitats with the slower velocities that are typically found in pool habitat. CPW and BLM agreed upon an approach to protect sufficient flows for flannelmouth suckers and bluehead suckers and then assume that there will be sufficient water to maintain roundtail chub habitat in the pools.

When developing ISF recommendations to support flannelmouth sucker and bluehead sucker, BLM and CPW personnel examined tables and graphs produced by the PHABSIM model that show the relationship between "weighted usable area" (suitable habitat) and flow rates for each of the two species within the PHABSIM site. We then identified the most efficient flow rate for providing

[1] See "Impacts of stream flow alterations on native fish abundance and native fish habitat and the use of native fish population data to support instream flow recommendations made using a 2D instream flow methodology."

habitat protection. In this case, the most efficient flow rate is defined as the minimum flow rate that protects at least 90 percent of the habitat that is potentially available within the stream channel for both species. For example, if a PHABSIM modeling run showed that an equal amount of weighted usable area was available at either of two different flow rates, then lower flow rate was identified for protection because it is more efficient.

When identifying minimum flow rates, BLM and CPW personnel also considered the amount of time weighted usable area is available in the Dolores River channel, specifically the number of days within a calendar year. The team considered this factor because much of the potential habitat in the Dolores River is typically available during a 2-month period during the peak of snowmelt runoff; this typically occurs between April 15 and June 14. This 60 day period is only 16.7% of a calendar year. There are certain life functions of the species that can only occur during this very short period, so protecting the high flow rates associated with snowmelt runoff is essential for the long-term viability of these fish populations.

Use of Standard and Modified R2CROSS Hydraulic Criteria

The primary objective of most cross section methodologies, including R2CROSS, is to maintain quality riffles. Riffles are the most vulnerable habitat to dewatering and riffles are important for invertebrate productivity. For many species, riffles play an important role in spawning and incubation. Riffles comprise only a very small portion of the total habitat area in this stream reach, so the importance of maintaining riffle habitats cannot be dismissed. In early 2013, the two agencies conducted a survey of the various types of riffles within the Dolores River ISF reach, paying particular attention to width, dominate substrate types, slope, and water velocity. The team then selected four representative riffles for individual analysis using R2CROSS.

BLM and CPW personnel applied/modified the standard R2CROSS criteria in the following manner:

- For the percent wetted perimeter criterion, we used the standard identified in the CDOW research publication, Nehring, R.B., 1979, “Evaluation of instream flow methods and determination of water quantity needs for streams in the State of Colorado.” Due to the top width of the Dolores River (it always exceeds 60 feet), the Nehring publication suggests maintaining 70% of wetted perimeter.
- The average velocity and average depth criteria were modified from Nehring to values suggested by the 2003 Riverine Fish Flow Investigation Study Report referenced earlier in this letter. Anderson and Stewart recommended an average velocity of 1.3 feet per second and an average depth of 1.0 foot, These criteria were suggested to maintain marginally suitable habitat for flannelmouth sucker and bluehead sucker.

These standard and modified criteria were applied to the R2CROSS computer runs that were performed on all the riffle cross sections collected by the agencies.

The R2CROSS model utilizes the Manning's Equation and it provides reliable predictive results for flows that are between 40% and 250% of the flow measured during the data collection effort. This range of accuracy is referred to as the "confidence interval" for R2CROSS modeling. When the flow rate that meets the ISF criteria falls outside of this confidence interval, data from that cross section is not used to develop an ISF recommendations. The results from cross sections with usable results (inside the confidence interval) are averaged to develop the recommended flow rates.

Dolores River Instream Flow Recommendations

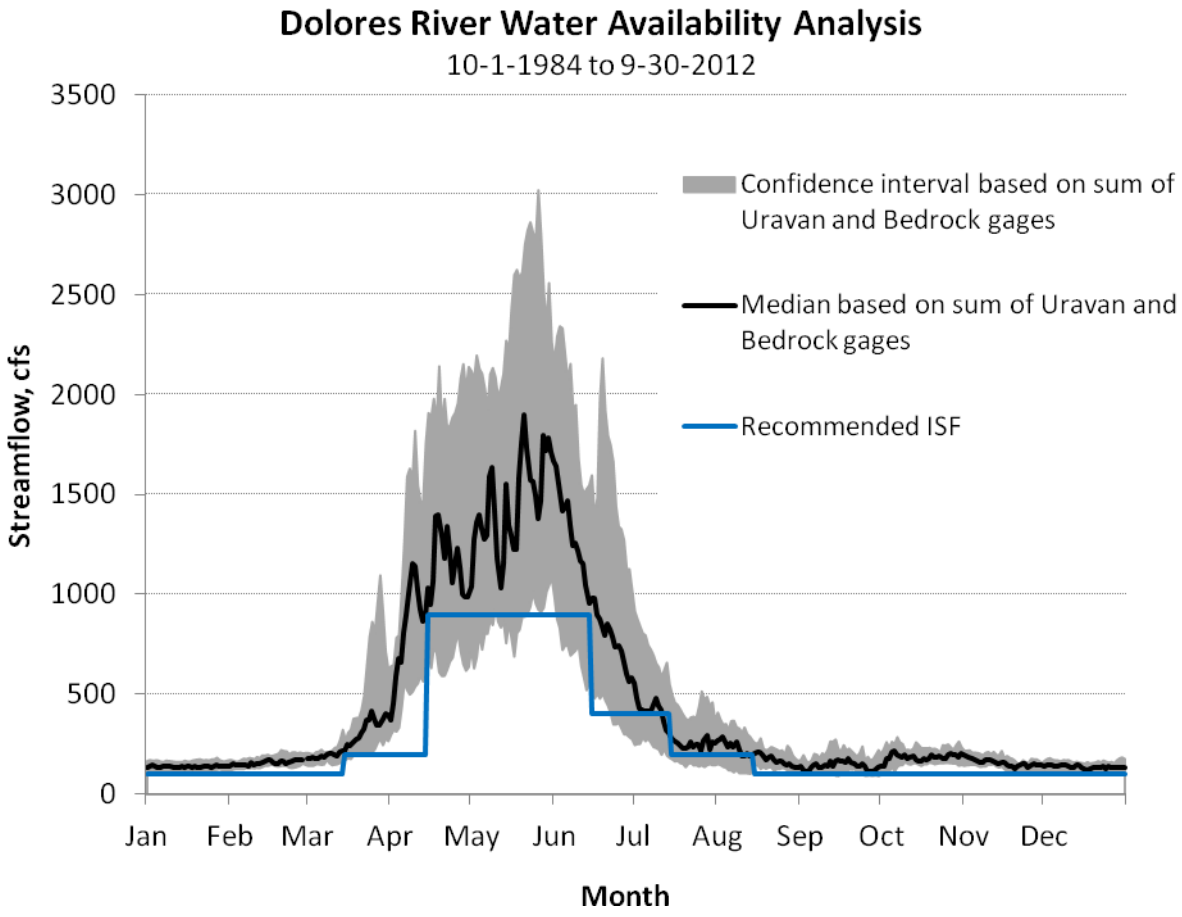
Utilizing the approach and applying the criteria described above and our collective professional judgment, CPW and BLM professionals (biologists and hydrologists) developed the following ISF recommendations. As discussed above, both the PHABSIM incremental methodology and the R2CROSS standard setting methodology were employed in this effort.
The PHABSIM output files (tables and graphs) show that the maximum amount of usable habitat for bluehead suckers is produced at a flow of 1200 cfs and for flannelmouth suckers at a flow of 875 cfs. BLM and CPW determined that a flow rate of 900 cfs would adequately protect the flannelmouth sucker habitat while protecting more than 90% of the usable habitat for bluehead sucker. As stated above. this usable habitat is typically available for only two months of the year. Accordingly, the initial biological recommendation for the summer/high flow/snowmelt period (typically from March 15 and August 14) from the PHABSIM method is 900 cfs.

As stated above, the R2CROSS method was selected to develop ISF recommendations for the fall/winter time period (typically between August 15 and March 14). The R2CROSS analysis for the five riffle cross sections yielded a flow recommendation of approximately 100 cfs to meet two out of the three of the hydraulic criteria. This flow rate is an average of the "in range" R2CROSS flow recommendations collected at the five riffles. BLM and CPW personnel are also of the opinion that a flow of 100 cfs would also protect other habitat types, such as pools and glides, during the base flow period. Accordingly, the initial biological recommendation for the base flow period between August 15 and March 14 is 100 cfs.

Initial Water Availability Analyses

The initial biologic ISF recommendations are next compared to some preliminary hydrologic analyses. Typically the recommending agencies perform some simple

water availability analyses to fine tune or revise the initial flow recommendations to match hydrologic reality. CPW compared our flow recommendations to a hydrograph produced by the combination of two USGS stream gages on the Dolores River and the San Miguel River near the confluence of these two rivers. This confluence also corresponds with the upper terminus of this ISF recommendation. The result of this rather simple hydrologic exercise is displayed in the graph below.



This graph clearly shows that the 900 cfs PHABSIM summer high flow ISF recommendation is only available between mid-April and mid-June. During the

rest of the of the critical summer time period (when spawning, incubation and growth are occurring in the fish populations), the agencies determined that the ISF recommendation needs to be as high as can be supported by the water available. Therefore, CPW and BLM modified the summer ISF recommendation down to 400 cfs (mid-June through mid-July) and to 200 cfs (mid-March through mid-April and mid-July through mid-August) thus creating "shoulders" on the ISF hydrograph. The graph also clearly shows that the 100 cfs R2CROSS generated winter base flow recommendation is available for the entire winter from mid-August through mid-March – no revision or modification of the initial ISF recommendation for this time period was necessary.

CWCB Water Availability Analyses

During the latter part of 2013, CWCB staff conducted several more sensitive and sophisticated hydrologic analyses utilizing the CDSS models, StateMOD models, and other hydrologic techniques to more precisely determine physical and legal water availability for the ISF appropriation. Some Dolores River basin stakeholders requested some specific examinations of water availability. CPW, BLM and CWCB staff have met and reviewed all of the results of the hydrologic work and no additional revisions appear to be necessary at this time.

Summary and Conlusions

As a result of nearly three years of data collection and analysis, CPW and BLM have developed what we believe to be an ISF proposal that is both reasonable and protective of the Dolores River's natural environment. We are of the opinion that a natural environment exists and that that environment can be preserved to a reasonable degree with the flows recommended by the agencies. The flow recommendations are as follows (modified by initial water availability analyses):

- 900 cfs is necessary to preserve the natural environment from April 15 through June 14;
- 400 cfs* is necessary to preserve the natural environment from June 15 through July 15;
- 200 cfs* is necessary to preserve the natural environment from July 16 through August 14;
- 100 cfs is necessary to preserve the natural environment from August 15 through March 15; and
- 200 cfs* is necessary to preserve the natural environment from March 16 through April 14.

  (* = flow recommendation modified due ot water availability considerations)

If you have any questions about the information contained herein, please call me at 303-291-7260. Thank you for the opportunity to submit these important flow recommendations; CPW will be represented at the January, 2014 CWCB meeting to address any questions or comments generated by the Board or public.

Sincerely,

Jay W. Skinner

Jay W. Skinner
Instream Flow Program Coordinator
Colorado Parks and Wildlife

CC: Chad Bishop, CPW Asst. Director – Wildlife & Natural Resources Branch
Alex Davis, CPW Water Resources Section Manager
Regional Staff

Fish Sampling Report

Paul Jones
Aquatic Biologist
Southwest Region

Water: Dolores River
Reaches: Big Gypsum, Mesa Creek to Roc Creek (RM 114.3-RM117.5), River Mile 124 to River Mile 126, Blue Creek to Salt Creek (RM 127.8-RM 130.6)
Dates: 6/14/2010 - 6/16/2010
Gear: 14 ft. electrofishing raft with booms and Smith Root 2.5 GPP
Drainage: Dolores
Water Codes: 39760

OBJECTIVE
With the exception of the Big Gypsum reach, the Dolores River was sampled with single pass CPUE electrofishing to monitor native fish populations on four separate reaches. The reaches sampled were the Big Gypsum reach, Mesa Creek to Roc Creek reach, River Mile 124 to River Mile 126 reach, and the Blue Creek to Salt Creek Reach (Figure 1). .

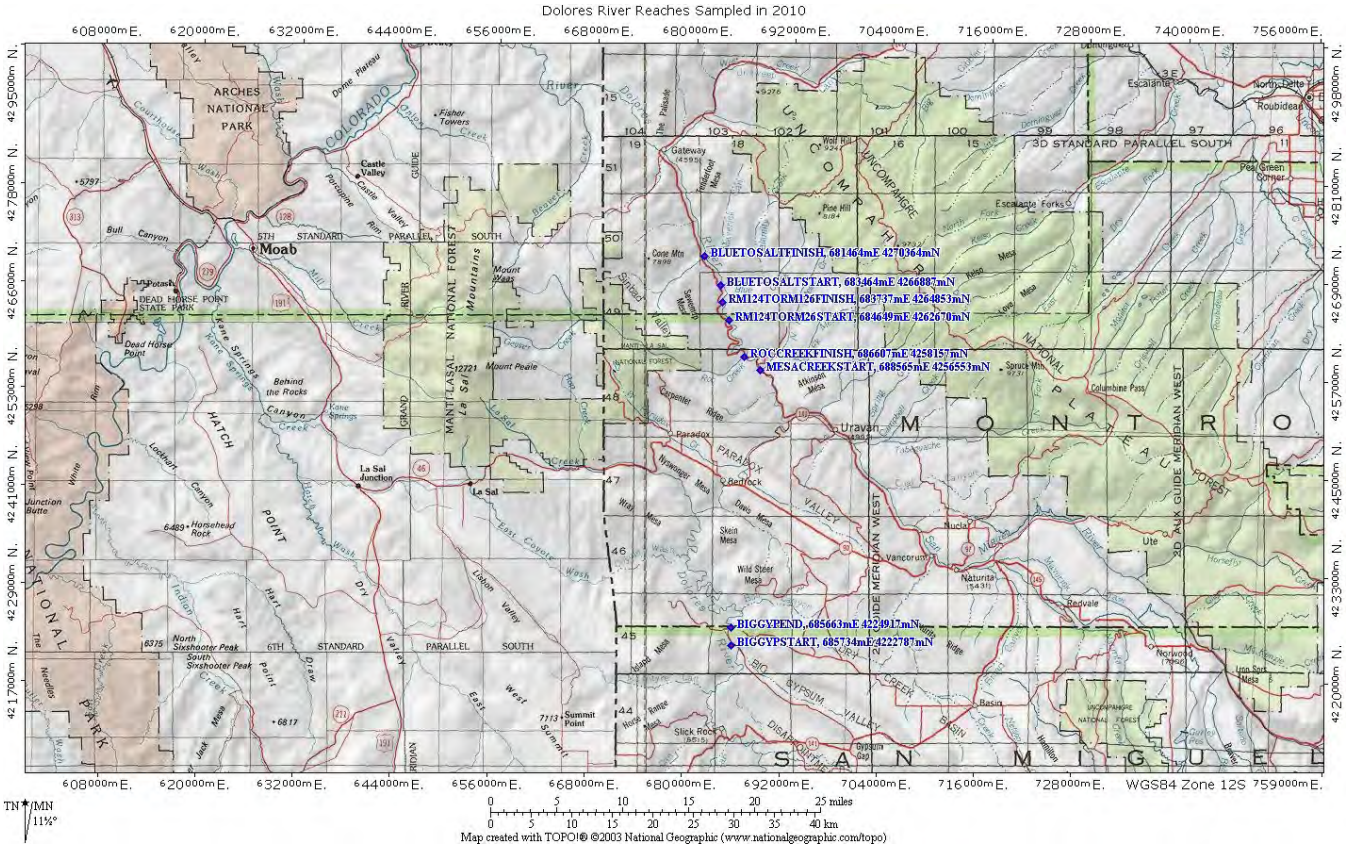


Figure 1. Dolores River Reaches Sampled in 2010

The first section that was sampled was the Big Gypsum reach on 6/14/2010. The reach runs from the Gypsum Valley Recreation Site/Boat Launch just downstream of river mile 61 to the San Miguel County Road 20R (Gyp Road) bridge at approximately river mile 63.5. This section was sampled with two pass CPUE electrofishing to monitor native fish populations Total pooled sampling distance was 5 miles (Figure 2).

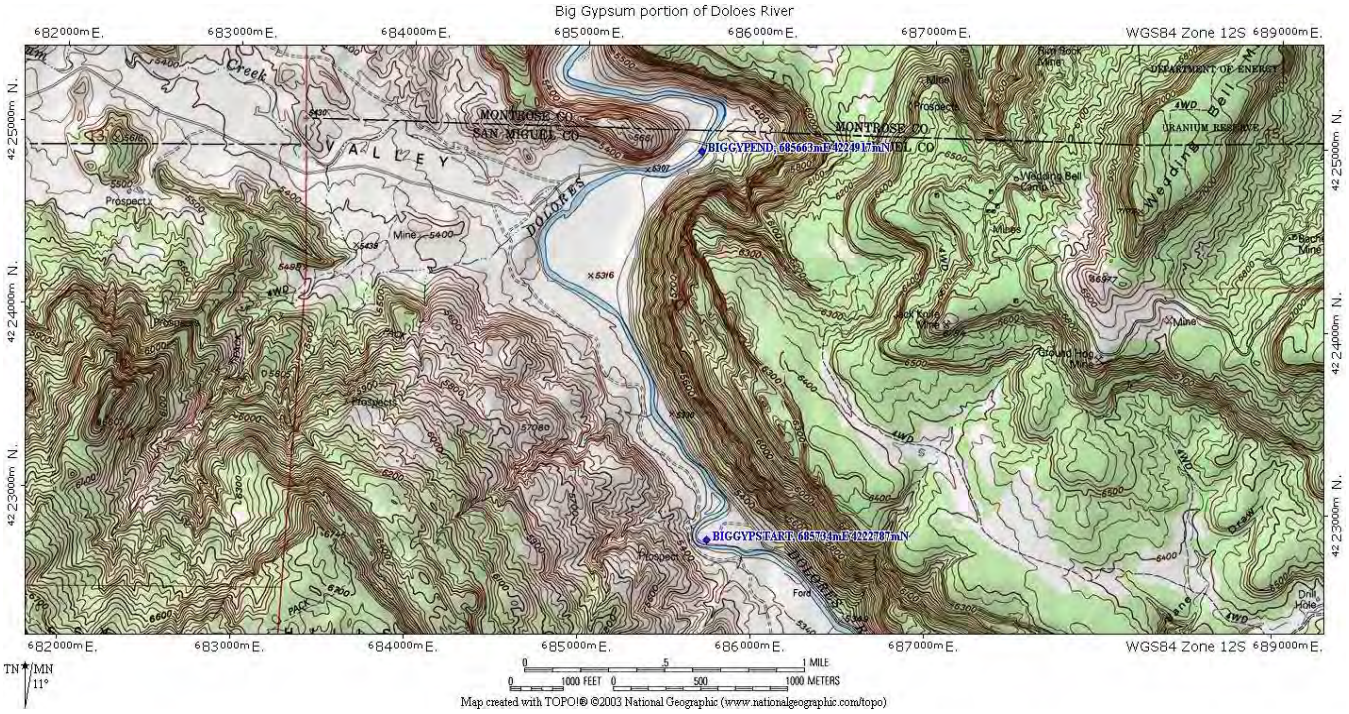


Figure 2. Big Gypsum Reach of the Dolores River Sampled in 2010

The Mesa Creek to Roc Creek sections of the Dolores River was sampled on June Fifteenth with single pass CPUE from the mouth of Mesa Creek to the mouth of Roc Creek (Figure 3). Total pooled sampling distance was 3.2 miles.

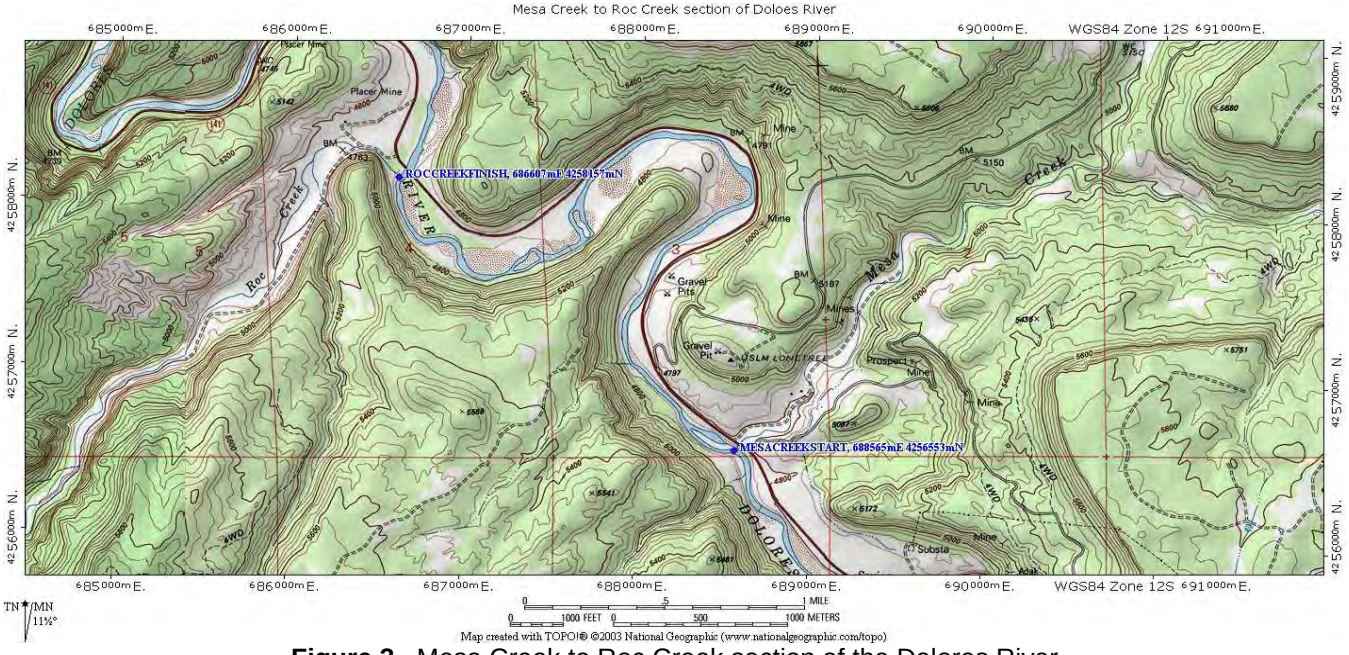


Figure 3. Mesa Creek to Roc Creek section of the Dolores River

The next reach of Dolores River that was sampled ran from the top of the island at RM 124 to the bottom of the island at RM 126 (Figure 4), and was sampled on the Sixteenth of June. Total pooled sampling distance was 2 miles.

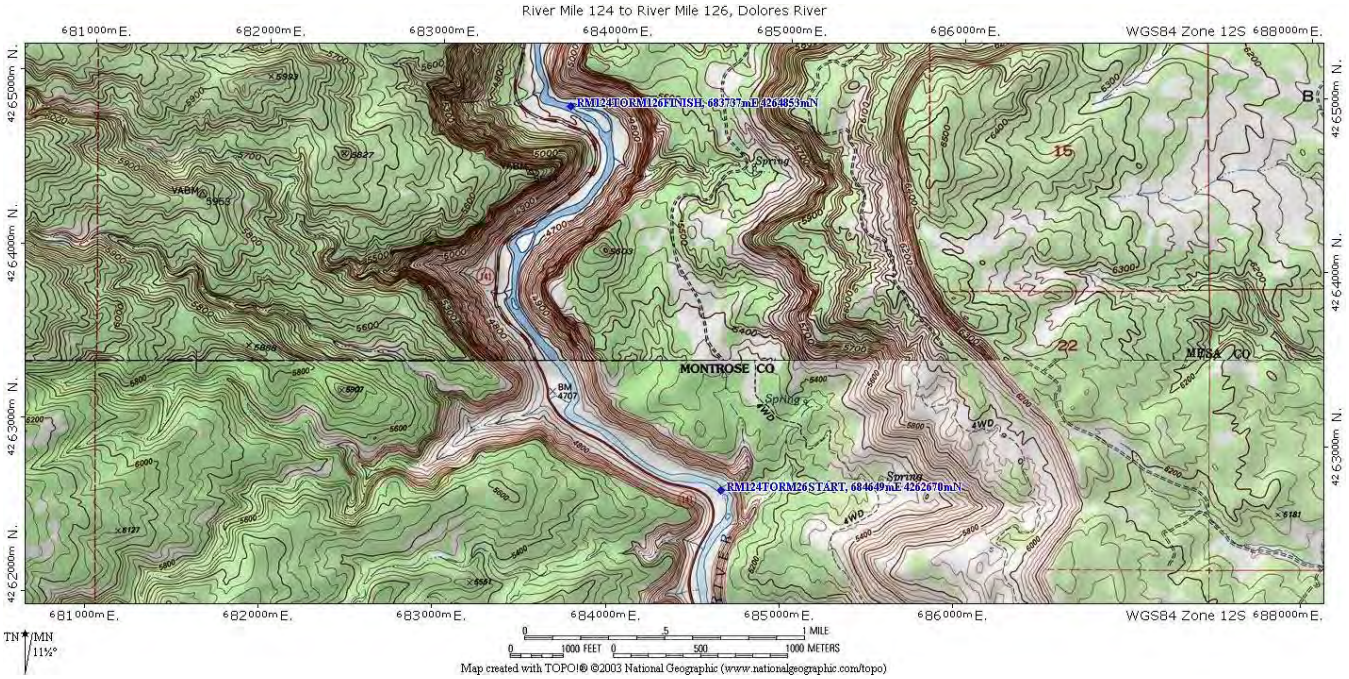


Figure 4. Dolores River from RM 124 to RM 126

The final reach of the Dolores River was sampled on the afternoon of June Sixteen, and it ran from the mouth of Blue Creek to the top of the rapids at the mouth of Salt Creek (Figure 5). Total pooled sampling distance was 2.8 miles.

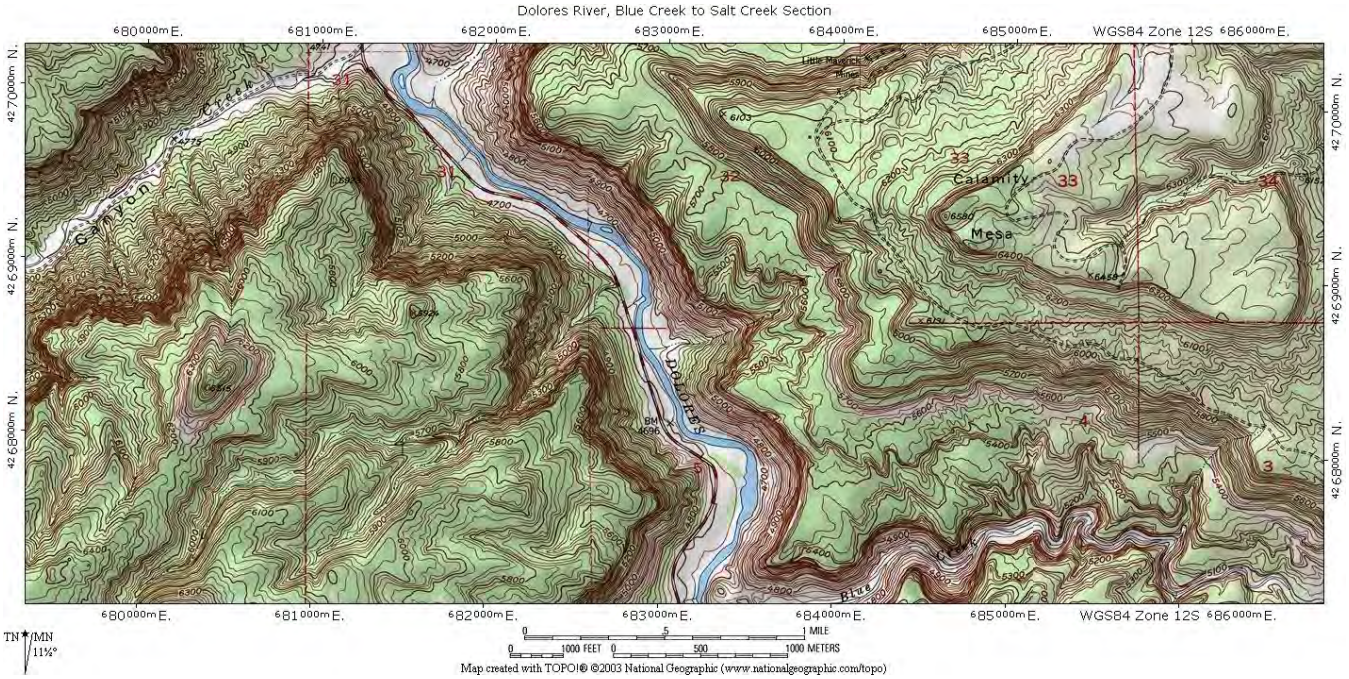


Figure 5. Dolores River from Blue Creek to Salt Creek

RESULTS

B IG GYPSUM REACH:

The results of the survey for the Big Gypsum reach are summarized in Table 1 and length frequency histograms for the three species are presented in Figure 5. Eighty five percent of the fish sampled were native species and flannelmouth suckers, bluehead suckers, and roundtail chub had a catch rate of 10.8 fish per mile. Only one

bluehead sucker was caught, but both flannel mouth suckers and round tail chubs showed several distinct age classes. Of some concern however is the presence of smallmouth bass and green sunfish. Two distinct size classes of smallmouth bass were captured, confirming that these fish are now breeding in the Dolores River below McPhee Dam.

Species	# Caught	% Catch	# Caught Per Mile	Mean Length (in.)	Length Range (in.)
Flannelmouth Suckers	3	4	0.6	6.6	4.0-8.1
Bluehead Suckers	1	1	0.2	3.3	3.3
Roundtail Chub	50	62	10	6.1	2.9-10.9
Speckled Dace	4	5	0.8	3.2	1.9-4.0
Common Carp	1	1	0.2	2.6	2.6
Redside Shiner	2	2	0.4	2.9	2.8-3.0
Channel Catfish	3	4	0.6	7.5	6.5-8.8
Black Bullhead	3	4	0.6	6.6	4.0-8.1
Smallmouth Bass	2	2	0.4	8	6.1-9.8
Green Sunfish	1	1	0.2	6.5	6.5

Table 1. Summary of fish sampled in the Big Gypsum section of the Dolores River in 2010.

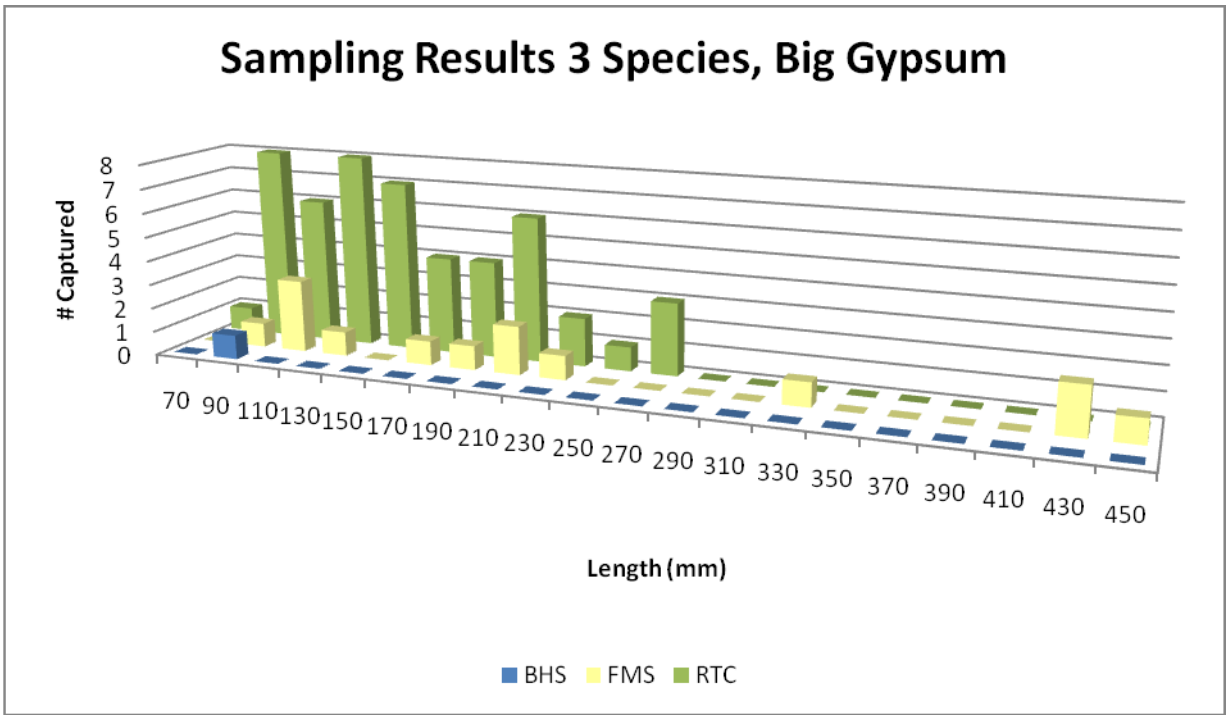


Figure 5. Length frequency histogram the three species captured in the Big Gypsum section of the Dolores River in 2010.

MESA TO ROC CREEK REACH:

The results of the Mesa Creek to Roc Creek survey are summarized in Table 2 and length frequency histograms for the three species are presented in Figures 6. Ninety three percent of the fish sampled were native species and the three species had a combined catch rate of 20.3 fish per mile. Bluehead suckers, flannel mouth suckers and round tail chubs showed several distinct age classes. While two channel catfish were captured, no smallmouth bass or sunfish were captured during the survey.

Species	# Caught	% Catch	# Caught Per Mile	Mean Length (in.)	Length Range (in.)
Flannelmouth Suckers	30	40	9.4	16.6	6.5-21.7
Bluehead Suckers	27	36	8.4	12.8	10.4-15.2
Roundtail Chub	8	11	2.5	6.2	4.1-9.8
Speckled Dace	5	7	1.6	3.3	2.8-3.9
Common Carp	2	3	.6	18.6	15.7-21.5
Channel Catfish	2	3	.6	17.3	14.4-20.3
Sand Shiner	1	1	.3	2.6	2.6

Table 2. Summary of fish sampled in the Dolores River from Mesa Creek to Roc Creek in 2010.

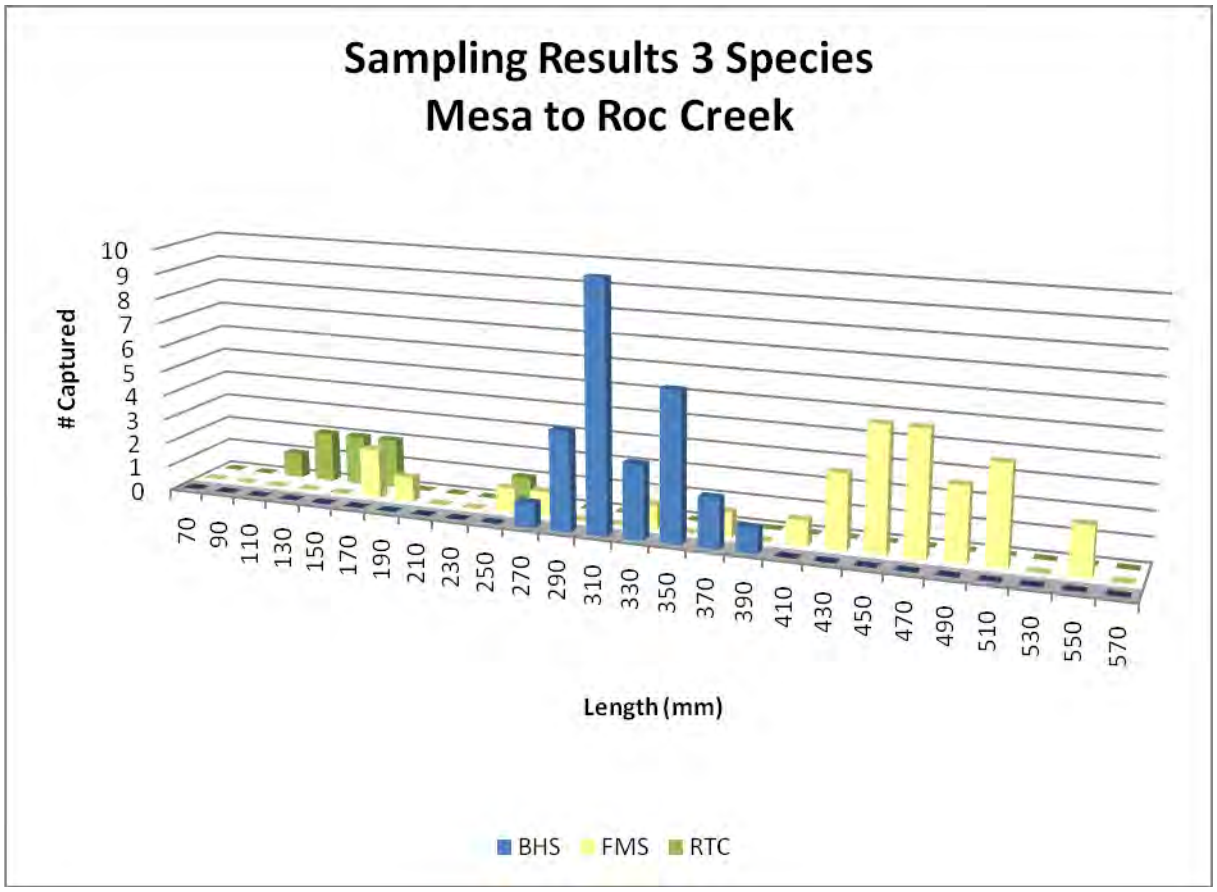


Figure 6. Length frequency histogram histogram the three species captured in the Mesa Creek to Roc Creek section of the Dolores River in 2010.

RIVER MILE 124 TO RIVER MILE 126 REACH:
The results of the survey are summarized in Table 3 and length frequency histograms for the three species are presented in Figures 7. Just over 80% of the fish sampled were native species of which 55% were three species. Bluehead suckers, flannelmouth suckers and roundtail chubs had a combined catch rate of 28 fish per mile. Bluehead suckers, flannel mouth suckers and round tail chubs showed several distinct age classes. Only one channel catfish was captured, and no smallmouth bass or sunfish were captured during the survey.

Species	# Caught	% Catch	# Caught Per Mile	Mean Length (in.)	Length Range (in.)
Flannelmouth Suckers	17	17	8.5	11.6	4.6-18
Bluehead Suckers	19	19	9.5	10.0	4.1-15.8
Roundtail Chub	20	20	10.0	5.2	3.1-7.4
Speckled Dace	26	25	13	3.3	2.2-4.0
Redside Shiner	1	1	0.5	2.6	2.6
Common Carp	4	4	2.0	21.8	20.6-22.8
Fathead Minnow	1	1	0.5	2.5	2.5
Red Shiner	10	10	5.0	3.0	2.6-3.3
Sand Shiner	3	3	1.5	2.6	2.4-2.8
Channel Catfish	1	1	0.5	11.7	11.7

Table 3. Summary of fish sampled in the Dolores River from RM 124 to RM 126 in 2010.

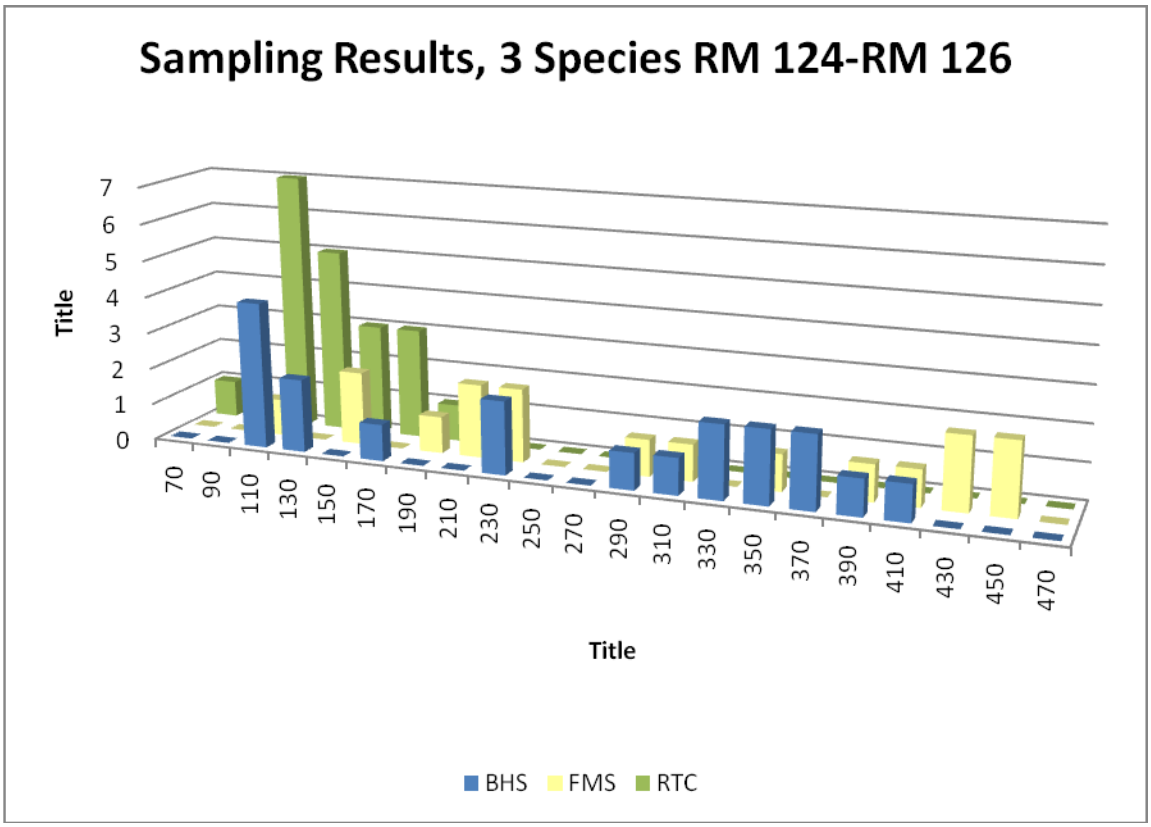


Figure 7. Length frequency histogram for the three species captured in the Dolores River from RM 124 to RM 126 in 2010.

BLUE CREEK TO SALT CREEK REACH:

The results for the final reach of the Dolores River sampled in 2010 are summarized in Table 4 and length frequency histograms for the three species are presented in Figure 8. Seventy six percent of the fish sampled were native species of which 58% were three species. Bluehead suckers, flannelmouth suckers and roundtail chubs had a combined catch rate of 13.2 fish per mile. Bluehead suckers, flannel mouth suckers and round tail chubs showed several distinct age classes. Only two channel catfish was captured, and no smallmouth bass or sunfish were captured during the survey.

Species	# Caught	% Catch	# Caught Per Mile	Mean Length (in.)	Length Range (in.)
Flannelmouth Suckers	22	44	7.9	16.9	3.8-22.2
Bluehead Suckers	6	12	2.1	14.0	11.7-17.9
Roundtail Chub	9	18	3.2	6.3	4.5-7.5
Speckled Dace	1	2	0.4	2.8	2.8
Common Carp	4	8	1.4	18.7	17.3-20.1
Red Shiner	3	6	1.1	3.1	2.8-3.5
Sand Shiner	1	2	0.4	2.6	2.6
Channel Catfish	2	4	0.7	16.5	10.9-22.0

Table 4. Summary of fish sampled in the Dolores River from Blue Creek to Salt Creek in 2010.

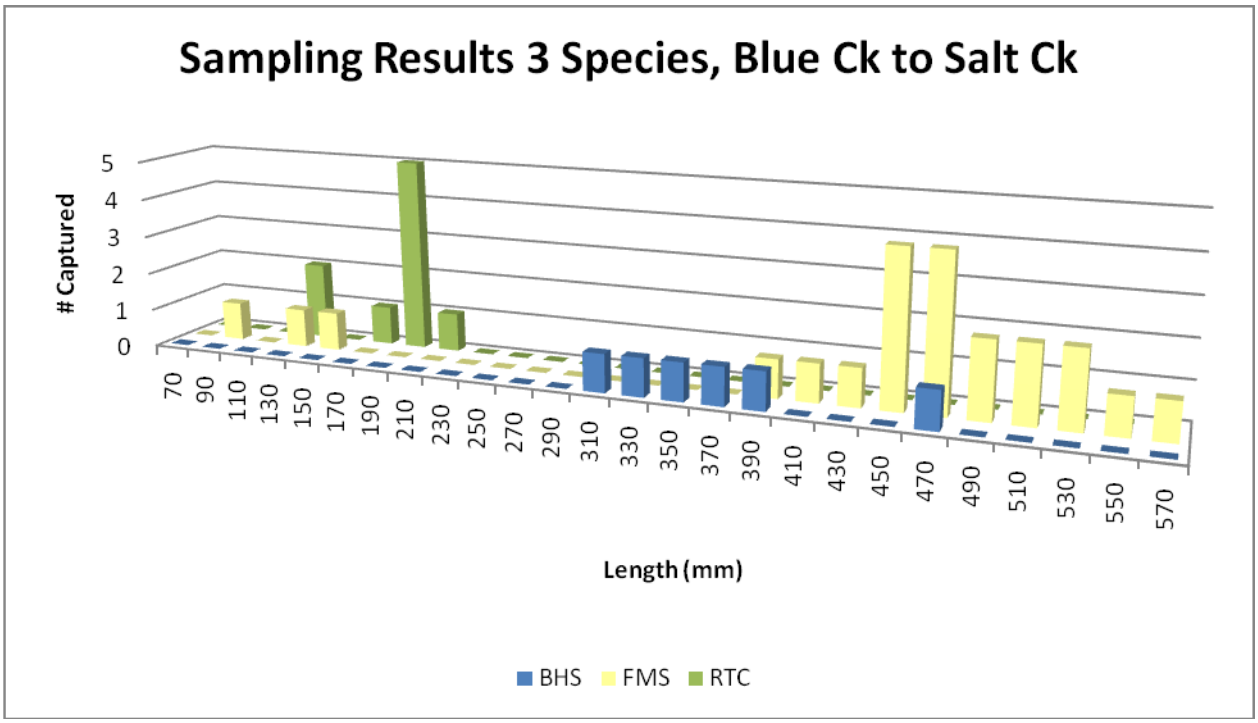


Figure 8. Length frequency histogram the three species captured in the Dolores River from Blue Creek to Salt Creek in 2010.

CONCLUSIONS

Above the confluence with the San Miguel River, the Dolores River contains a remnant population of native fish and should be managed as degraded water. The Dolores River above the confluence with the San Miguel River no longer has a natural peak flow hydrograph. Flows leaving the reservoir are significantly lower than those that enter the reservoir, impacting base flows in river below McPhee throughout the year (Figure 8). The hydrograph for the Dolores River above the confluence with the San Miguel no longer functions as it did historically. As a result, the decreased instream flows found in the Big Gypsum reach in late summer not only degrade the quality and quantity of native fish habitat but provide conditions more favorable to non-native fish like channel catfish and smallmouth bass. Two distinct age classes of smallmouth bass that were sampled in the Big Gypsum reach indicate that species is now reproducing in this portion of the river. The lower Dolores River below the confluence with the San Miguel still has a diverse native fish community and should continue to be managed as a native fish conservation water. The San Miguel now has a more natural hydrograph than the Dolores (Figures 9), and has a higher discharge than the Dolores above the confluence, even though it drains a much smaller watershed. Below the confluence of the San Miguel and Dolores Rivers the hydrograph is smaller than it was historically, but is much more natural. Native fish populations are healthy and contain multiple age classes.

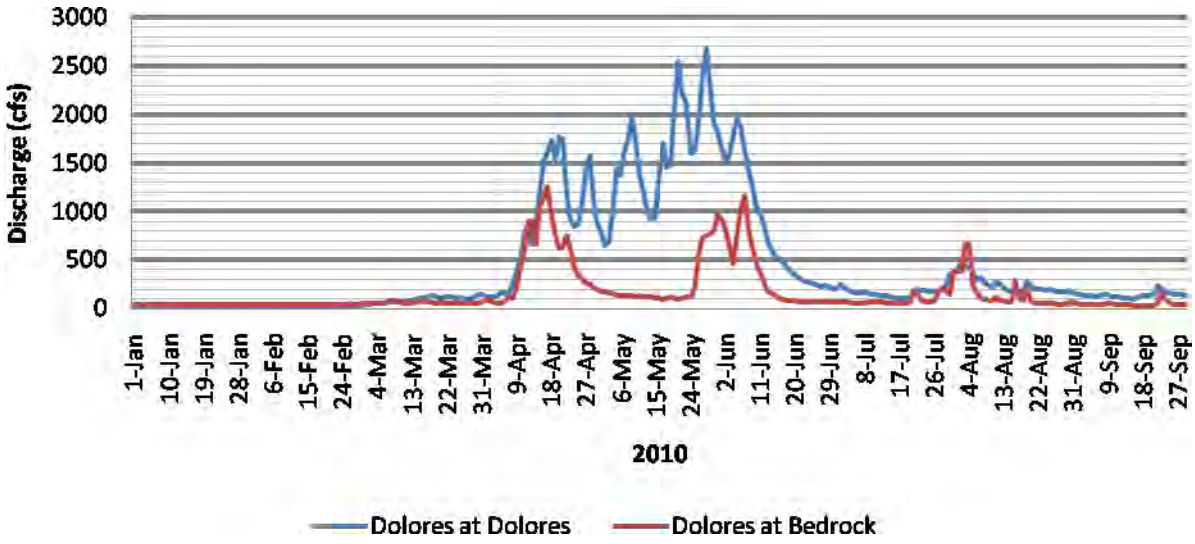


Figure 8 Discharge for the Dolores River above the confluence with the San Miguel River, 2010

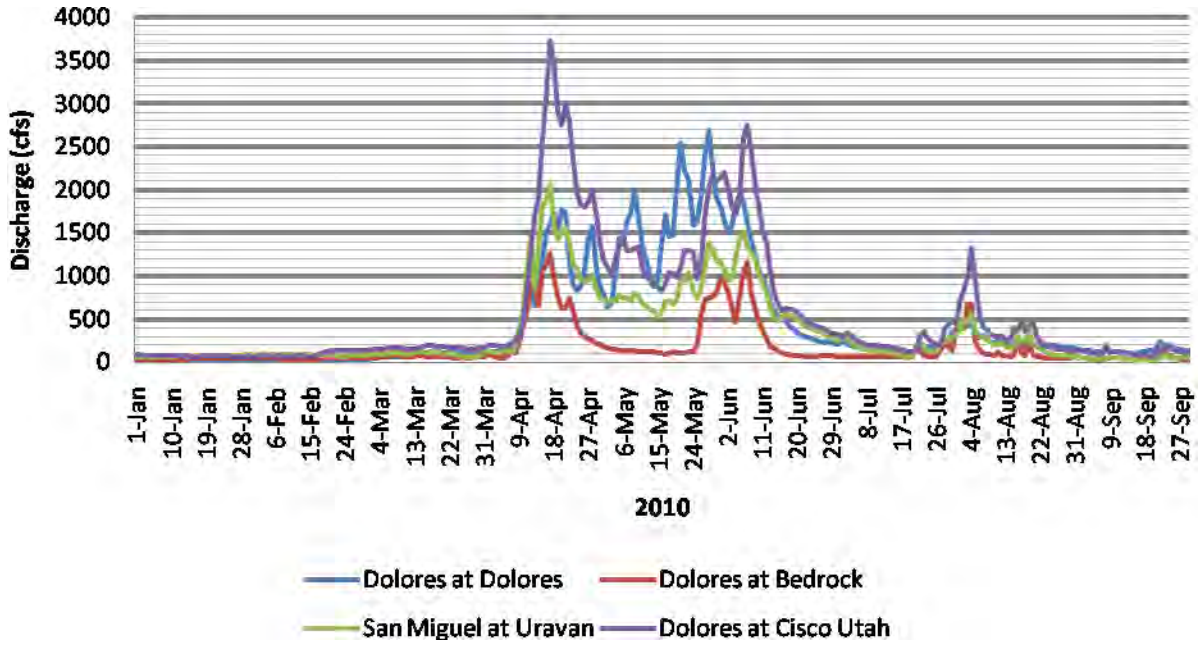


Figure 9 Discharge for the Dolores River and the San Miguel River, 2010

Flannelmouth suckers were distributed throughout the Dolores River in all reaches sampled in 2010 (Figure 10). However, higher numbers and larger age classes of fish were found downstream of the confluence with the San Miguel River as compared with the reach above the confluence. Smaller age classes of flannelmouth suckers were more concentrated in the Big Gypsum and reach between River Mile 124 and River Mile 126. Older Age classes were more common in the Blue Creek to Salt Creek reach and the Mesa Creek to Roc Creek reach.

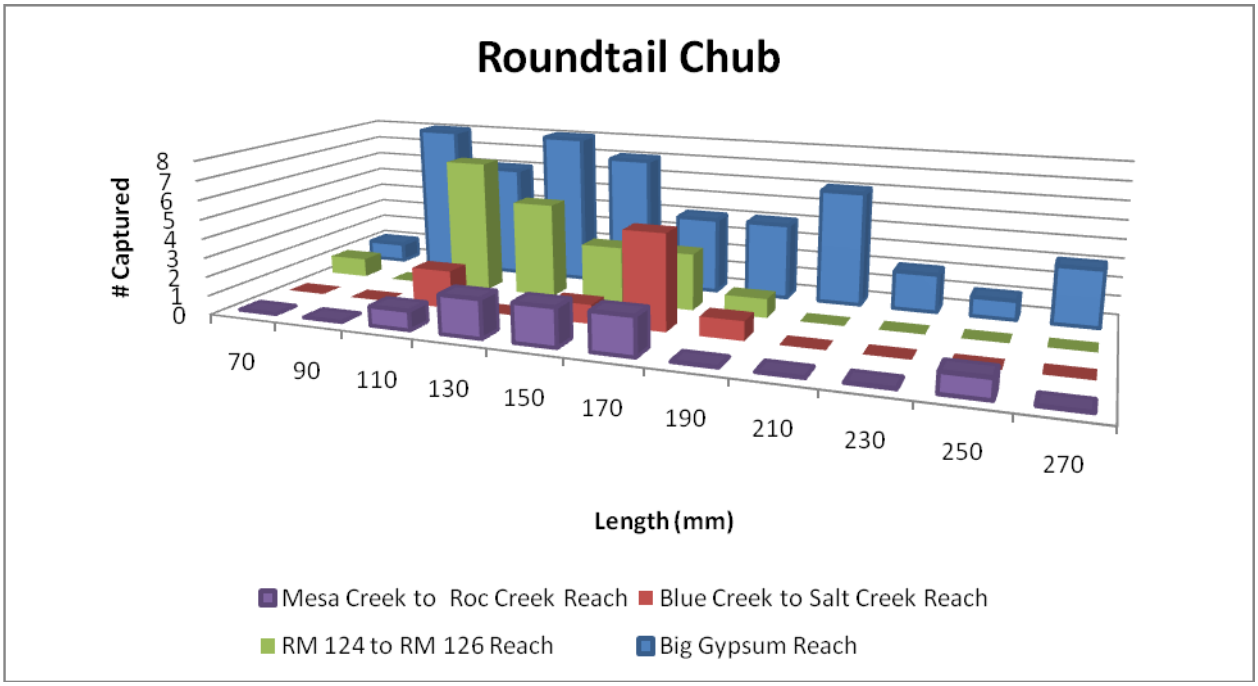


Figure 12 Roundtail Chub Pooled Length Frequency Distributions Dolores River, 2010

Some interesting trends appear from the figures above. First, roundtail chub are the most common member of the three species found in the degraded reach of the river, and was more common in that stretch than downstream. The Mesa Creek to Roc Creek section appears to hold the more and larger suckers of both species than the other reaches sampled, but at the same time it holds the least number of chubs. The Blue Creek to Salt Creek reach holds significantly fewer bluehead suckers and round tail chubs than the other two downstream reaches, but a high number of older age class flannelmouth suckers. A detailed habitat assessment of these reaches may help sort out these differences and should be conducted in the near future.

Non native fish that pose a threat to native species, such as smallmouth bass, green sunfish and channel catfish are greatly reduced in numbers or absent altogether below the confluence with the San Miguel. Their numbers continue to decline the further downstream one samples. Management efforts should be taken to prevent any further introductions of nonnative fish and to minimize the spread of channel catfish and smallmouth bass in the Dolores River. Efforts should be taken to enhance the flow regime in the lower Dolores including spring peak flows and especially base flows. Tributaries that could be used by native fish seasonally for spawning should also be evaluated for instream flow protection.

MANAGEMENT RECCOMENDATION SUMMARY

1. Management: Continue to manage the reaches below the confluence as a category 204 (Native Fish Conservation Stream), and the reaches above the confluence as category 800 Degraded Waters as well as trying to restore it to a category 204 Native Fish Conservation Stream.
2. Stocking: No supplemental stocking necessary at this time.
3. Regulations: Maintain current regulation that removes bag and possession limit on channel catfish and other non-native warmwater fish.
4. Habitat Improvement: Work to conserve native fish habitat by enhancing existing peak and base flows with water from McPhee. Improve native fish habitat by pursuing water leasing and/or purchasing opportunities from upstream senior water right holders to supplement late summer base flows.
5. Access/ Facilities: None needed.
6. Information and Education: Work with local water users and watershed coalition to educate stakeholders on the importance of these native fish populations to the whole Dolores River basin.

Fish Sampling Report

Paul Jones
Aquatic Biologist
Southwest Region

Water: Dolores River
Reaches: Mesa Creek to Roc Creek (RM 114.3-RM117.5), River Mile 124 to River Mile 126, Blue Creek to Salt Creek (RM 127.8-RM 130.6)
Dates: 6/15/2010 - 6/16/2010
Gear: 14 ft. electrofishing raft with booms and Smith Root 2.5 GPP
Drainage: Dolores
Water Codes: 39760

OBJECTIVE

The Dolores River was sampled with single pass CPUE electrofishing to monitor native fish populations on three separate reaches. The reaches sampled were the Mesa Creek to Roc Creek reach, River Mile 124 to River Mile 126 reach, and the Blue Creek to Salt Creek Reach (Figure 1). .

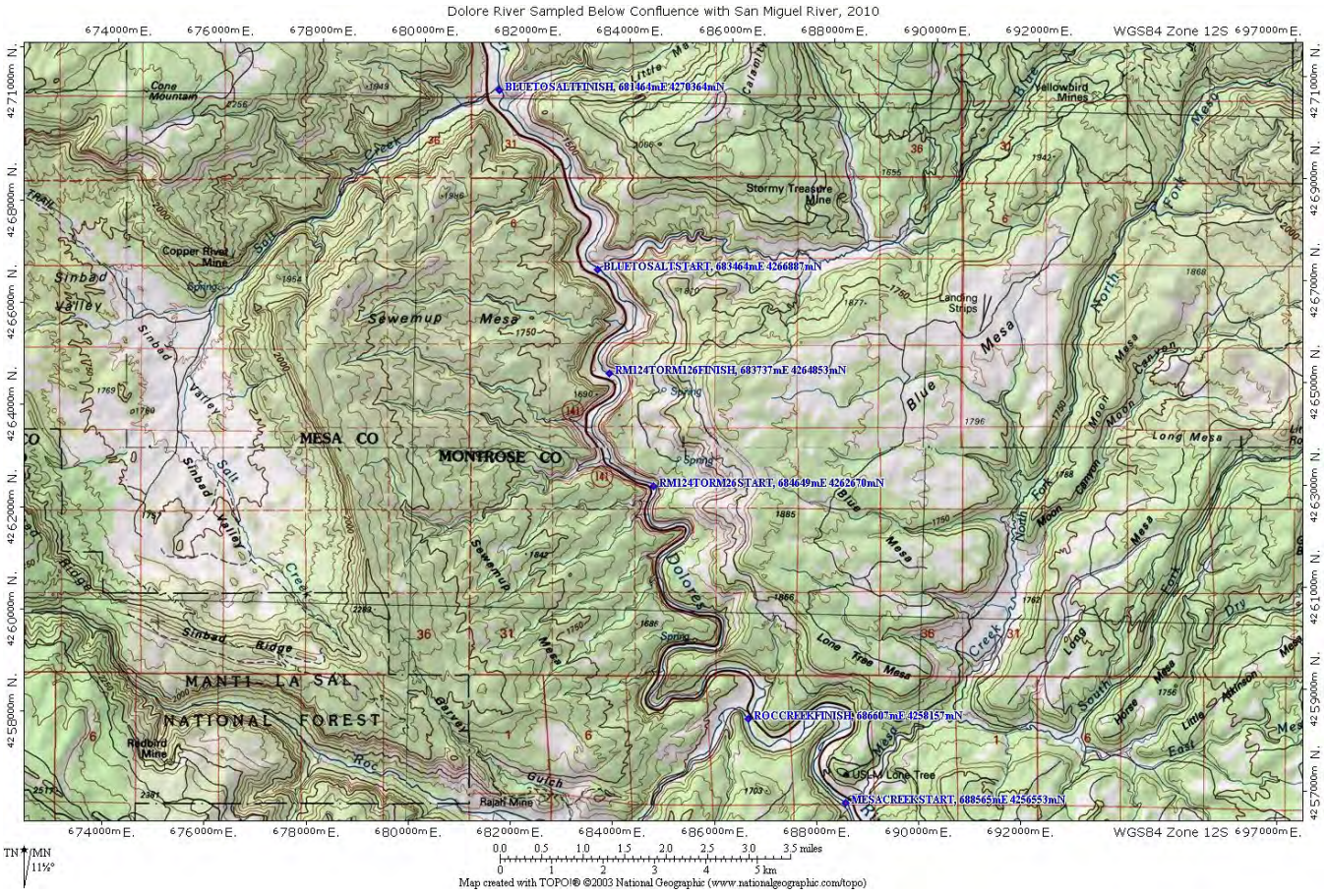


Figure 1. Dolores River Reaches Sampled in 2010

The Mesa Creek to Roc Creek sections of the Dolores River was sampled on June 15th with single pass CPUE from the mouth of Mesa Creek to the mouth of Roc Creek (Figure 2). Total pooled sampling distance was 3.2 miles.

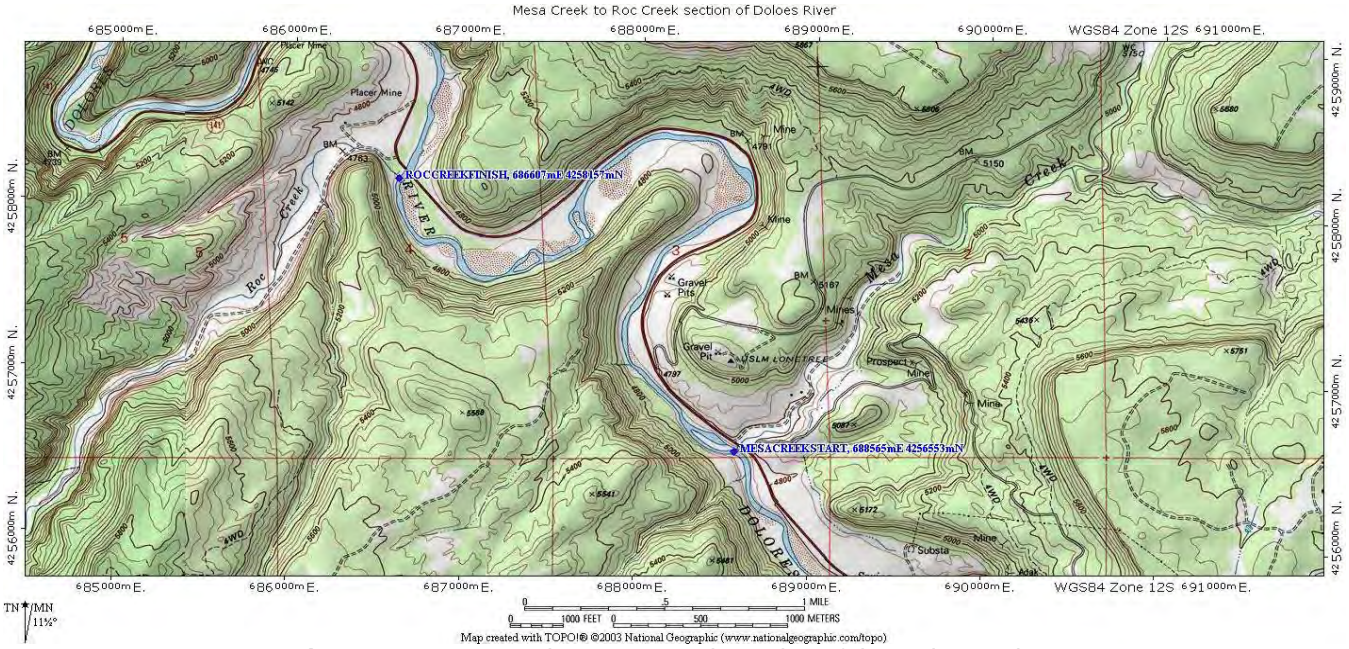


Figure 2. Mesa Creek to Roc Creek section of the Dolores River

The next reach of Dolores River that was sampled ran from the top of the island at RM 124 to the bottom of the island at RM 126 (Figure 3), and was sampled on the 16th of June. Total pooled sampling distance was 2 miles.

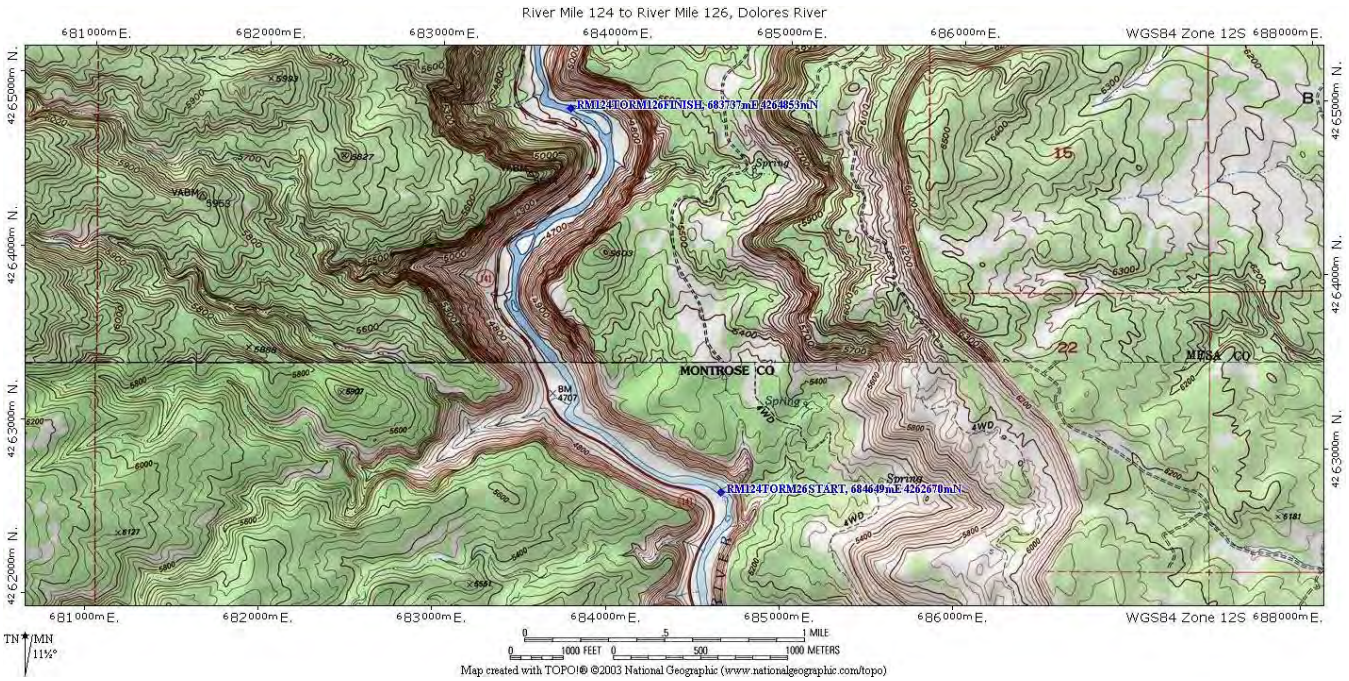


Figure 3. Dolores River from RM 124 to RM 126

The final reach of the Dolores River was sampled on the afternoon of June Sixteen, and it ran from the mouth of Blue Creek to the top of the rapids at the mouth of Salt Creek (Figure 4). Total pooled sampling distance was 2.8 miles.

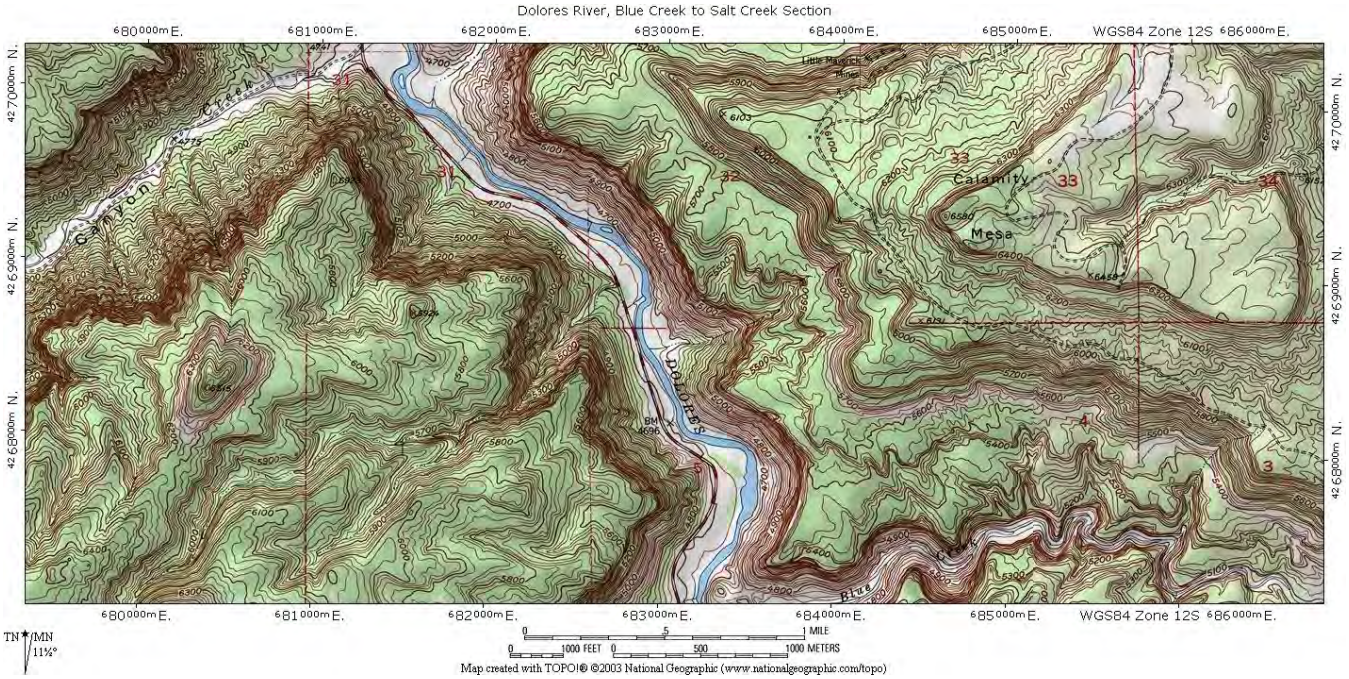


Figure 4. Dolores River from Blue Creek to Salt Creek

RESULTS

MESA TO ROC CREEK REACH:

The results of the Mesa Creek to Roc Creek survey are summarized in Table 1 and length frequency histogram for the three species are presented in Figure 5. The Level II report is located in Appendix A. Ninety three percent of the fish sampled were native species, with 87 percent being three species, which had a combined catch rate of 20.3 fish per mile. Bluehead suckers, flannel mouth suckers and round tail chubs showed several distinct age classes. While two channel catfish were captured, no smallmouth bass or sunfish were captured during the survey.

Species	# Caught	% Catch	# Caught Per Mile	Mean Length (in.)	Length Range (in.)
Flannelmouth Suckers	30	40	9.4	16.6	6.5-21.7
Bluehead Suckers	27	36	8.4	12.8	10.4-15.2
Roundtail Chub	8	11	2.5	6.2	4.1-9.8
Speckled Dace	5	7	1.6	3.3	2.8-3.9
Common Carp	2	3	.6	18.6	15.7-21.5
Channel Catfish	2	3	.6	17.3	14.4-20.3
Sand Shiner	1	1	.3	2.6	2.6

Table 2. Summary of fish sampled in the Dolores River from Mesa Creek to Roc Creek in 2010.

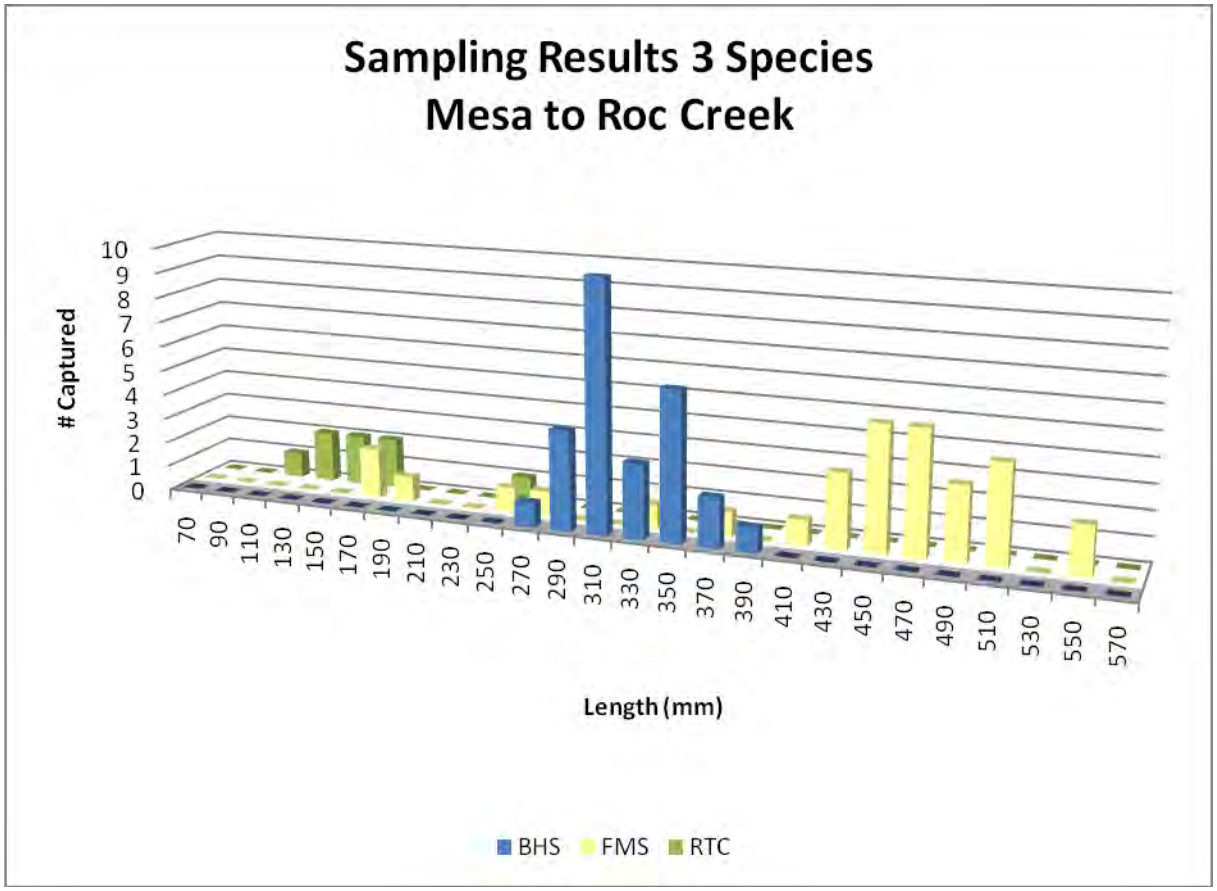


Figure 5. Length frequency histogram of Three Species captured in the Mesa Creek to Roc Creek section of the Dolores River in 2010.

RIVER MILE 124 TO RIVER MILE 126 REACH:
The results of the survey are summarized in Table 2 and length frequency histogram for the three species is presented in Figure 6. Appendix B contains the Level II report. Just over 80% of the fish sampled were native species of which 55% were three species. Bluehead suckers, flannelmouth suckers and roundtail chubs had a combined catch rate of 28 fish per mile. Bluehead suckers, flannel mouth suckers and round tail chubs showed several distinct age classes. Only one channel catfish was captured, and no smallmouth bass or sunfish were captured during the survey.

Species	# Caught	% Catch	# Caught Per Mile	Mean Length (in.)	Length Range (in.)
Flannelmouth Suckers	17	17	8.5	11.6	4.6-18
Bluehead Suckers	19	19	9.5	10.0	4.1-15.8
Roundtail Chub	20	20	10.0	5.2	3.1-7.4
Speckled Dace	26	25	13	3.3	2.2-4.0
Redside Shiner	1	1	0.5	2.6	2.6
Common Carp	4	4	2.0	21.8	20.6-22.8
Fathead Minnow	1	1	0.5	2.5	2.5
Red Shiner	10	10	5.0	3.0	2.6-3.3
Sand Shiner	3	3	1.5	2.6	2.4-2.8
Channel Catfish	1	1	0.5	11.7	11.7

Table 2. Summary of fish sampled in the Dolores River from RM 124 to RM 126 in 2010.

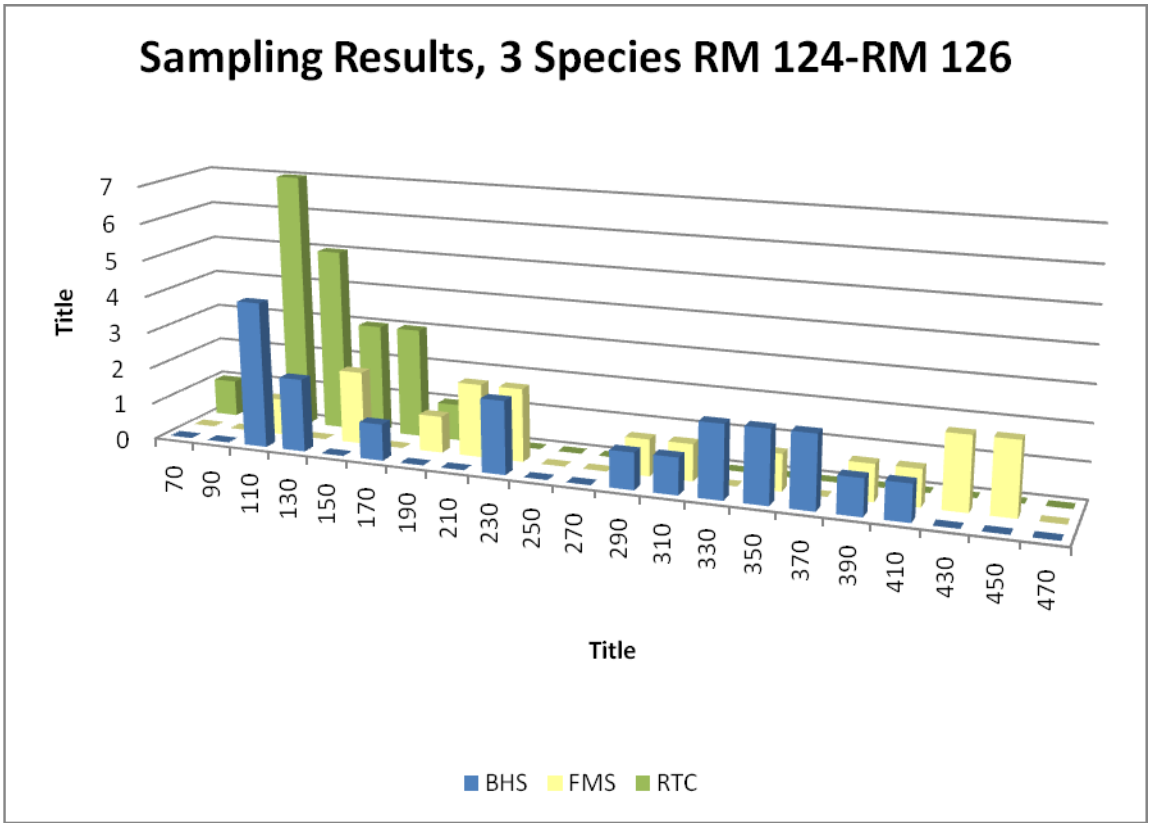


Figure 6. Length frequency histogram of Three Species captured in the RM 124-RM 126 section of the Dolores River in 2010.

BLUE CREEK TO SALT CREEK REACH:
The results for the final reach of the Dolores River sampled in 2010 are summarized in Table 3 and the length frequency histogram for the three species is presented in Figure 7. The Level II report can be found in Appendix C. Seventy six percent of the fish sampled were native species of which 58% were three species. Bluehead suckers, flannelmouth suckers and roundtail chubs had a combined catch rate of 13.2 fish per mile. Bluehead suckers, flannel mouth suckers and round tail chubs showed several distinct age classes. Only two channel catfish was captured, and no smallmouth bass or sunfish were captured during the survey.

Species	# Caught	% Catch	# Caught Per Mile	Mean Length (in.)	Length Range (in.)
Flannelmouth Suckers	22	44	7.9	16.9	3.8-22.2
Bluehead Suckers	6	12	2.1	14.0	11.7-17.9
Roundtail Chub	9	18	3.2	6.3	4.5-7.5
Speckled Dace	1	2	0.4	2.8	2.8
Common Carp	4	8	1.4	18.7	17.3-20.1
Red Shiner	3	6	1.1	3.1	2.8-3.5
Sand Shiner	1	2	0.4	2.6	2.6
Channel Catfish	2	4	0.7	16.5	10.9-22.0

Table 3. Summary of fish sampled in the Dolores River from Blue Creek to Salt Creek in 2010.

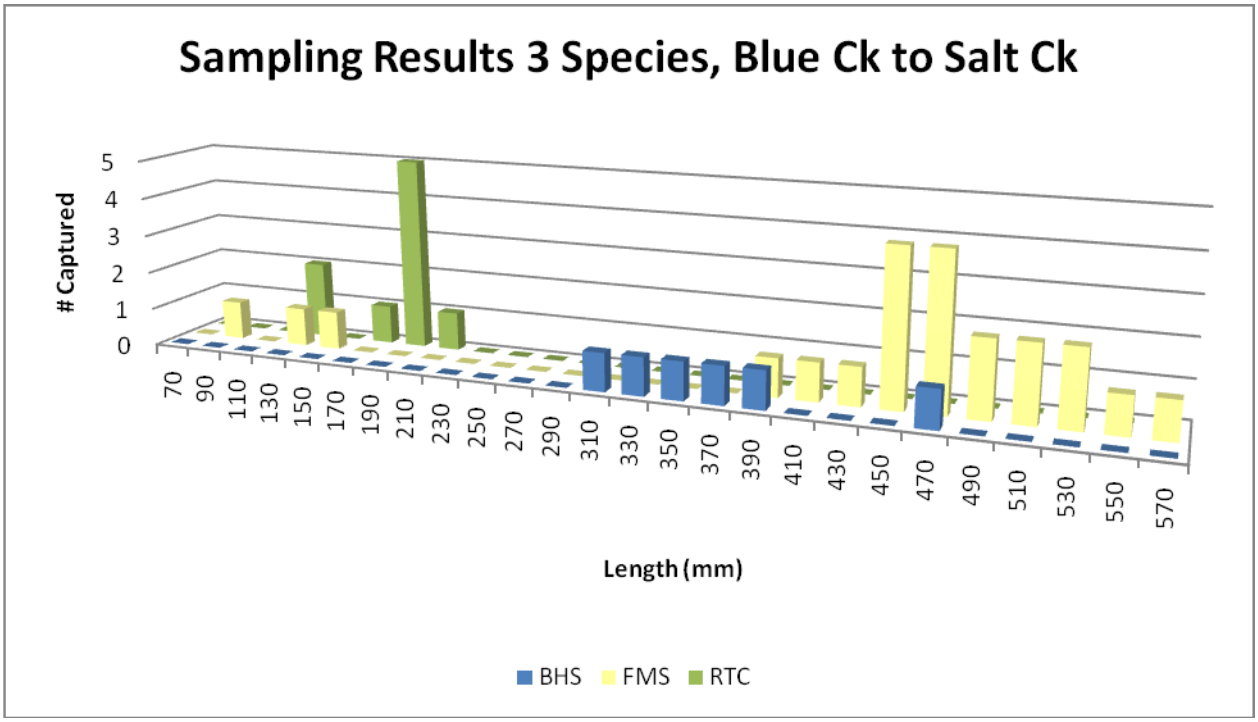


Figure 7. Length frequency histogram of Three Species captured in the Blue Creek to Salt Creek section of the Dolores River in 2010.

CONCLUSIONS

Flows in the Dolores River below the confluence with the San Miguel River have a more natural hydrograph than those above the confluence, which have been impacted by McPhee Reservoir (Figure 8). Flows begin to return to a more natural hydrograph after the San Miguel joins the Dolores River. Native fish populations also begin to

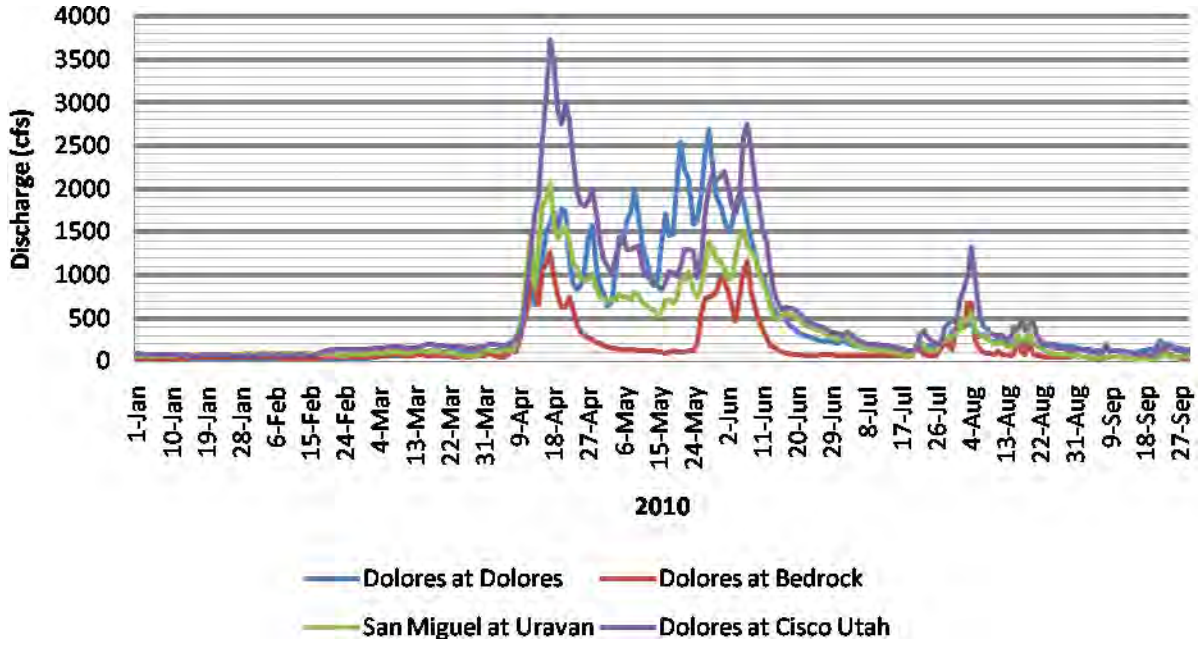


Figure 8. Discharge for the Dolores River and the San Miguel River, 2010

rebound below the confluence as well. Bluehead suckers were found in all three reaches sampled below the confluence (Figure 9). While numbers and the distribution of age classes declined as we sampled downstream, they were present in all three reaches.

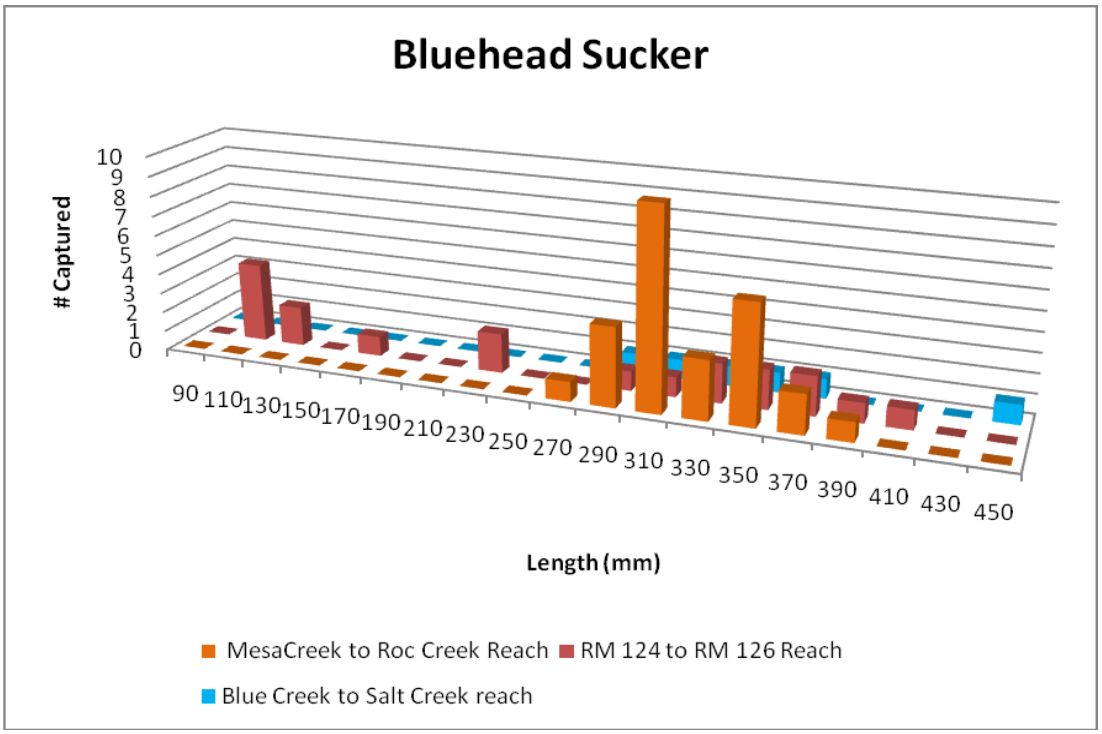


Figure 9. Bluehead Sucker Length Frequency in the Lower Dolores Below the San Miguel River

Flannelmouth Suckers were distributed throughout the Dolores River in all reaches sampled in 2010 (Figure 10). Smaller age classes of flannelmouth suckers were more concentrated in the reach between River Mile 124 and River Mile 126 than the other reaches. Older Age classes were more common in the Blue Creek to Salt Creek reach and the Mesa Creek to Roc Creek reaches.

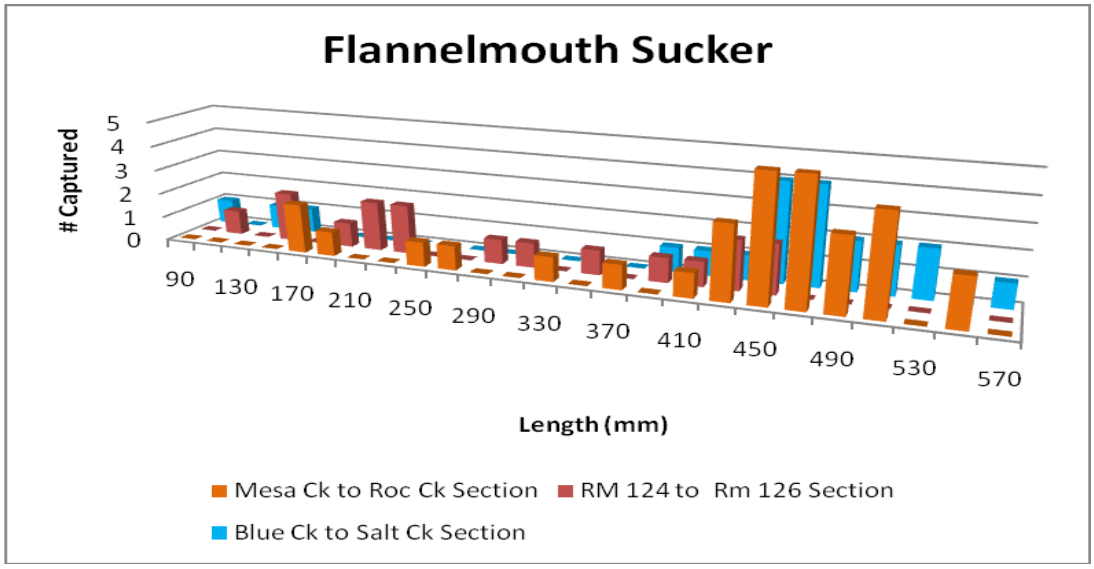


Figure 10. Flannelmouth Sucker Length Frequency in the Lower Dolores Below the San Miguel River

Roundtail chub were found in all three reaches and were of similar size in all three reaches(Figure 10). They were most numerous in the between River Miles 124 and 126. The Mesa Creek reach had the fewest number of roundtail chubs of the reaches sampled.

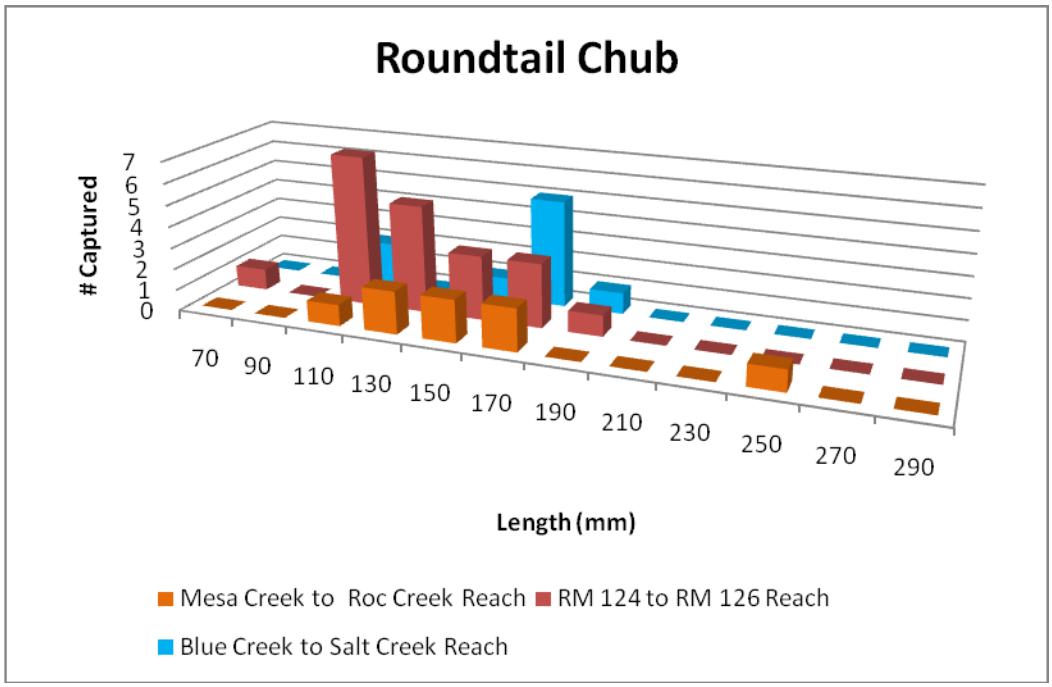


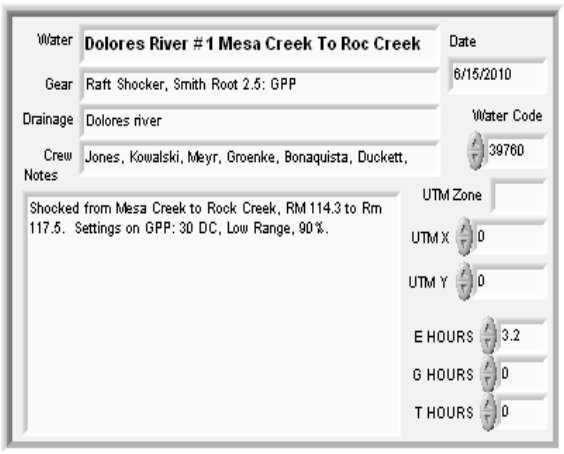
Figure 10. Roundtail Chub Length Frequency in the Lower Dolores Below the San Miguel River

Some interesting trends appear from the figures above. The Mesa Creek to Roc Creek section appears to hold the more and larger suckers of both species than the other reaches sampled, but at the same time it holds the least number of chubs. The Blue Creek to Salt Creek reach holds significantly fewer bluehead suckers and roundtail chubs than the other two downstream reaches, but a high number of older age class flannelmouth suckers. A detailed habitat assessment of these reaches may help sort out these differences and should be conducted in the near future.

Non native fish that pose a threat to native species, such as smallmouth bass, green sunfish and channel catfish are greatly reduced in numbers or absent altogether below the confluence with the San Miguel. Their numbers continue to decline the further downstream one samples. Management efforts should be taken to prevent any further introductions of nonnative fish and to minimize the spread of channel catfish and smallmouth bass in the Dolores River. Efforts should be taken to enhance the flow regime in the lower Dolores including spring peak flows and especially base flows. Tributaries that could be used by native fish seasonally for spawning should also be evaluated for instream flow protection.

MANAGEMENT RECCOMENDATION SUMMARY

1. Management: Continue to manage the reaches below the confluence as a category 204 (Native Fish Conservation Stream.
2. Stocking: No supplemental stocking necessary at this time.
3. Regulations: Maintain current regulation that removes bag and possession limit on channel catfish and other non-native warmwater fish.
4. Habitat Improvement: Work to conserve native fish habitat by enhancing existing peak and base flows with water from McPhee. Improve native fish habitat by pursuing water leasing and/or purchasing opportunities from upstream senior water right holders to supplement late summer base flows.
5. Access/ Facilities: None needed.
6. Information and Education: Work with local water users and watershed coalition to educate stakeholders on the importance of these native fish populations to the whole Dolores River basin.



LEVEL 2 - LAKE SURVEY

SAVE PRINT PRINT DONE

SUMMARY INFORMATION

Species	# Caught	% Catch	Mean Ln (in)	Ln Range (in)	Mean Wt (lbs)	Wt Range (lbs)	E CPUE	G CPUE	T CPUE	PSD
BHS	27	36	12.8	10.4-15.2	0.00	0.0-0.0	8.4	NaN	NaN	100
CCF	2	3	17.3	14.4-20.3	0.00	0.0-0.0	0.6	NaN	NaN	50
CPP	2	3	18.6	15.7-21.5	0.00	0.0-0.0	0.6	NaN	NaN	50
FMS	30	40	16.6	6.5-21.7	0.00	0.0-0.0	9.4	NaN	NaN	100
RTC	8	11	6.2	4.1-9.8	0.00	0.0-0.0	2.5	NaN	NaN	100
SAH	1	1	2.6	2.6-2.6	0.00	0.0-0.0	0.3	NaN	NaN	100
SPD	5	7	3.3	2.8-3.9	0.00	0.0-0.0	1.6	NaN	NaN	100

LENGTH FREQUENCY RECORD (cm)

	Species	0-3	3-6	6-9	9-12	12-15	15-18	18-21	21-24	24-27	27-30	30-33	33-36	36-39	39-42	42-45	45-48	48-51	51-54	54-57	57-60	60-63	63-66	66-69	69-72	72-75	75-78	78-81	81-84	84-87	87-90	90-93	93-96	>96
1	BHS									1	3	13	7	3																				
2	CCF													1					1															
3	CPP														1					1														
4	FMS						1	2		1	1	1		1	1	5	8	4	3	2														
5	RTC				1	2	4			1																								
6	SAH			1																														
7	SPD			3	2																													
8																																		
9																																		
10																																		
11																																		
12																																		
13																																		
14																																		

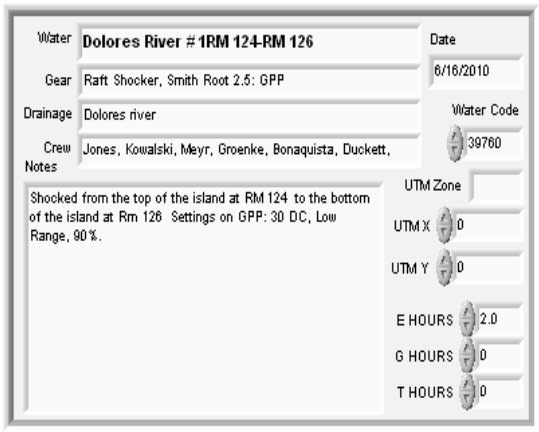
Water: Dolores River # 1 Mesa Creek To Roc Creek
Date: 6/15/2010
Gear: Raft Shocker, Smith Root 2.5: GPP
Drainage: Dolores river
Water Code: 39760
UTM Zone:
UTM X: 0 m
UTM Y: 0 m
E Hours = 3.2
G Hours = 0
T Hours = 0
Crew: Jones, Kowalski, Meyr, Groenke, Bonaquista, Duckett, Delpocalo
Notes: Shocked from Mesa Creek to Rock Creek, RM 114.3 to Rm 117.5. Settings on GPP: 30 DC, Low Range, 90%.

Species	Count	Length (mm)	Weight (g)	Status	Mark	TagID
FMS	1	545	E1			
FMS	1	441	E1			
FMS	1	476	E1			
RTC	1	250	E1			
BHS	1	315	E1			
BHS	1	310	E1			
BHS	1	315	E1			
BHS	1	362	E1			
BHS	1	306	E1			

BHS	1	320	E1	
SPD	1	80	E1	
SPD	1	91	E1	
FMS	1	473	E1	
BHS	1	300	E1	
BHS	1	309	E1	RIPE MALE
BHS	1	310	E1	
SPD	1	72	E1	
RTC	1	155	E1	
FMS	1	495	E1	
FMS	1	504	E1	
FMS	1	411	E1	
FMS	1	430	E1	
CPP	1	545	E1	
BHS	1	320	E1	
FMS	1	465	E1	
CCF	1	365	E1	
RTC	1	170	E1	
FMS	1	165	E1	
RTC	1	105	E1	
FMS	1	455	E1	
FMS	1	427	E1	
SSH	1	66	E1	
FMS	1	463	E1	
BHS	1	358	E1	
FMS	1	512	E1	
CCF	1	515	E1	
FMS	1	520	E1	
FMS	1	486	E1	
FMS	1	550	E1	
BHS	1	387	E1	
FMS	1	422	E1	
BHS	1	265	E1	
FMS	1	280	E1	
RTC	1	167	E1	
RTC	1	135	E1	
SPD	1	81	E1	
CPP	1	400	E1	
FMS	1	465	E1	
FMS	1	451	E1	
BHS	1	286	E1	
BHS	1	326	E1	
BHS	1	356	E1	
FMS	1	321	E1	
FMS	1	186	E1	
FMS	1	448	E1	
BHS	1	281	E1	
FMS	1	180	E1	
FMS	1	512	E1	
FMS	1	496	E1	
FMS	1	456	E1	
FMS	1	367	E1	
BHS	1	318	E1	
RTC	1	122	E1	
SPD	1	98	E1	
BHS	1	329	E1	
BHS	1	354	E1	
BHS	1	353	E1	

BHS	1	304	E1
BHS	1	368	E1
BHS	1	351	E1
RTC	1	152	E1
FMS	1	255	E1
BHS	1	353	E1
BHS	1	330	E1
BHS	1	298	E1

Appendix B



LEVEL 2 - LAKE SURVEY

SAVE PRINT PRINT DONE

SUMMARY INFORMATION

Species	# Caught	% Catch	Mean Ln (in)	Ln Range (in)	Mean Wt (lbs)	Wt Range (lbs)	E CPUE	G CPUE	T CPUE	PSD
BHS	19	19	10.0	4.1-15.8	0.00	0.0-0.0	9.5	NaN	NaN	100
CCF	1	1	11.7	11.7-11.7	0.00	0.0-0.0	0.5	NaN	NaN	NaN
CPP	4	4	21.8	20.6-22.8	0.00	0.0-0.0	2.0	NaN	NaN	100
FMS	17	17	11.6	4.6-18.0	0.00	0.0-0.0	8.5	NaN	NaN	100
FMW	1	1	2.5	2.5-2.5	0.00	0.0-0.0	0.5	NaN	NaN	100
RDS	10	10	3.0	2.6-3.3	0.00	0.0-0.0	5.0	NaN	NaN	100
RSS	1	1	2.6	2.6-2.6	0.00	0.0-0.0	0.5	NaN	NaN	100
RTC	20	20	5.2	3.1-7.4	0.00	0.0-0.0	10.0	NaN	NaN	100
SAH	3	3	2.6	2.4-2.8	0.00	0.0-0.0	1.5	NaN	NaN	100
SPD	26	25	3.3	2.2-4.0	0.00	0.0-0.0	13.0	NaN	NaN	100

LENGTH FREQUENCY RECORD (cm)

	Species	0-3	3-6	6-9	9-12	12-15	15-18	18-21	21-24	24-27	27-30	30-33	33-36	36-39	39-42	42-45	45-48	48-51	51-54	54-57	57-60	60-63	63-66	66-69	69-72	72-75	75-78	78-81	81-84	84-87	87-90	90-93	93-96	>96
1	BHS				4	2	1		2		1	2	3	2	2																			
2	CCF										1																							
3	CPP																		1	2	1													
4	FMS				1	1	1	2	3		1	1	1	1	1	3	1																	
5	FMW			1																														
6	RDS			10																														
7	RSS			1																														
8	RTC			1	6	7	5	1																										
9	SAH			3																														
10	SPD		2	19	5																													
11																																		
12																																		
13																																		
14																																		

Water: Dolores River # 1RM 124-RM 126
Date: 6/16/2010
Gear: Raft Shocker, Smith Root 2.5: GPP
Drainage: Dolores river
Water Code: 39760
UTM Zone:
UTM X: 0 m
UTM Y: 0 m
E Hours = 2.0
G Hours = 0
T Hours = 0
Crew: Jones, Kowalski, Meyr, Groenke, Bonaquista, Duckett, Delpocalo, Jones and Jones
Notes: Shocked from the top of the island at RM 124 to the bottom of the island at Rm 126 Settings on GPP: 30 DC, Low Range, 90%.

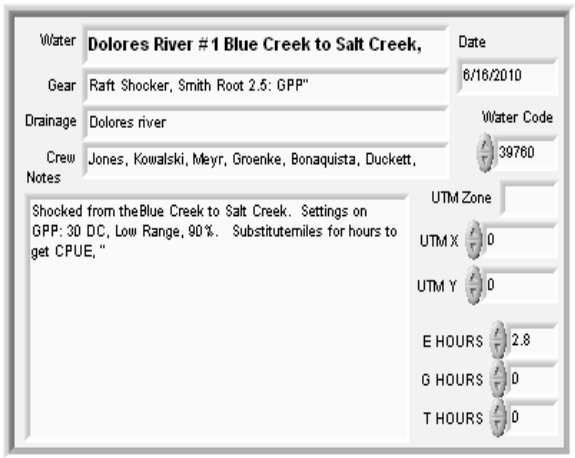
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Species	Count	Length (mm)	Weight (g)	Status	Mark	TagID
CPP	1	580	E2			
BHS	1	342	E2			
CPP	1	565	E2			
FMS	1	404	E2			
RTC	1	120	E2			
CPP	1	545	E2			
RTC	1	189	E2			
SPD	1	89	E2			

FMS	1	440	E2
BHS	1	394	E2
RSS	1	67	E2
FMS	1	117	E2
RTC	1	128	E2
SPD	1	83	E2
SAH	1	70	E2
RTC	1	163	E2
FMS	1	195	E2
FMS	1	216	E2
RTC	1	153	E2
RTC	1	158	E2
RTC	1	133	E2
RTC	1	130	E2
RTC	1	105	E2
RTC	1	147	E2
RTC	1	170	E2
BHS	1	233	E2
RTC	1	126	E2
RDS	1	76	E2
RTC	1	125	E2
RDS	1	79	E2
RDS	1	85	E2
SAH	1	70	E2
RTC	1	103	E2
RDS	1	71	E2
RDS	1	75	E2
RTC	1	116	E2
SPD	1	83	E2
SPD	1	78	E2
FMW	1	64	E2
FMS	1	145	E2
CPP	1	522	E2
BHS	1	363	E2
RDS	1	80	E2
FMS	1	387	E2
SPD	1	83	E2
RTC	1	102	E2
RTC	1	105	E2
RTC	1	78	E2
SPD	1	86	E2
RDS	1	71	E2
SPD	1	102	E2
SPD	1	100	E2
RDS	1	75	E2
SPD	1	73	E2
SPD	1	82	E2
SPD	1	75	E2
RDS	1	73	E2
FMS	1	430	E2
FMS	1	298	E2
FMS	1	456	E2
FMS	1	447	E2
BHS	1	117	E2
BHS	1	108	E2
BHS	1	132	E2
SPD	1	88	E2
SPD	1	85	E2

SPD	1	77	E2	
SPD	1	57	E2	
RTC	1	179	E2	
BHS	1	103	E2	
RTC	1	111	E2	
FMS	1	357	E2	
BHS	1	401	E2	CATARACTS
BHS	1	364	E2	
BHS	1	329	E2	
FMS	1	158	E2	
SPD	1	95	E2	
SPD	1	78	E2	
SPD	1	79	E2	
CCF	1	298	E2	
FMS	1	305	E2	
BHS	1	140	E2	
RDS	1	66	E2	
SPD	1	83	E2	
SPD	1	81	E2	
SAH	1	60	E2	
SPD	1	93	E2	
BHS	1	340	E2	
BHS	1	221	E2	
SPD	1	79	E2	
BHS	1	316	E2	
BHS	1	351	E2	
FMS	1	224	E2	
SPD	1	102	E2	
SPD	1	86	E2	
BHS	1	164	E2	
BHS	1	109	E2	
FMS	1	222	E2	
BHS	1	296	E2	
SPD	1	86	E2	
FMS	1	205	E2	
SPD	1	59	E2	

Appendix C



LEVEL 2 - LAKE SURVEY

SAVE PRINT PRINT DONE

SUMMARY INFORMATION

Species	# Caught	% Catch	Mean Ln (in)	Ln Range (in)	Mean Wt (lbs)	Wt Range (lbs)	E CPUE	G CPUE	T CPUE	PSD
BHS	6	12	14.0	11.7-17.9	0.00	0.0-0.0	2.1	NaN	NaN	100
CCF	2	4	16.5	10.9-22.0	0.00	0.0-0.0	0.7	NaN	NaN	100
CPP	4	8	18.7	17.3-20.1	0.00	0.0-0.0	1.4	NaN	NaN	100
FMS	22	44	16.9	3.8-22.2	0.00	0.0-0.0	7.9	NaN	NaN	100
LOC	2	4	10.7	10.4-11.0	0.00	0.0-0.0	0.7	NaN	NaN	100
RDS	3	6	3.1	2.8-3.5	0.00	0.0-0.0	1.1	NaN	NaN	100
RTC	9	18	6.3	4.5-7.5	0.00	0.0-0.0	3.2	NaN	NaN	100
SAH	1	2	2.6	2.6-2.6	0.00	0.0-0.0	0.4	NaN	NaN	100
SPD	1	2	2.8	2.8-2.8	0.00	0.0-0.0	0.4	NaN	NaN	100

LENGTH FREQUENCY RECORD (cm)

	Species	0-3	3-6	6-9	9-12	12-15	15-18	18-21	21-24	24-27	27-30	30-33	33-36	36-39	39-42	42-45	45-48	48-51	51-54	54-57	57-60	60-63	63-66	66-69	69-72	72-75	75-78	78-81	81-84	84-87	87-90	90-93	93-96	>96
1	BHS										1	1	2	1			1																	
2	CCF										1									1														
3	CPP															1	1	1	1															
4	FMS				1	2								1	1	3	6	2	4	2														
5	LOC									1	1																							
6	RDS			2	1																													
7	RTC				2		5	2																										
8	SAH			1																														
9	SPD			1																														
10																																		
11																																		
12																																		
13																																		
14																																		

Water: Dolores River # 1 Blue Creek to Salt Creek, RM 127.8-RM 130.6"
Date: 6/16/2010
Gear: Raft Shocker, Smith Root 2.5: GPP"
Drainage: Dolores river
Water Code: 39760
UTM Zone:
UTM X: 0 m
UTM Y: 0 m
E Hours = 2.8
G Hours = 0
T Hours = 0
Crew: Jones, Kowalski, Meyr, Groenke, Bonaquista, Duckett, Delpocalo, Jones and Jones"
Notes: Shocked from theBlue Creek to Salt Creek. Settings on GPP: 30 DC, Low Range, 90%. Substitutemiles for hours to get CPUE, "

Species	Count	Length (mm)	Weight (g)	Status	Mark	TagID
BHS	1	355	E3			
FMS	1	526	E3			
RTC	1	180	E3			
RTC	1	162	E3			

FMS	1	137	E3	
BHS	1	455	E3	SPENT FEMALE
CCF	1	278	E3	
BHS	1	296	E3	
RTC	1	178	E3	
RDS	1	70	E3	
RTC	1	115	E3	
FMS	1	96	E3	
SAH	1	66	E3	
FMS	1	483	E3	
FMS	1	481	E3	
BHS	1	371	E3	
RDS	1	90	E3	
FMS	1	462	E3	
BHS	1	315	E3	
FMS	1	143	E3	
RTC	1	116	E3	
FMS	1	412	E3	
LOC	1	265	E3	
CCF	1	560	E3	
FMS	1	446	E3	
FMS	1	441	E3	
FMS	1	555	E3	
FMS	1	510	E3	
FMS	1	465	E3	
FMS	1	526	E3	
FMS	1	515	E3	
FMS	1	565	E3	
LOC	1	280	E3	
RTC	1	190	E3	
FMS	1	385	E3	
RTC	1	172	E3	
FMS	1	461	E3	
FMS	1	465	E3	
FMS	1	460	E3	
BHS	1	334	E3	
CPP	1	510	E3	
CPP	1	440	E3	
FMS	1	433	E3	
FMS	1	450	E3	
CPP	1	450	E3	
CPP	1	500	E3	
RTC	1	176	E3	
RTC	1	150	E3	
SPD	1	70	E3	
RDS	1	76	E3	

Fish Sampling Report

Dan Kowalski
Aquatic Biologist
Southwest Region

Water: Dolores River Below San Miguel
Date: 7/15/2009
Gear: 14 ft. electrofishing raft with Smith Root 2.5GPP
Drainage: Dolores
Water Codes: 39760

OBJECTIVE

The Dolores River below the San Miguel was sampled with one pass CPUE electrofishing to monitor native fish populations. The station began at the San Miguel confluence and ended at the County Rd R13 bridge and was 4.9 miles long.

RESULTS

The results of the survey are summarized in Table 1 and length frequency histograms of the native fish are presented in Figures 1-3. Eighty-nine percent of the fish sampled were native species. This reach of the Dolores contains excellent populations of flannelmouth suckers, bluehead suckers, and roundtail chubs represented by multiple age classes including many large adults. This reach appears to support some the best populations of the three species in the Dolores River basin and has much more robust and healthy native fish populations than sites on the Dolores upstream of the San Miguel.

Species	# Caught	% Catch	Mean Length (in.)	Length Range (in.)	CPUE (fish/mile)
Bluehead Suckers	129	33	8.5	4.0-14.2	26.3
Flannelmouth Suckers	128	33	14.6	4.6-22.1	26.1
Roundtail Chubs	56	14	7.1	2.7-14.4	11.4
Speckled Dace	37	9	3.4	2.7-4.4	7.6
Channel Catfish	31	8	11.1	7.2-21.8	6.3
Common Carp	8	2	21.3	19.9-22.0	1.6
Red Shiner	2	1	3.0	2.9-3.1	0.4
Sand Shiner	1	0	2.8	2.8	0.2

Table 1. Summary of fish sampled in 2009 in the Dolores River below the San Miguel.

CONCLUSIONS AND MANAGEMENT RECOMMENDATIONS

The Dolores River below the San Miguel contains a good native fish community and should continue to managed as a category 100 native fish conservation water. Many of the habitat and flow problems associated with the river below McPhee (low base flows, altered peak flows, altered temperature regime, and reduced nutrient and sediment inputs) are improved by the influence of the San Miguel. The San Miguel River has a relatively natural spring peak hydrograph but base flows are impacted by irrigation withdrawals. However, unlike the trans-basin diversions associated with McPhee, irrigation return flows in the San Miguel basin come back to the river and reduce the impacts of base flow diversions. Efforts should be taken to protect the flow regime of this reach of river including spring peak flows and especially base flows. Major tributaries like Mesa Creek, Roc Creek, and Blue Creek that could be used seasonally for spawning should also be protected both for native fish habitat and the beneficial flows inputs to the main stem.

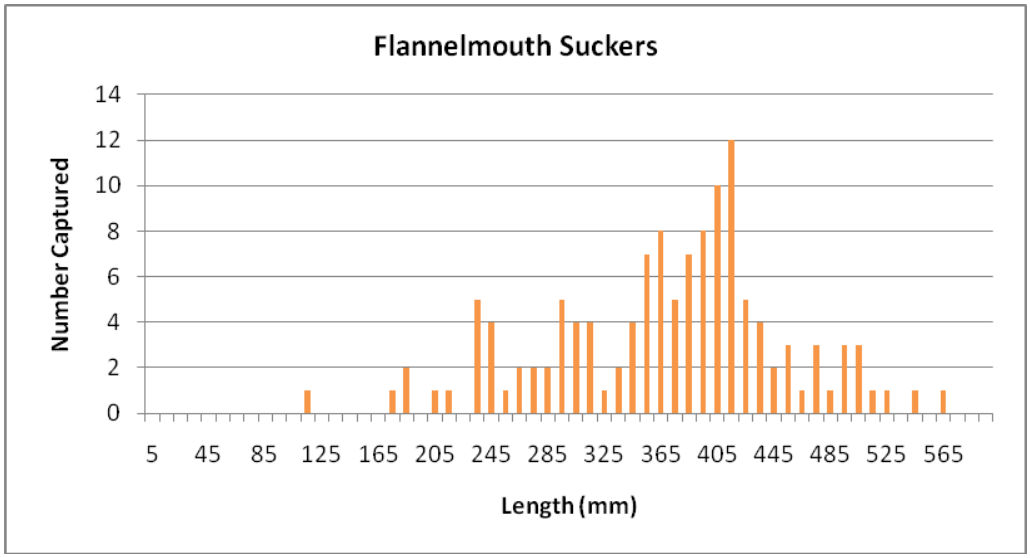


Figure 1. Length frequency histogram of flannelmouth suckers captured in the Dolores River in 2009.

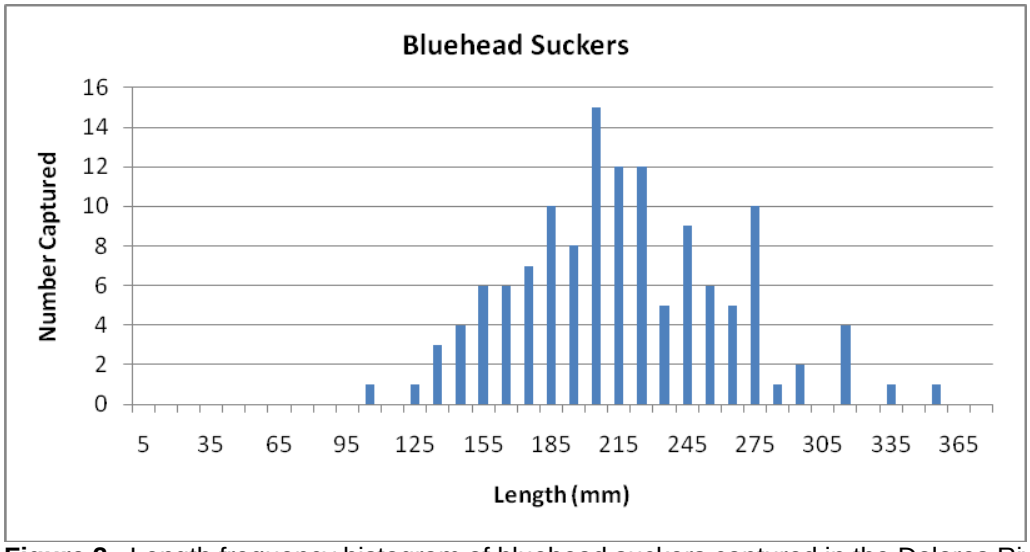


Figure 2. Length frequency histogram of bluehead suckers captured in the Dolores River in 2009.

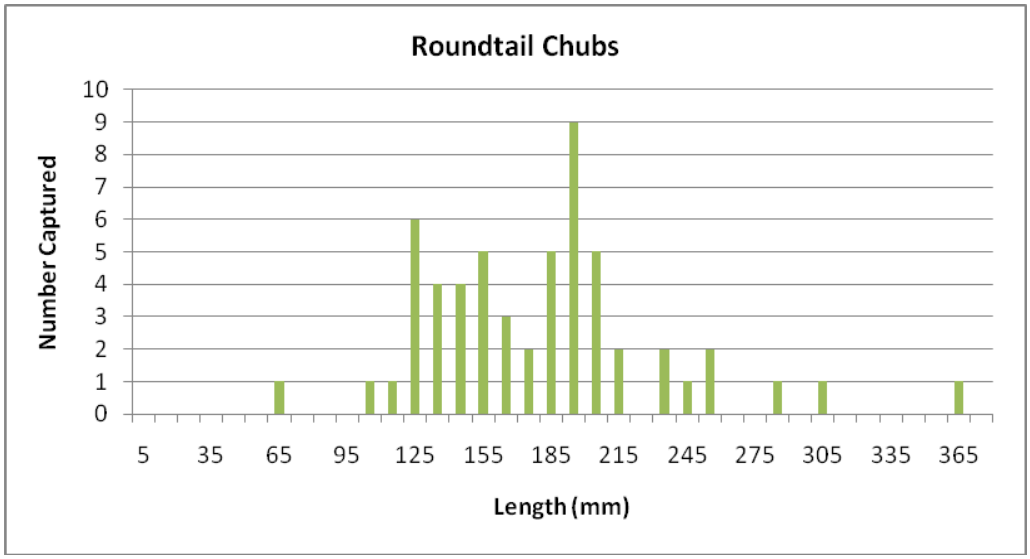


Figure 3. Length frequency histogram of roundtail chubs captured in the Dolores River in 2009.

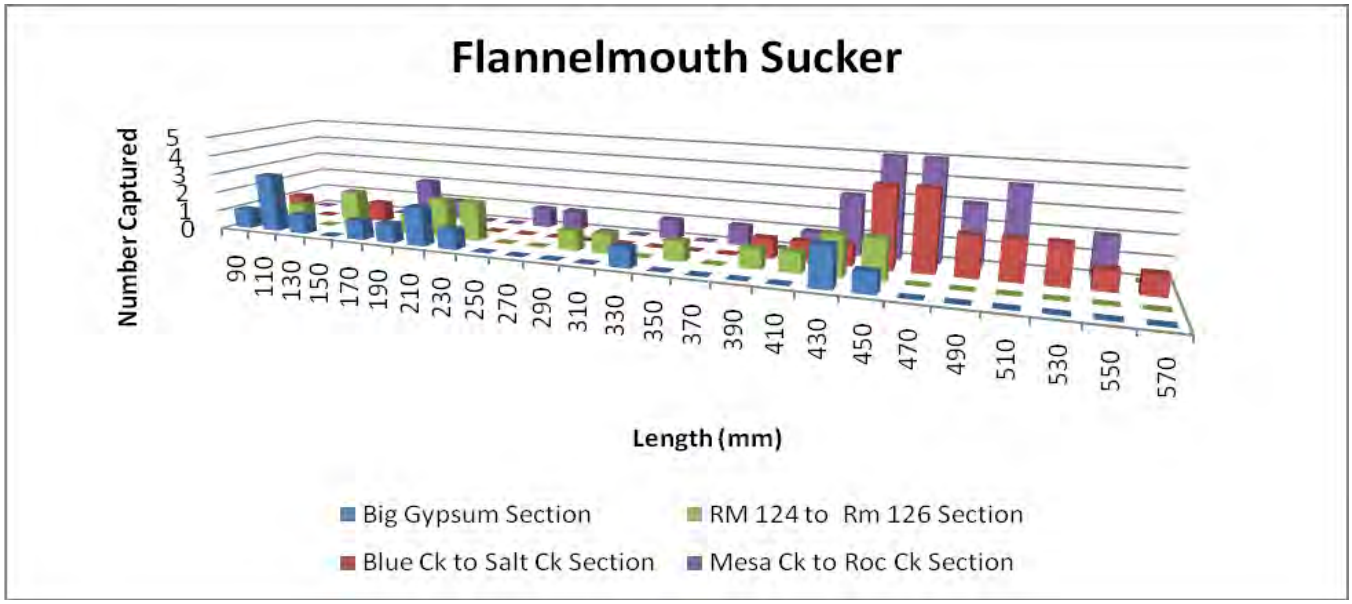


Figure 10 Flannelmouth Sucker Pooled Length Frequency Distributions Dolores River, 2010

Only one young bluehead sucker was captured in the Big Gypsum reach, while more and larger fish were increasingly common as we moved downstream (Figure 10). The only other portion of the river where we encountered smaller age classes of bluehead suckers was the reach between River Mile 124 and River Mile 126.

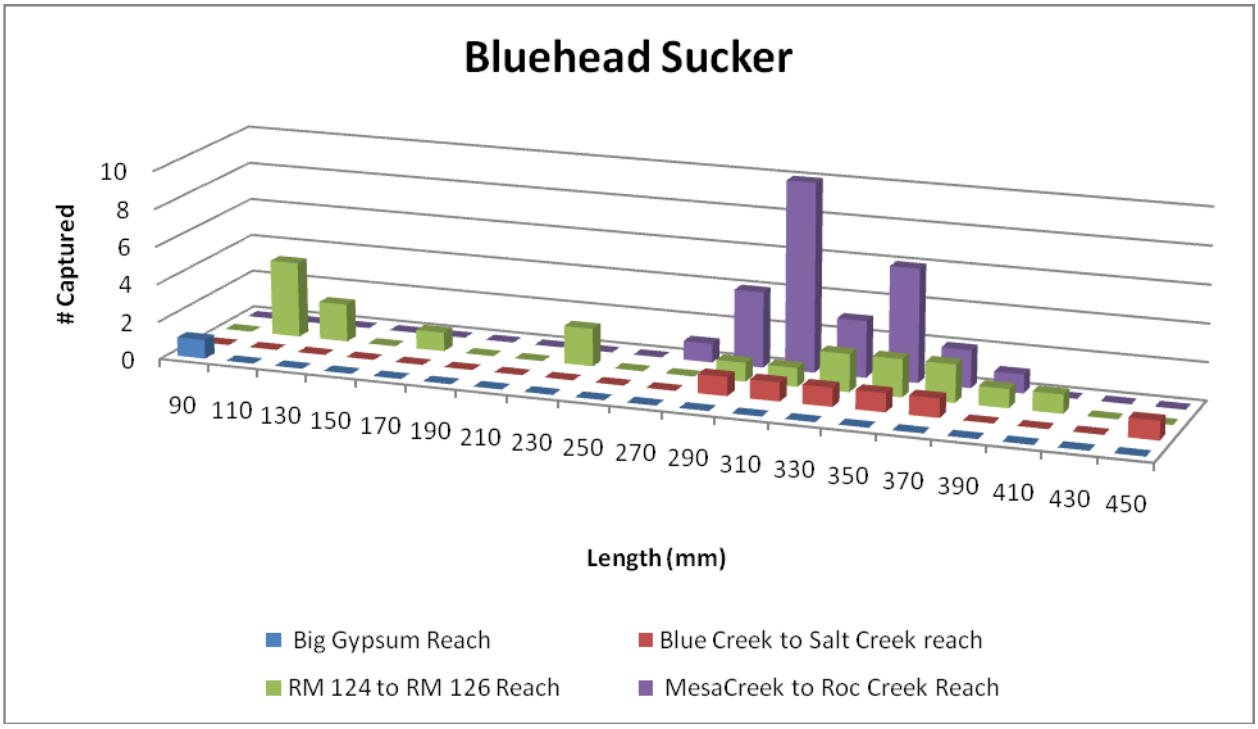


Figure 11 Bluehead Sucker Pooled Length Frequency Distributions Dolores River, 2010

Unlike flannelmouth and bluehead suckers, roundtail chub were much more common and more age classes were sampled in the Big Gypsum reach than in the reaches down stream (Figure 11). The reach between River Miles 124 and 126 had higher numbers of younger age classes than the other reaches below the confluence of the Dolores and San Miguel Rivers, and Mesa Creek had the fewest number of roundtail chubs of the reaches sampled.

Dolores River Instream Flow Project

R2Cross Data Summary – As Of April 10, 2013

X-Section Date and Number	Flow That Meets 2 of 3 Criteria	Flow That Meets 3 of 3 Criteria
2-27-13 #1	78.57 cfs	227.10 cfs
2-27-13 #2	Out of confidence interval	251.33 cfs
2-27-13 #3	92.35 cfs	153.37 cfs
2-27-13 #4	98.13 cfs	184.96 cfs
11-8-11 (riffle cross section in PHABSIM reach)	123.96	324.94 cfs
Averages	98.25 cfs	228.34 cfs

Preliminary Dolores River Recommendation From April 10, 2013 Conference Call

Note: March 15 to August 14 recommendations based upon PHABSIM results. August 15 to March 14 recommendations based R2Cross results.

900 cfs – April 15 to June 14
400 cfs – June 15 to July 14
200 cfs – July 15 to August 14
100 cfs – August 15 to March 14
200 cfs – March 15 to April 14

For Comparison: Instream Flow Water Rights on San Miguel River Appropriated by CWCB

325 cfs – April 15 to June 14
170 cfs – June 15 to July 31
115 cfs – August 1 to August 31
80 cfs – September 1 to February 29
115 cfs – March 1 to April 14

COLORADO WATER CONSERVATION BOARD

FIELD DATA FOR INSTREAM FLOW DETERMINATIONS

COLORADO DIVISION OF WILDLIFE

LOCATION INFORMATION

STREAM NAME: Dolores River					CROSS-SECTION NO.: 1
CROSS-SECTION LOCATION: Mile Marker 101				GPS Zone 12	681524 4269902
DATE: 2-27-13	OBSERVERS: R. Smith, D. Graf				4639 Rd.
LEGAL DESCRIPTION	¼ SECTION: NW	SECTION: 31	TOWNSHIP: 50 (N)/S	RANGE: 18 E/(W)	PM: NM
COUNTY: Mesa	WATERSHED: Dolores	WATER DIVISION: 4	DOW WATER CODE: 39760		
MAP(S): USGS:					
USFS:					

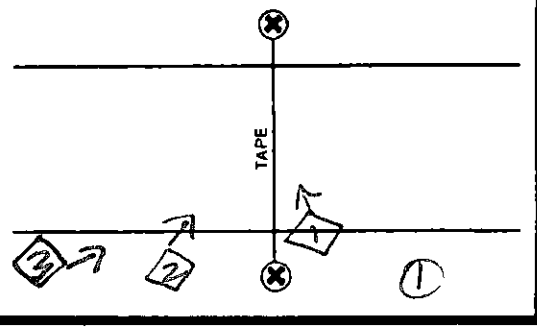
SUPPLEMENTAL DATA

SAG TAPE SECTION SAME AS DISCHARGE SECTION: (YES)/NO	METER TYPE: M-M			
METER NUMBER:	DATE RATED:	CALIB/SPIN: ____ sec	TAPE WEIGHT: surveyed ____ lbs/foot	TAPE TENSION: surveyed ____ lbs
CHANNEL BED MATERIAL SIZE RANGE: 4-6" cobbles to 2-foot boulders	PHOTOGRAPHS TAKEN: (YES)/NO	NUMBER OF PHOTOGRAPHS: 3		

CHANNEL PROFILE DATA

STATION	DISTANCE FROM TAPE (ft)	ROD READING (ft)
(X) Tape @ Stake LB	0.0	surveyed
(X) Tape @ Stake RB	0.0	surveyed
(1) WS @ Tape LB/RB	0.0	6.11 / 6.23
(2) WS Upstream	299.0	2.03
(3) WS Downstream	60.0'	7.09
SLOPE	5.06/359.0 = .014	

SKETCH



AQUATIC SAMPLING SUMMARY

STREAM ELECTROFISHED: YES/(NO)	DISTANCE ELECTROFISHED: ____ ft	FISH CAUGHT: YES/NO	WATER CHEMISTRY SAMPLED: YES/(NO)

LENGTH - FREQUENCY DISTRIBUTION BY ONE-INCH SIZE GROUPS (1.0-1.9, 2.0-2.9, ETC.)

SPECIES (FILL IN)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	>15	TOTAL

AQUATIC INSECTS IN STREAM SECTION BY COMMON OR SCIENTIFIC ORDER NAME

COMMENTS

DISCHARGE/CROSS SECTION NOTES

STREAM NAME: Dolores River | CROSS-SECTION NO: 1 | DATE: 7-27-13 | SHEET ___ OF ___

BEGINNING OF MEASUREMENT | EDGE OF WATER LOOKING DOWNSTREAM: (0.0 AT STAKE) LEFT / RIGHT | Gage Reading: _____ ft | TIME: 11:00 am

Features (Stake (S) Grassline (G) Waterline (W) Rock (R))	Distance From Initial Point (ft)	Width (ft)	Total Vertical Depth From Tape/Inst (ft)	Water Depth (ft)	Depth of Observation (ft)	Revolutions	Time (sec)	Velocity (ft/sec) At Point	Velocity (ft/sec) Mean in Vertical at 0.2	Area (ft²) at 0.5	Discharge (cfs)
LS	0.6		3.59								
	2.0		2.80								
G	4.0		4.21								
	5.0		4.66								
	6.0		5.43								
W	6.5	<7.0 6.8>	6.11	0.7				>0.83			
	8		7.45	1.30				1.60			
	10		7.84	1.70				1.54			
	12		6.89	0.80				2.48			
	14		7.93	1.70				2.69			
	16		7.88	1.60				3.50			
	18		8.90	2.70				3.39	2.94	3.83	
	20		8.73	2.50				2.59	1.60	3.57	
	22		8.53	2.40				1.90	1.51	2.29	
	24		8.22	2.00				2.80			
	26		8.40	2.10				3.91	3.26	4.56	
	28		8.25	2.00				3.02			
	30		8.02	1.80				∅			
	32		7.83	1.70				2.57			
	34		7.76	1.50				2.47			
	36		8.05	1.75				2.45			
	38		7.77	1.40				3.12			
	40		7.50	1.20				2.00			
	42		7.02	.6				2.62			
	44		7.16	1.0				1.82			
	46		7.61	1.3				1.55			
	48		7.11	.9				1.28			
	50		6.82	.5				0.01			
W	53		6.33								
	58.5		5.92								
	60.6		5.77								
	64		5.77								
	66.4		5.82								
	75.5		5.77								
	79		5.01								
G	83.5		4.23								
	88.0		3.97								
RS	98.5		2.66								
TOTALS											

End of Measurement | Time | Gage Reading ft | CALCULATIONS PERFORMED BY | CALCULATIONS CHECKED BY

COLORADO WATER CONSERVATION BOARD
INSTREAM FLOW / NATURAL LAKE LEVEL PROGRAM
STREAM CROSS-SECTION AND FLOW ANALYSIS

LOCATION INFORMATION

STREAM NAME:	Dolores River
XS LOCATION:	Mile Marker 101
XS NUMBER:	1
DATE:	27-Feb-13
OBSERVERS:	R. Smith, D. Graf, N. Dieterich, E. Rumbold
1/4 SEC:	NW
SECTION:	31
TWP:	50
RANGE:	18
PM:	NM
COUNTY:	Mesa
WATERSHED:	Dolores
DIVISION:	4
DOW CODE:	39760
USGS MAP:	0
USFS MAP:	0

SUPPLEMENTAL DATA

TAPE WT:	0.0106
TENSION:	99999

*** NOTE ***
Leave TAPE WT and TENSION at defaults for data collected with a survey level and rod

CHANNEL PROFILE DATA

SLOPE:	0.014

INPUT DATA CHECKED BY: .....DATE.....

ASSIGNED TO: ….....……..…….....DATE.....

STREAM NAME: Dolores River
XS LOCATION: Mile Marker 101
XS NUMBER: 1

DATA POINTS= 39

VALUES COMPUTED FROM RAW FIELD DATA

FEATURE	DIST	VERT DEPTH	WATER DEPTH	VEL	WETTED PERIM.	WATER DEPTH	AREA (Am)	Q (Qm)	% Q CELL
LS	0.60	3.59			0.00		0.00	0.00	0.0%
	2.00	2.80			0.00		0.00	0.00	0.0%
1 G	4.00	4.21			0.00		0.00	0.00	0.0%
	5.00	4.66			0.00		0.00	0.00	0.0%
	6.00	5.43			0.00		0.00	0.00	0.0%
W	6.50	6.11	0.00	0.00	0.00		0.00	0.00	0.0%
	7.00	6.80	0.70	0.83	0.85	0.70	0.53	0.44	0.3%
	8.00	7.45	1.30	1.60	1.19	1.30	1.95	3.12	1.9%
	10.00	7.84	1.70	1.54	2.04	1.70	3.40	5.24	3.2%
	12.00	6.89	0.80	2.48	2.21	0.80	1.60	3.97	2.4%
	14.00	7.93	1.70	2.69	2.25	1.70	3.40	9.15	5.6%
	16.00	7.88	1.60	3.50	2.00	1.60	3.20	11.20	6.8%
	18.00	8.90	2.70	3.39	2.25	2.70	5.40	18.31	11.1%
	20.00	8.73	2.50	2.59	2.01	2.50	5.00	12.95	7.9%
	22.00	8.53	2.40	1.90	2.01	2.40	4.80	9.12	5.5%
	24.00	8.22	2.00	2.80	2.02	2.00	4.00	11.20	6.8%
	26.00	8.40	2.10	3.91	2.01	2.10	4.20	16.42	10.0%
	28.00	8.25	2.00	3.02	2.01	2.00	4.00	12.08	7.3%
	30.00	8.02	1.80	0.00	2.01	1.80	3.60	0.00	0.0%
	32.00	7.83	1.70	2.57	2.01	1.70	3.40	8.74	5.3%
	34.00	7.76	1.50	2.47	2.00	1.50	3.00	7.41	4.5%
	36.00	8.05	1.75	2.45	2.02	1.75	3.50	8.58	5.2%
	38.00	7.77	1.40	3.12	2.02	1.40	2.80	8.74	5.3%
	40.00	7.50	1.20	2.00	2.02	1.20	2.40	4.80	2.9%
	42.00	7.02	0.60	2.62	2.06	0.60	1.20	3.14	1.9%
	44.00	7.16	1.00	1.82	2.00	1.00	2.00	3.64	2.2%
	46.00	7.61	1.30	1.55	2.05	1.30	2.60	4.03	2.4%
	48.00	7.11	0.90	1.28	2.06	0.90	1.80	2.30	1.4%
	50.00	6.82	0.50	0.01	2.02	0.50	1.25	0.01	0.0%
W	53.00	6.23	0.00	0.00	3.06		0.00	0.00	0.0%
	58.50	5.92			0.00		0.00	0.00	0.0%
	60.60	5.77			0.00		0.00	0.00	0.0%
	64.00	5.77			0.00		0.00	0.00	0.0%
	66.40	5.82			0.00		0.00	0.00	0.0%
	75.50	5.77			0.00		0.00	0.00	0.0%
	79.00	5.01			0.00		0.00	0.00	0.0%
1 G	83.50	4.23			0.00		0.00	0.00	0.0%
	88.00	3.97			0.00		0.00	0.00	0.0%
RS	98.50	2.66			0.00		0.00	0.00	0.0%
TOTALS ----------					48.18	2.7 (Max.)	69.03	164.57	100.0%

Manning's n = 0.0937
Hydraulic Radius= 1.43250135

STREAM NAME: Dolores River
XS LOCATION: Mile Marker 101
XS NUMBER: 1

WATER LINE COMPARISON TABLE

WATER LINE	MEAS AREA	COMP AREA	AREA ERROR
	69.03	72.13	4.5%
5.92	69.03	84.58	22.5%
5.94	69.03	83.55	21.0%
5.96	69.03	82.51	19.5%
5.98	69.03	81.49	18.1%
6.00	69.03	80.47	16.6%
6.02	69.03	79.46	15.1%
6.04	69.03	78.46	13.7%
6.06	69.03	77.47	12.2%
6.08	69.03	76.48	10.8%
6.10	69.03	75.50	9.4%
6.12	69.03	74.53	8.0%
6.13	69.03	74.04	7.3%
6.14	69.03	73.56	6.6%
6.15	69.03	73.08	5.9%
6.16	69.03	72.60	5.2%
6.17	69.03	72.13	4.5%
6.18	69.03	71.65	3.8%
6.19	69.03	71.18	3.1%
6.20	69.03	70.71	2.4%
6.21	69.03	70.24	1.8%
6.22	69.03	69.77	1.1%
6.24	69.03	68.84	-0.3%
6.26	69.03	67.92	-1.6%
6.28	69.03	67.00	-2.9%
6.30	69.03	66.07	-4.3%
6.32	69.03	65.15	-5.6%
6.34	69.03	64.24	-6.9%
6.36	69.03	63.32	-8.3%
6.38	69.03	62.41	-9.6%
6.40	69.03	61.50	-10.9%
6.42	69.03	60.59	-12.2%

WATERLINE AT ZERO
AREA ERROR = 6.236

STREAM NAME: Dolores River
XS LOCATION: Mile Marker 101
XS NUMBER: 1

Constant Manning's n

GL = lowest Grassline elevation corrected for sag
STAGING TABLE *WL* = Waterline corrected for variations in field measured water surface elevations and sag

	DIST TO WATER (FT)	TOP WIDTH (FT)	AVG. DEPTH (FT)	MAX. DEPTH (FT)	AREA (SQ FT)	WETTED PERIM. (FT)	PERCENT WET PERIM (%)	HYDR RADIUS (FT)	FLOW (CFS)	AVG. VELOCITY (FT/SEC)
GL	4.23	79.46	2.60	4.67	206.68	82.00	100.0%	2.52	718.22	3.47
	5.24	72.21	1.81	3.66	130.60	74.38	90.7%	1.76	356.66	2.73
	5.29	71.92	1.77	3.61	127.00	74.06	90.3%	1.71	341.38	2.69
	5.34	71.62	1.72	3.56	123.41	73.74	89.9%	1.67	326.39	2.64
	5.39	71.32	1.68	3.51	119.84	73.42	89.5%	1.63	311.68	2.60
	5.44	71.03	1.64	3.46	116.28	73.11	89.2%	1.59	297.26	2.56
	5.49	70.77	1.59	3.41	112.73	72.81	88.8%	1.55	283.08	2.51
	5.54	70.50	1.55	3.36	109.20	72.51	88.4%	1.51	269.19	2.47
	5.59	70.23	1.50	3.31	105.68	72.22	88.1%	1.46	255.59	2.42
	5.64	69.97	1.46	3.26	102.18	71.92	87.7%	1.42	242.28	2.37
	5.69	69.70	1.42	3.21	98.69	71.62	87.3%	1.38	229.28	2.32
	5.74	69.43	1.37	3.16	95.21	71.32	87.0%	1.33	216.57	2.27
	5.79	61.91	1.48	3.11	91.83	63.77	77.8%	1.44	219.70	2.39
	5.84	53.38	1.67	3.06	89.01	55.21	67.3%	1.61	229.62	2.58
	5.89	52.64	1.64	3.01	86.36	54.45	66.4%	1.59	220.37	2.55
	5.94	51.84	1.62	2.96	83.75	53.62	65.4%	1.56	211.51	2.53
	5.99	50.92	1.59	2.91	81.18	52.67	64.2%	1.54	203.21	2.50
	6.04	49.99	1.57	2.86	78.65	51.72	63.1%	1.52	195.15	2.48
	6.09	49.07	1.55	2.81	76.18	50.77	61.9%	1.50	187.32	2.46
	6.14	48.15	1.53	2.76	73.75	49.82	60.8%	1.48	179.72	2.44
	6.19	47.22	1.51	2.71	71.36	48.87	59.6%	1.46	172.34	2.41
WL	6.24	46.38	1.49	2.66	69.02	48.00	58.5%	1.44	165.00	2.39
	6.29	46.09	1.45	2.61	66.71	47.68	58.1%	1.40	156.59	2.35
	6.34	45.80	1.41	2.56	64.42	47.36	57.7%	1.36	148.38	2.30
	6.39	45.51	1.37	2.51	62.13	47.04	57.4%	1.32	140.35	2.26
	6.44	45.22	1.32	2.46	59.87	46.71	57.0%	1.28	132.52	2.21
	6.49	44.93	1.28	2.41	57.61	46.39	56.6%	1.24	124.88	2.17
	6.54	44.63	1.24	2.36	55.37	46.07	56.2%	1.20	117.44	2.12
	6.59	44.34	1.20	2.31	53.15	45.75	55.8%	1.16	110.20	2.07
	6.64	44.05	1.16	2.26	50.94	45.43	55.4%	1.12	103.15	2.02
	6.69	43.76	1.11	2.21	48.74	45.11	55.0%	1.08	96.30	1.98
	6.74	43.47	1.07	2.16	46.56	44.79	54.6%	1.04	89.65	1.93
	6.79	43.18	1.03	2.11	44.40	44.47	54.2%	1.00	83.21	1.87
	6.84	42.83	0.99	2.06	42.24	44.10	53.8%	0.96	77.02	1.82
	6.89	42.41	0.95	2.01	40.11	43.66	53.2%	0.92	71.13	1.77
	6.94	41.80	0.91	1.96	38.01	43.01	52.4%	0.88	65.67	1.73
	6.99	41.18	0.87	1.91	35.93	42.34	51.6%	0.85	60.43	1.68
	7.04	40.26	0.84	1.86	33.89	41.38	50.5%	0.82	55.67	1.64
	7.09	38.72	0.82	1.81	31.92	39.78	48.5%	0.80	51.70	1.62
	7.14	37.25	0.81	1.76	30.02	38.26	46.7%	0.78	47.91	1.60
	7.19	36.10	0.78	1.71	28.19	37.06	45.2%	0.76	44.07	1.56
	7.24	35.19	0.75	1.66	26.41	36.10	44.0%	0.73	40.22	1.52
	7.29	34.28	0.72	1.61	24.67	35.14	42.8%	0.70	36.56	1.48
	7.34	33.37	0.69	1.56	22.98	34.17	41.7%	0.67	33.09	1.44
	7.39	32.47	0.66	1.51	21.33	33.21	40.5%	0.64	29.80	1.40
	7.44	31.56	0.63	1.46	19.73	32.24	39.3%	0.61	26.69	1.35
	7.49	30.52	0.60	1.41	18.18	31.15	38.0%	0.58	23.82	1.31
	7.54	29.31	0.57	1.36	16.68	29.90	36.5%	0.56	21.21	1.27
	7.59	28.06	0.54	1.31	15.25	28.61	34.9%	0.53	18.81	1.23
	7.64	27.03	0.51	1.26	13.87	27.54	33.6%	0.50	16.48	1.19
	7.69	26.20	0.48	1.21	12.54	26.68	32.5%	0.47	14.23	1.13
	7.74	25.38	0.44	1.16	11.25	25.82	31.5%	0.44	12.14	1.08
	7.79	23.63	0.42	1.11	10.02	24.04	29.3%	0.42	10.48	1.05
	7.84	21.15	0.42	1.06	8.90	21.52	26.2%	0.41	9.27	1.04
	7.89	19.54	0.40	1.01	7.88	19.89	24.3%	0.40	7.97	1.01
	7.94	16.37	0.43	0.96	6.99	16.69	20.4%	0.42	7.33	1.05
	7.99	15.05	0.41	0.91	6.20	15.34	18.7%	0.40	6.36	1.03

STREAM NAME: Dolores River
XS LOCATION: Mile Marker 101
XS NUMBER: 1

SUMMARY SHEET

MEASURED FLOW (Qm)=	164.57	cfs
CALCULATED FLOW (Qc)=	165.00	cfs
(Qm-Qc)/Qm * 100 =	-0.3	%
MEASURED WATERLINE (WLm)=	6.17	ft
CALCULATED WATERLINE (WLc)=	6.24	ft
(WLm-WLc)/WLm * 100 =	-1.1	%
MAX MEASURED DEPTH (Dm)=	2.70	ft
MAX CALCULATED DEPTH (Dc)=	2.66	ft
(Dm-Dc)/Dm * 100	1.3	%
MEAN VELOCITY=	2.39	ft/sec
MANNING'S N=	0.094	
SLOPE=	0.014	ft/ft
.4 * Qm =	65.8	cfs
2.5 * Qm=	411.4	cfs

RECOMMENDED INSTREAM FLOW:
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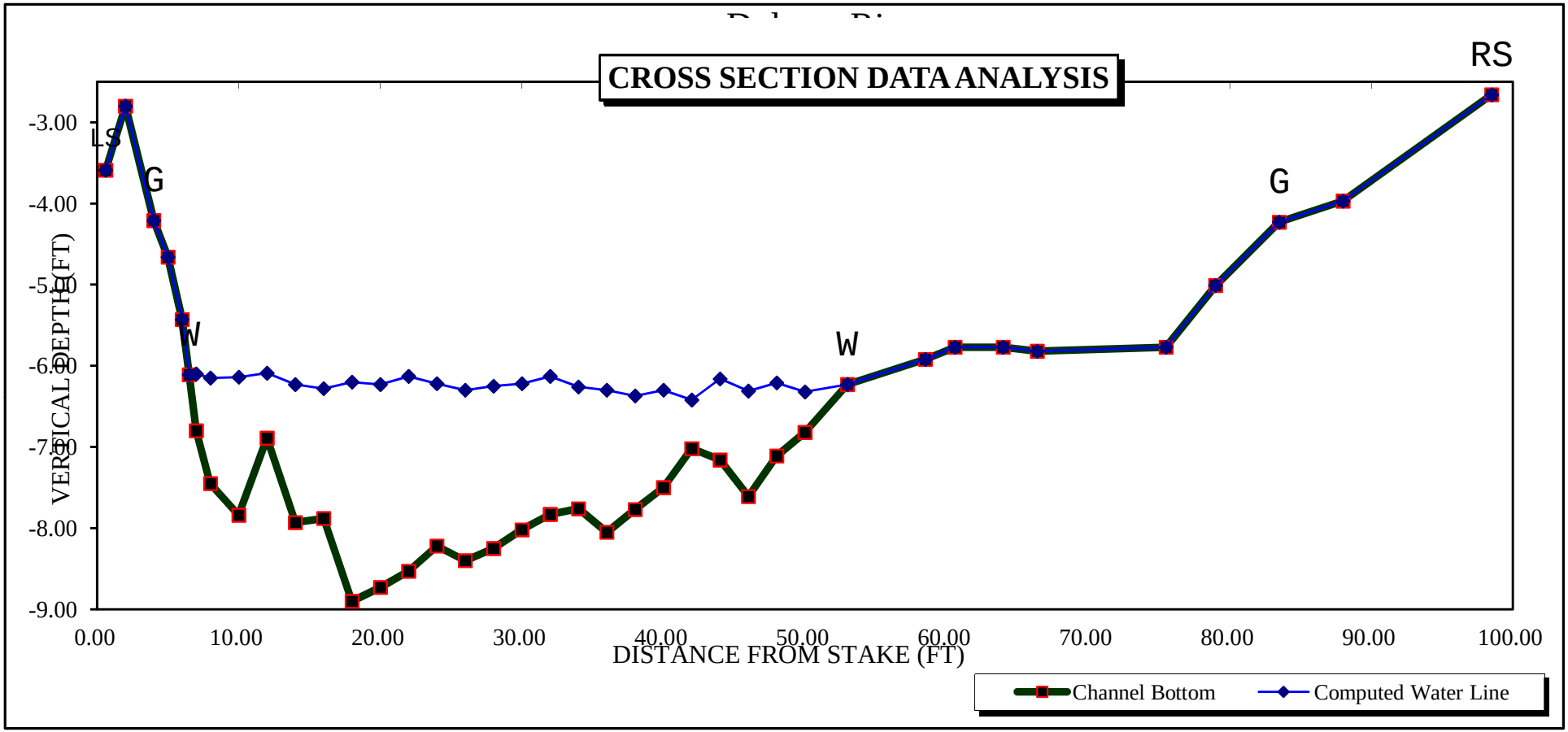
FLOW (CFS)	PERIOD
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_____	_____
_____	_____
_____	_____

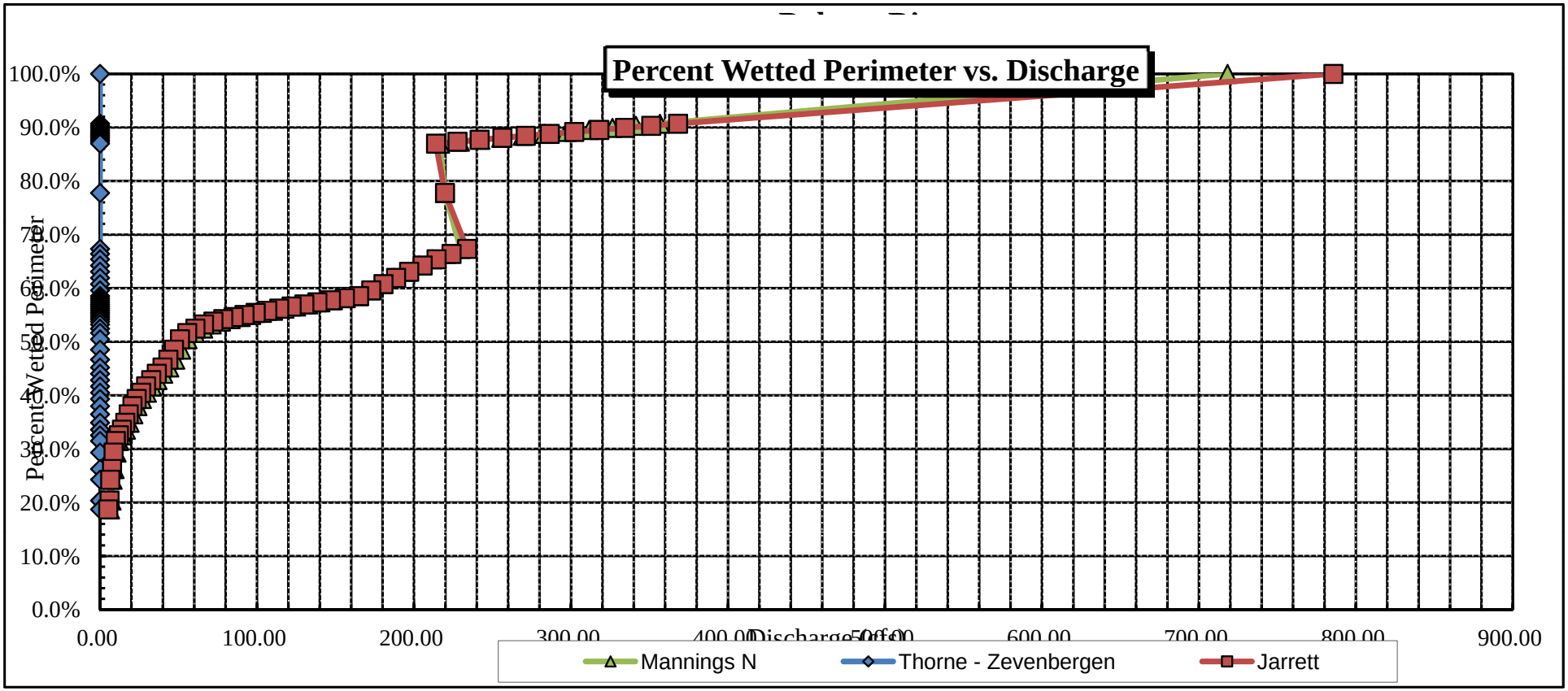
RATIONALE FOR RECOMMENDATION:
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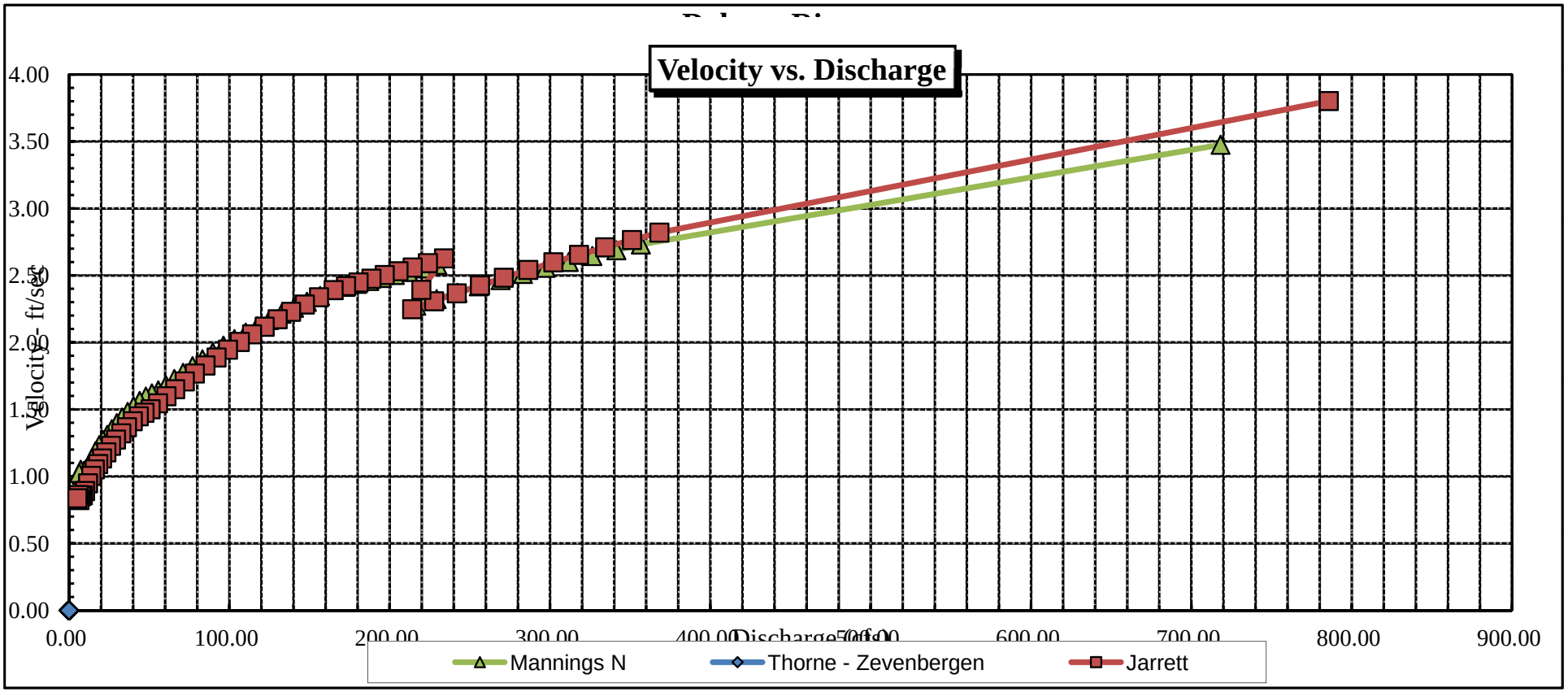
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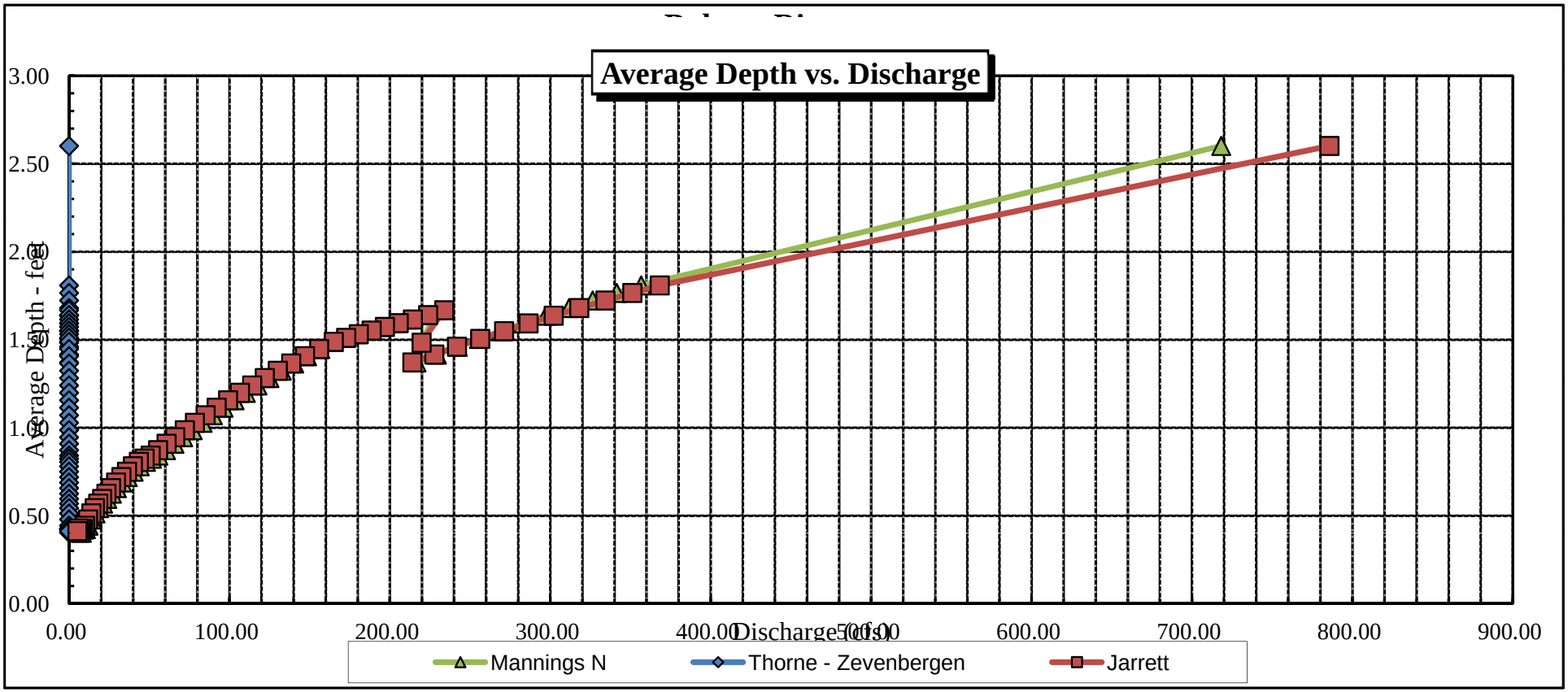
RECOMMENDATION BY: …….. AGENCY..…….. DATE:.....

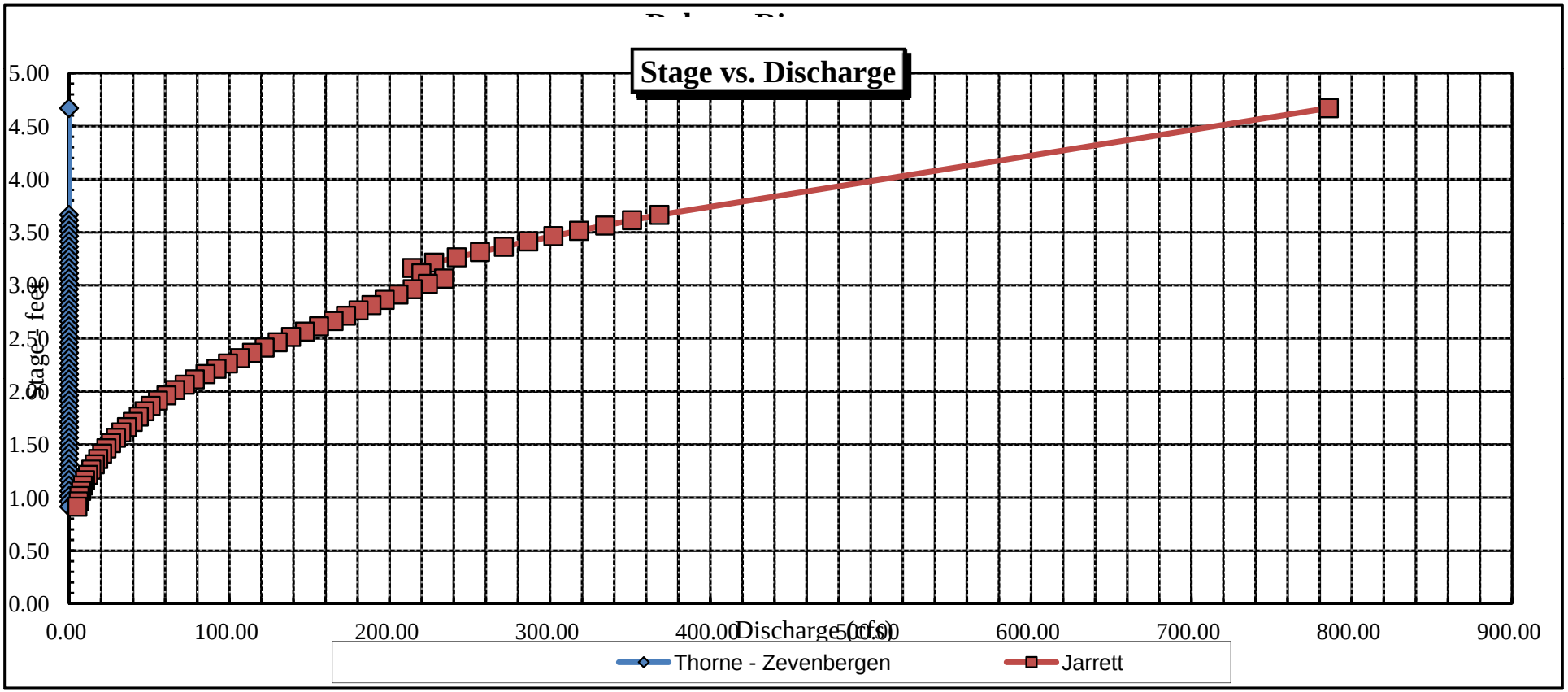
CWCB REVIEW BY: ..…….. DATE:.....


CROSS SECTION DATA ANALYSIS
RS
LS
G
W
W
G
-3.00
-4.00
-5.00
-6.00
-7.00
-8.00
-9.00
VERTICAL DEPTH (FT)
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00
DISTANCE FROM STAKE (FT)
Channel Bottom
Computed Water Line


Percent Wetted Perimeter vs. Discharge
Percent Wetted Perimeter
100.0%
90.0%
80.0%
70.0%
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
0.00
100.00
200.00
300.00
400.00
500.00
600.00
700.00
800.00
900.00
Discharge (cfs)
Mannings N
Thorne - Zevenbergen
Jarrett


Velocity vs. Discharge
Velocity - ft/sec
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0.00
100.00
200.00
300.00
400.00
600.00
700.00
800.00
900.00
Mannings N
Thorne - Zevenbergen
Jarrett


Average Depth vs. Discharge
Average Depth - feet
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0.00
100.00
200.00
300.00
400.00
500.00
600.00
700.00
800.00
900.00
Discharge (cfs)
Mannings N
Thorne - Zevenbergen
Jarrett


Stage vs. Discharge
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Stage, feet
0.00
100.00
200.00
300.00
400.00
500.00
600.00
700.00
800.00
900.00
Discharge, (cfs)
Thorne - Zevenbergen
Jarrett

COLORADO WATER CONSERVATION BOARD

FIELD DATA FOR INSTREAM FLOW DETERMINATIONS

COLORADO DIVISION OF WILDLIFE

LOCATION INFORMATION

STREAM NAME: Dolores River X-section #2 | CROSS-SECTION NO.: #2

CROSS-SECTION LOCATION: Nad 1983 Zone 12S 0681592, 4216985

DATE: 2/27/13 | OBSERVERS: N. Dieterich (BLM), E. Rumbold (BLM), Cullin? (CPW)

LEGAL DESCRIPTION | ¼ SECTION: NW | SECTION: 31 | TOWNSHIP: 50 (N)/S | RANGE: 18 E(W) | PM: NM

COUNTY: Mesa | WATERSHED: Dolores | WATER DIVISION: 4 | DOW WATER CODE: 39760

MAP(S): USGS:

USFS:

SUPPLEMENTAL DATA

SAG TAPE SECTION SAME AS DISCHARGE SECTION: (YES)/NO | METER TYPE: Marsh Mcbirney Flowmate

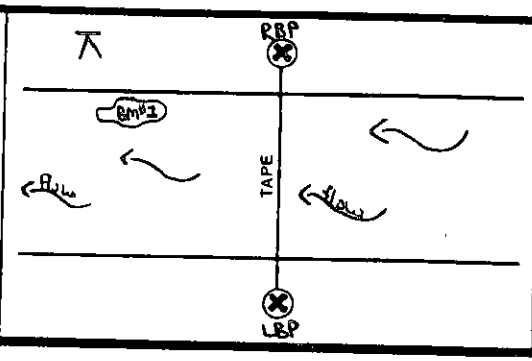
METER NUMBER: | DATE RATED: | CALIB/SPIN. _____ sec | TAPE WEIGHT: _____ lbs/foot | TAPE TENSION: _____ lbs

CHANNEL BED MATERIAL SIZE RANGE: gravel - sm. boulder | PHOTOGRAPHS TAKEN: (YES)/NO | NUMBER OF PHOTOGRAPHS:

CHANNEL PROFILE DATA

STATION	DISTANCE FROM TAPE (ft)	ROD READING (ft)
⊗ Tape @ Stake LB	0.0	Surveyed
⊗ Tape @ Stake RB	0.0	Surveyed
① WS @ Tape LB/RB	0.0	6.33/7.15
② WS Upstream		
③ WS Downstream		
SLOPE	.014	

SKETCH



LEGEND: Stake ⊗ | Station ① | Photo ◇→ | Direction of Flow

AQUATIC SAMPLING SUMMARY

STREAM ELECTROFISHED: YES/(NO) | DISTANCE ELECTROFISHED: _____ ft | FISH CAUGHT: YES/NO | WATER CHEMISTRY SAMPLED: YES/(NO)

LENGTH - FREQUENCY DISTRIBUTION BY ONE-INCH SIZE GROUPS (1.0-1.9, 2.0-2.9, ETC.)

SPECIES (FILL IN)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	>15	TOTAL
Species? (Blue-head sucker?)																	

AQUATIC INSECTS IN STREAM SECTION BY COMMON OR SCIENTIFIC ORDER NAME:

COMMENTS

Discharge (Q) calculated using area derived from depths measured w/ tape at wading and given velocity measurements were based off of these depths. In cells where wading was depths were not measured, depths calculated from the survey rod were used. Velocities were caused to these cells from adjacent measurements to calculate discharge (Q). * Suitable from 30.5' to 72' w/ noticeable flow.

DISCHARGE/CROSS SECTION NOTES

STREAM NAME: Dolores River	CROSS-SECTION NO.:	DATE: 2/27/13	SHEET 1 OF 2
BEGINNING OF MEASUREMENT	EDGE OF WATER LOOKING DOWNSTREAM: (0.0 AT STAKE) LEFT (RIGHT)	Gage Reading: _____ ft	TIME: 1130

Features (Stake (S), Grassline (G), Waterline (W), Rock (R))	Distance From Initial Point (ft)	Width (ft)	Total Vertical Depth From Tape (Inst) (ft)	Water Depth (ft) *profile depth	Depth of Observation (ft)	Revolutions / Cleaned profile elevation relative to BM=100	Time (sec)	Velocity (ft/sec) At Point	Velocity (ft/sec) Mean in Vertical	Using profile & adding rod lengths Area (ft^2)	Discharge (cfs)
BM#1 rock	BS=5.65	HI=105.65				100.0	20				
RBF (L)(S)	0	0	4.85		0.6d	100.8					
	22	22	5.94			99.71					
	27	5	6.59			99.06					
RWE (W)	30.3	3.3	7.15	*0		98.5		0		0	0
	30.5	0.2	7.15	0				0		0	0
	32.0	1.5	7.48	*0.23		98.17		0.05		~~0.52~~	~~0.026~~
	32.5	0.5	7.60	0.35				0.05			
	35.5	3	7.60	0.35				0.1		~~1.205~~	~~0.1205~~
	36.0	0.5	7.56	*0.31		98.09		0.1			
	39.5	3.5	7.15	0				0		0	0
bar	40.0	0.5	6.75	bar		98.9		bar			
bar	44.0	4	6.87	bar		98.78		bar			
bar	48.0		7.03	bar		98.62		bar			
	52.0		7.5	0.4		98.15		0.24		1	0.24
	56.0		7.58	0.5		98.07		0.26		1.32	0.3432
rock	60.0		6.92	rock		98.73		0			
	64.0		7.35	*0.1		98.3		0		0.4	0
	68.0		7.29	*0.04		98.36		0		0.16	0
	72.0		7.44	0.32		98.21		0		1.28	0
	76.0		7.62	0.3		98.03		0.29		1.2	0.348
	79.0	3	7.72	0.4				0.08		~~1.56~~	~~0.1248~~
	80.0	1	7.61	*0.36		98.04		0.08			
	82.0	2	7.95	0.7				0.64		1.4	0.896
	84.0	2	8.22	*0.97		97.43		1.4		~~2.44~~	~~3.416~~
	85.0	1	8.01	0.5				1.4			
Rock/eddy	88.0	3	7.91	0.4		97.74		0		1.2	0
	90.0	2	8.01	0.5				0.12		1	0.12
	92.0		8.61	1.2		97.04		2.03		2.4	4.872
	94.0		7.86	0.35				0.84		0.7	0.238
	96.0		8.31	0.8		97.34		0		1.6	0
	98.0		8.35	1.25				0.89		2.5	2.225
	100		8.1	1		97.55		2.74		2	5.48
	102		8.72	1.5				3.48		3	10.44
	104		8.82	1.6		96.83		1.8		3.2	5.76
	106		8.82	1.6				3.24		3.2	10.368
	108		8.83	1.5		96.82		2.59		3	7.77
	110		8.77	1.4				1.14		2.8	3.192
	112		8.77	1.4		96.88		2.83		2.8	7.924
	114		8.70	1				0.53		2	1.06
	116		8.3	0.55		97.35		1.41		1.1	1.551
	118		8.25	0.5				2.2		1	2.2
TOTALS:											

End of Measurement	Time:	Gage Reading: _____ ft	CALCULATIONS PERFORMED BY:	CALCULATIONS CHECKED BY:

DISCHARGE/CROSS SECTION NOTES

STREAM NAME:	CROSS-SECTION NO.:	DATE:	SHEET 2 OF 2

BEGINNING OF MEASUREMENT	EDGE OF WATER LOOKING DOWNSTREAM: (0.0 AT STAKE) LEFT / RIGHT	Gage Reading: _____ ft	TIME:

Features: Stake (S), Grassline (G), Waterline (W), Rock (R)	Distance From Initial Point (ft)	Width (ft)	Total (FS) Vertical Depth From Tape/Inst (ft)	Water Depth (ft)	Depth of Obser-vation (ft)	~~Revolutions~~ Channel profile relative to BM = 100'	Time (sec)	Velocity (ft/sec): At Point	Velocity (ft/sec): Mean in Vertical	Area (ft^2)	Discharge (cfs)
	120	2	8.16	0.6	0.6d	97.49	20	1.07		1.2	1.284
	122		7.89	0.5				3		1	3
	124		8.09	0.7		97.56		0.43		1.4	0.602
Rock/eddy	126		8.64	0.9				0		1.8	0
	128		8.59	0.85		97.06		0.29		1.7	0.493
	130		8.72	1.2				1.86		2.4	4.464
	132		8.82	1.3		96.83		2.05		2.6	5.33
Rock/eddy	134		8.01	0.1				0		0.2	0
	136		8.86	0.95		96.79		2.07		1.9	3.933
	138		8.38	1.3				1.21		2.6	3.146
	140		8.48	1.4		97.17		1.86		2.8	5.208
	142		8.18	1.1				1.61		2.2	3.542
	144		9.2	1.85		96.45		2.04		3.7	7.548
	146		9.25	1.9				3.38		3.8	12.844
Rock	148		9.39	0.95		96.26		2.37		1.9	4.503
Plunge pool	150		8.94	1.3				1.14		2.6	2.964
	152		9.24	1.6		96.41		2.83		3.2	9.056
	154		9.24	1.6				3.61		3.2	11.552
	156		8.85	1.5		96.8		3.77		3	11.31
	158		8.55	1.2				2.4		2.4	5.76
	160		8.28	0.5		97.37		1.12		1	1.12
	162		7.35	0				0		0	0
	162.3	0.3	7.35	0		98.3		0		0	0
LWE (W)	163	0.7	6.33			99.32					
LBF (G)	163.5	0.5	4.85			100.8					
S	165	1.5	4.45			101.2					
✓ BM #1 check	5.64					100					
											Q = 166.4 cfs
TOTALS:											

End of Measurement	Time:	Gage Reading: _____ ft	CALCULATIONS PERFORMED BY:	CALCULATIONS CHECKED BY:

COLORADO WATER CONSERVATION BOARD
INSTREAM FLOW / NATURAL LAKE LEVEL PROGRAM
STREAM CROSS-SECTION AND FLOW ANALYSIS

LOCATION INFORMATION

STREAM NAME:	Dolores River
XS LOCATION:	Mile Marker 101
XS NUMBER:	2
DATE:	27-Feb-12
OBSERVERS:	R. Smith, N. Dieterich, E. Rumbold, D. Graf
1/4 SEC:	NW
SECTION:	31
TWP:	50N
RANGE:	18W
PM:	NM
COUNTY:	Mesa
WATERSHED:	Dolores
DIVISION:	4
DOW CODE:	39760
USGS MAP:	0
USFS MAP:	0

SUPPLEMENTAL DATA

TAPE WT:	0.0106
TENSION:	99999

*** NOTE ***
Leave TAPE WT and TENSION at defaults for data collected with a survey level and rod

CHANNEL PROFILE DATA

SLOPE:	0.014

INPUT DATA CHECKED BY: .....DATE.....

ASSIGNED TO: ….....……..…….....DATE.....

STREAM NAME: Dolores River
XS LOCATION: Mile Marker 101
XS NUMBER: 2

DATA POINTS= 67

VALUES COMPUTED FROM RAW FIELD DATA

	FEATURE	DIST	VERT DEPTH	WATER DEPTH	VEL	WETTED PERIM.	WATER DEPTH	AREA (Am)	Q (Qm)	% Q CELL
1	RS & G	0.00	4.85			0.00		0.00	0.00	0.0%
		22.00	5.94			0.00		0.00	0.00	0.0%
		27.00	6.59			0.00		0.00	0.00	0.0%
	W	30.30	7.15	0.00	0.00	0.00		0.00	0.00	0.0%
		30.50	7.15	0.00	0.00	0.00		0.00	0.00	0.0%
		32.00	7.48	0.23	0.05	1.54	0.23	0.23	0.01	0.0%
		32.50	7.60	0.35	0.05	0.51	0.35	0.61	0.03	0.0%
		35.50	7.60	0.35	0.10	3.00	0.35	0.61	0.06	0.0%
		36.00	7.56	0.31	0.10	0.50	0.31	0.62	0.06	0.0%
		39.50	7.15	0.00	0.00	3.52		0.00	0.00	0.0%
		40.00	6.75	0.00	0.00	0.00		0.00	0.00	0.0%
		44.00	6.87	0.00	0.00	0.00		0.00	0.00	0.0%
		48.00	7.03	0.00	0.00	0.00		0.00	0.00	0.0%
		52.00	7.50	0.40	0.24	4.03	0.40	1.60	0.38	0.2%
		56.00	7.58	0.50	0.26	4.00	0.50	2.00	0.52	0.3%
		60.00	6.92	0.00	0.00	4.05		0.00	0.00	0.0%
		64.00	7.35	0.10	0.00	4.02	0.10	0.40	0.00	0.0%
		68.00	7.29	0.04	0.00	4.00	0.04	0.16	0.00	0.0%
		72.00	7.44	0.32	0.00	4.00	0.32	1.28	0.00	0.0%
		76.00	7.62	0.30	0.29	4.00	0.30	1.05	0.30	0.2%
		79.00	7.72	0.40	0.08	3.00	0.40	0.80	0.06	0.0%
		80.00	7.61	0.36	0.08	1.01	0.36	0.54	0.04	0.0%
		82.00	7.95	0.70	0.64	2.03	0.70	1.40	0.90	0.5%
		84.00	8.22	0.97	1.40	2.02	0.97	1.46	2.04	1.2%
		85.00	8.01	0.50	1.40	1.02	0.50	1.00	1.40	0.8%
		88.00	7.91	0.40	0.00	3.00	0.40	1.00	0.00	0.0%
		90.00	8.01	0.50	0.12	2.00	0.50	1.00	0.12	0.1%
		92.00	8.61	1.20	2.03	2.09	1.20	2.40	4.87	2.9%
		94.00	7.86	0.35	0.34	2.14	0.35	0.70	0.24	0.1%
		96.00	8.31	0.80	0.00	2.05	0.80	1.60	0.00	0.0%
		98.00	8.35	1.25	0.89	2.00	1.25	2.50	2.23	1.3%
		100.00	8.10	1.00	2.74	2.02	1.00	2.00	5.48	3.3%
		102.00	8.72	1.50	3.48	2.09	1.50	3.00	10.44	6.3%
		104.00	8.82	1.60	1.80	2.00	1.60	3.20	5.76	3.5%
		106.00	8.82	1.60	3.24	2.00	1.60	3.20	10.37	6.2%
		108.00	8.83	1.50	2.59	2.00	1.50	3.00	7.77	4.7%
		110.00	8.77	1.40	1.14	2.00	1.40	2.80	3.19	1.9%
		112.00	8.77	1.40	2.83	2.00	1.40	2.80	7.92	4.8%
		114.00	8.70	1.00	0.53	2.00	1.00	2.00	1.06	0.6%
		116.00	8.30	0.55	1.41	2.04	0.55	1.10	1.55	0.9%
		118.00	8.25	0.50	2.20	2.00	0.50	1.00	2.20	1.3%
		120.00	8.16	0.60	1.07	2.00	0.60	1.20	1.28	0.8%
		122.00	7.89	0.50	3.00	2.02	0.50	1.00	3.00	1.8%
		124.00	8.09	0.70	0.43	2.01	0.70	1.40	0.60	0.4%
		126.00	8.64	0.90	0.00	2.07	0.90	1.80	0.00	0.0%
		128.00	8.59	0.85	0.29	2.00	0.85	1.70	0.49	0.3%
		130.00	8.72	1.20	1.86	2.00	1.20	2.40	4.46	2.7%
		132.00	8.82	1.30	2.05	2.00	1.30	2.60	5.33	3.2%
		134.00	8.01	0.10	0.00	2.16	0.10	0.20	0.00	0.0%
		136.00	8.86	0.95	2.07	2.17	0.95	1.90	3.93	2.4%
		138.00	8.38	1.30	1.21	2.06	1.30	2.60	3.15	1.9%
		140.00	8.48	1.40	1.86	2.00	1.40	2.80	5.21	3.1%
		142.00	8.18	1.10	1.61	2.02	1.10	2.20	3.54	2.1%
		144.00	9.20	1.85	2.04	2.25	1.85	3.70	7.55	4.5%
		146.00	9.25	1.90	3.38	2.00	1.90	3.80	12.84	7.7%
		148.00	8.39	0.95	2.37	2.18	0.95	1.90	4.50	2.7%
		150.00	8.94	1.30	1.14	2.07	1.30	2.60	2.96	1.8%
		152.00	9.24	1.60	2.83	2.02	1.60	3.20	9.06	5.4%
		154.00	9.24	1.60	3.61	2.00	1.60	3.20	11.55	6.9%
		156.00	8.85	1.50	3.77	2.04	1.50	3.00	11.31	6.8%
		158.00	8.55	1.20	2.40	2.02	1.20	2.40	5.76	3.5%
		160.00	8.28	0.50	1.12	2.02	0.50	1.00	1.12	0.7%
		162.00	7.35	0.00	0.00	2.21		0.00	0.00	0.0%
		162.30	7.35	0.00	0.00	0.00		0.00	0.00	0.0%
	W	163.00	6.33	0.00	0.00	0.00		0.00	0.00	0.0%
1	G	163.50	4.85			0.00		0.00	0.00	0.0%
	LS	165.00	4.45			0.00		0.00	0.00	0.0%
	TOTALS ----------					125.03	1.9 (Max.)	93.66	166.67	100.0%

Manning's n = 0.0815
Hydraulic Radius= 0.74912877

STREAM NAME: Dolores River
XS LOCATION: Mile Marker 101
XS NUMBER: 2

WATER LINE COMPARISON TABLE

WATER LINE	MEAS AREA	COMP AREA	AREA ERROR
	93.66	107.72	15.0%
7.00	93.66	137.65	47.0%
7.02	93.66	135.17	44.3%
7.04	93.66	132.72	41.7%
7.06	93.66	130.27	39.1%
7.08	93.66	127.84	36.5%
7.10	93.66	125.42	33.9%
7.12	93.66	123.01	31.3%
7.14	93.66	120.62	28.8%
7.16	93.66	118.24	26.2%
7.18	93.66	115.87	23.7%
7.20	93.66	113.53	21.2%
7.21	93.66	112.36	20.0%
7.22	93.66	111.19	18.7%
7.23	93.66	110.03	17.5%
7.24	93.66	108.88	16.2%
7.25	93.66	107.72	15.0%
7.26	93.66	106.57	13.8%
7.27	93.66	105.43	12.6%
7.28	93.66	104.29	11.3%
7.29	93.66	103.15	10.1%
7.30	93.66	102.02	8.9%
7.32	93.66	99.80	6.6%
7.34	93.66	97.63	4.2%
7.36	93.66	95.51	2.0%
7.38	93.66	93.43	-0.2%
7.40	93.66	91.36	-2.5%
7.42	93.66	89.32	-4.6%
7.44	93.66	87.30	-6.8%
7.46	93.66	85.31	-8.9%
7.48	93.66	83.33	-11.0%
7.50	93.66	81.37	-13.1%

WATERLINE AT ZERO
AREA ERROR = 7.378

STREAM NAME: Dolores River
XS LOCATION: Mile Marker 101
XS NUMBER: 2

Constant Manning's n

GL = lowest Grassline elevation corrected for sag
STAGING TABLE *WL* = Waterline corrected for variations in field measured water surface elevations and sag

	DIST TO WATER (FT)	TOP WIDTH (FT)	AVG. DEPTH (FT)	MAX. DEPTH (FT)	AREA (SQ FT)	WETTED PERIM. (FT)	PERCENT WET PERIM (%)	HYDR RADIUS (FT)	FLOW (CFS)	AVG. VELOCITY (FT/SEC)
GL	4.85	163.50	2.74	4.40	447.80	167.39	100.0%	2.68	1861.86	4.16
	6.38	137.60	1.60	2.87	220.74	140.34	83.8%	1.57	644.11	2.92
	6.43	137.18	1.56	2.82	213.87	139.90	83.6%	1.53	612.36	2.86
	6.48	136.76	1.51	2.77	207.02	139.45	83.3%	1.48	581.27	2.81
	6.53	136.34	1.47	2.72	200.20	139.00	83.0%	1.44	550.85	2.75
	6.58	135.92	1.42	2.67	193.39	138.55	82.8%	1.40	521.11	2.69
	6.63	135.57	1.38	2.62	186.60	138.17	82.5%	1.35	491.89	2.64
	6.68	135.24	1.33	2.57	179.83	137.81	82.3%	1.30	463.31	2.58
	6.73	134.92	1.28	2.52	173.08	137.45	82.1%	1.26	435.43	2.52
	6.78	133.63	1.24	2.47	166.35	136.12	81.3%	1.22	410.24	2.47
	6.83	131.57	1.21	2.42	159.72	134.02	80.1%	1.19	387.36	2.43
	6.88	129.58	1.18	2.37	153.20	131.97	78.8%	1.16	365.06	2.38
	6.93	127.82	1.15	2.32	146.76	130.17	77.8%	1.13	342.99	2.34
	6.98	125.41	1.12	2.27	140.43	127.70	76.3%	1.10	322.78	2.30
	7.03	123.00	1.09	2.22	134.22	125.24	74.8%	1.07	303.25	2.26
	7.08	121.38	1.06	2.17	128.11	123.55	73.8%	1.04	283.14	2.21
	7.13	119.79	1.02	2.12	122.08	121.91	72.8%	1.00	263.62	2.16
	7.18	117.84	0.99	2.07	116.14	119.91	71.6%	0.97	245.28	2.11
	7.23	115.96	0.95	2.02	110.29	117.98	70.5%	0.93	227.49	2.06
	7.28	114.08	0.92	1.97	104.54	116.06	69.3%	0.90	210.36	2.01
	7.33	108.69	0.91	1.92	98.95	110.63	66.1%	0.89	198.18	2.00
WL	7.38	103.90	0.90	1.87	93.66	105.79	63.2%	0.89	186.30	1.99
	7.43	101.07	0.88	1.82	88.53	102.94	61.5%	0.86	172.74	1.95
	7.48	98.42	0.85	1.77	83.55	100.26	59.9%	0.83	159.62	1.91
	7.53	94.69	0.83	1.72	78.71	96.51	57.7%	0.82	148.23	1.88
	7.58	89.96	0.82	1.67	74.09	91.75	54.8%	0.81	138.61	1.87
	7.63	84.91	0.82	1.62	69.73	86.69	51.8%	0.80	130.12	1.87
	7.68	82.56	0.79	1.57	65.54	84.31	50.4%	0.78	119.55	1.82
	7.73	80.50	0.76	1.52	61.47	82.23	49.1%	0.75	109.24	1.78
	7.78	80.09	0.72	1.47	57.46	81.81	48.9%	0.70	97.94	1.70
	7.83	79.69	0.67	1.42	53.46	81.40	48.6%	0.66	87.15	1.63
	7.88	79.17	0.63	1.37	49.49	80.85	48.3%	0.61	76.97	1.56
	7.93	76.88	0.59	1.32	45.57	78.53	46.9%	0.58	68.40	1.50
	7.98	72.71	0.58	1.27	41.83	74.32	44.4%	0.56	61.52	1.47
	8.03	69.15	0.55	1.22	38.29	70.72	42.2%	0.54	54.89	1.43
	8.08	66.80	0.52	1.17	34.90	68.30	40.8%	0.51	48.11	1.38
	8.13	64.38	0.49	1.12	31.61	65.81	39.3%	0.48	41.84	1.32
	8.18	61.53	0.46	1.07	28.46	62.87	37.6%	0.45	36.20	1.27
	8.23	57.88	0.44	1.02	25.48	59.12	35.3%	0.43	31.36	1.23
	8.28	54.23	0.42	0.97	22.67	55.39	33.1%	0.41	26.96	1.19
	8.33	50.10	0.40	0.92	20.06	51.18	30.6%	0.39	23.18	1.16
	8.38	46.86	0.38	0.87	17.65	47.86	28.6%	0.37	19.59	1.11
	8.43	43.55	0.35	0.82	15.39	44.46	26.6%	0.35	16.37	1.06
	8.48	40.11	0.33	0.77	13.30	40.91	24.4%	0.33	13.56	1.02
	8.53	37.94	0.30	0.72	11.35	38.65	23.1%	0.29	10.82	0.95
	8.58	35.85	0.27	0.67	9.50	36.47	21.8%	0.26	8.37	0.88
	8.63	31.80	0.25	0.62	7.80	32.33	19.3%	0.24	6.52	0.84
	8.68	28.90	0.22	0.57	6.30	29.35	17.5%	0.21	4.87	0.77
	8.73	25.73	0.19	0.52	4.92	26.11	15.6%	0.19	3.49	0.71
	8.78	19.08	0.20	0.47	3.76	19.41	11.6%	0.19	2.72	0.72
	8.83	11.05	0.27	0.42	2.95	11.31	6.8%	0.26	2.60	0.88
	8.88	9.58	0.26	0.37	2.45	9.80	5.9%	0.25	2.10	0.86
	8.93	8.93	0.22	0.32	1.99	9.12	5.4%	0.22	1.55	0.78
	8.98	8.16	0.19	0.27	1.56	8.32	5.0%	0.19	1.10	0.71
	9.03	7.36	0.16	0.22	1.17	7.48	4.5%	0.16	0.73	0.63
	9.08	6.55	0.13	0.17	0.82	6.65	4.0%	0.12	0.44	0.54
	9.13	5.75	0.09	0.12	0.52	5.81	3.5%	0.09	0.22	0.43

STREAM NAME: Dolores River
XS LOCATION: Mile Marker 101
XS NUMBER: 2

SUMMARY SHEET

MEASURED FLOW (Qm)=	166.67	cfs
CALCULATED FLOW (Qc)=	186.30	cfs
(Qm-Qc)/Qm * 100 =	-11.8	%
MEASURED WATERLINE (WLm)=	7.25	ft
CALCULATED WATERLINE (WLc)=	7.38	ft
(WLm-WLc)/WLm * 100 =	-1.8	%
MAX MEASURED DEPTH (Dm)=	1.90	ft
MAX CALCULATED DEPTH (Dc)=	1.87	ft
(Dm-Dc)/Dm * 100	1.5	%
MEAN VELOCITY=	1.99	ft/sec
MANNING'S N=	0.081	
SLOPE=	0.014	ft/ft
.4 * Qm =	66.7	cfs
2.5 * Qm=	416.7	cfs

RECOMMENDED INSTREAM FLOW:
==========

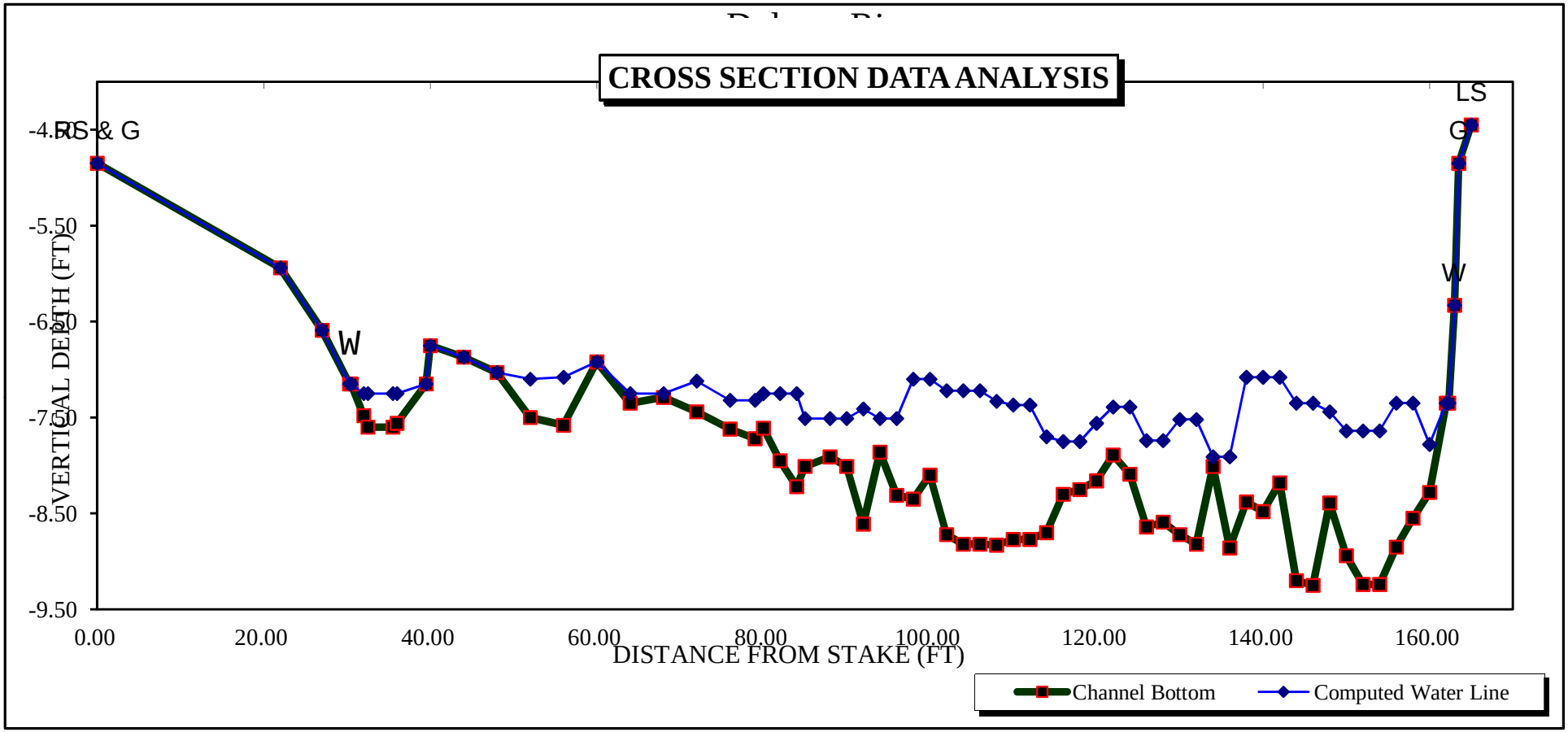
FLOW (CFS)	PERIOD
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_____	_____
_____	_____
_____	_____
_____	_____

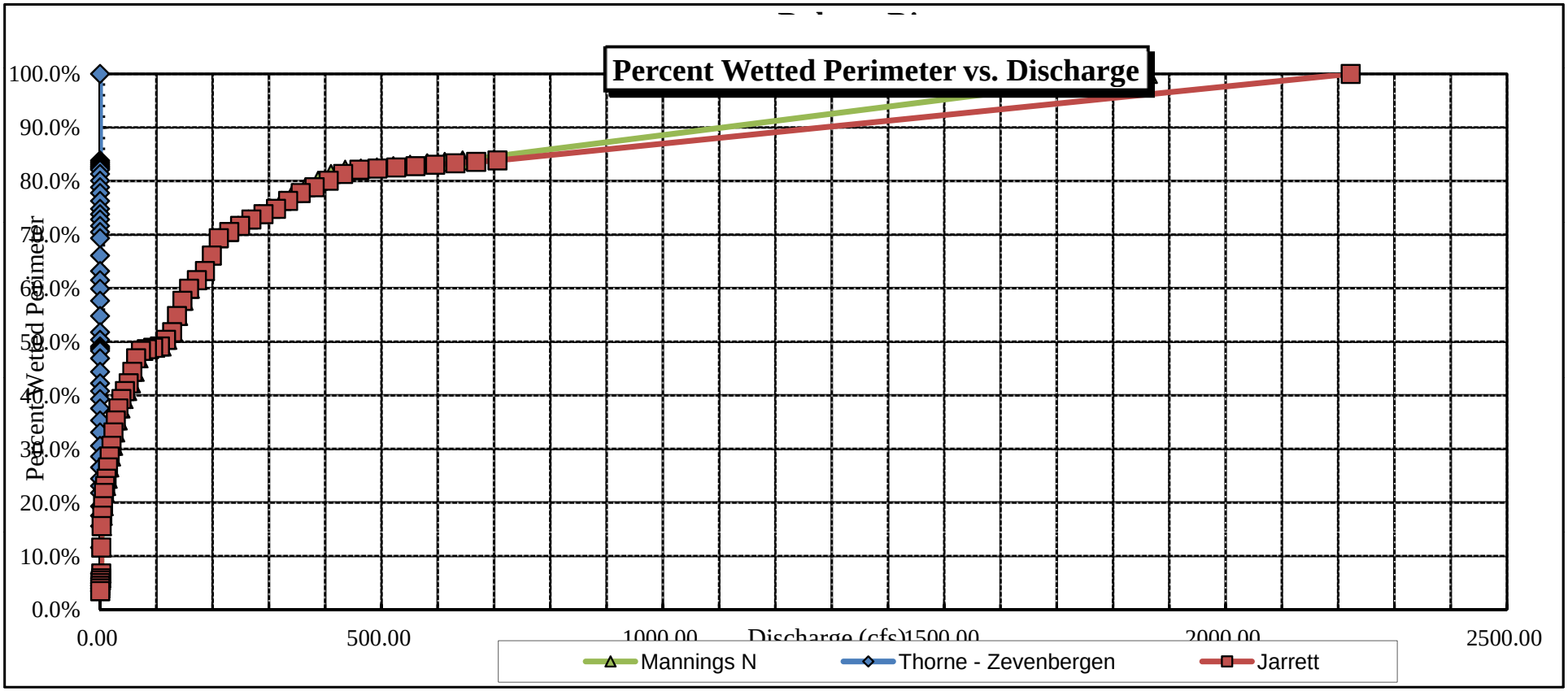
RATIONALE FOR RECOMMENDATION:
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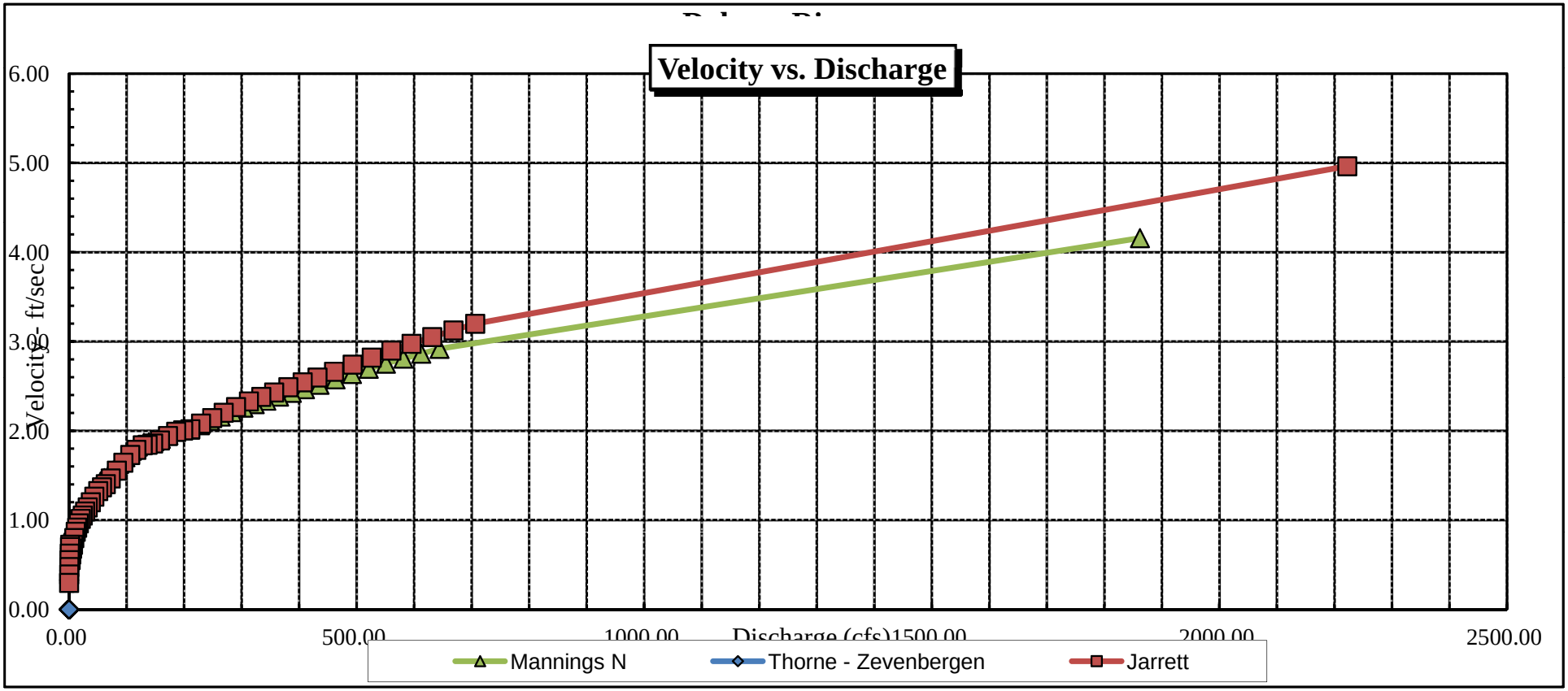
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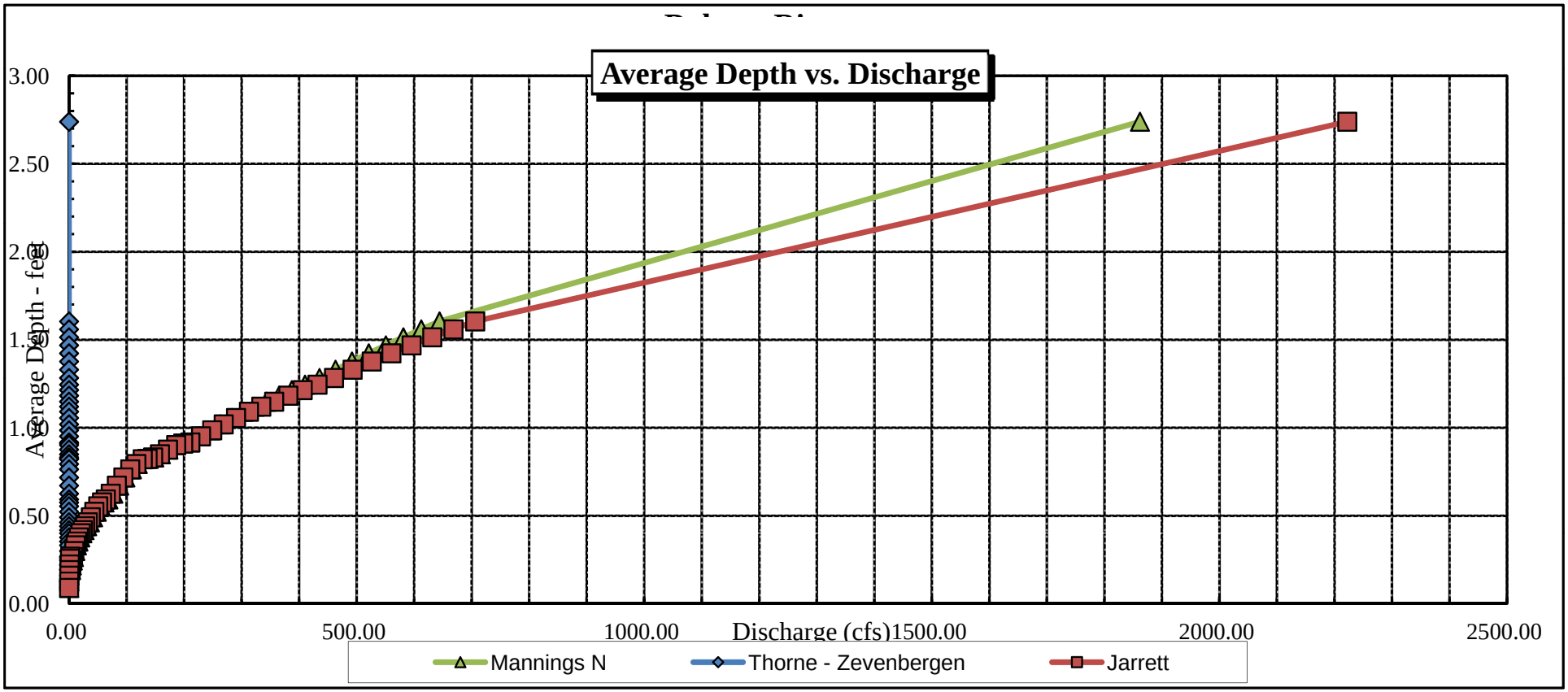
RECOMMENDATION BY: …….. AGENCY..…….. DATE:.....

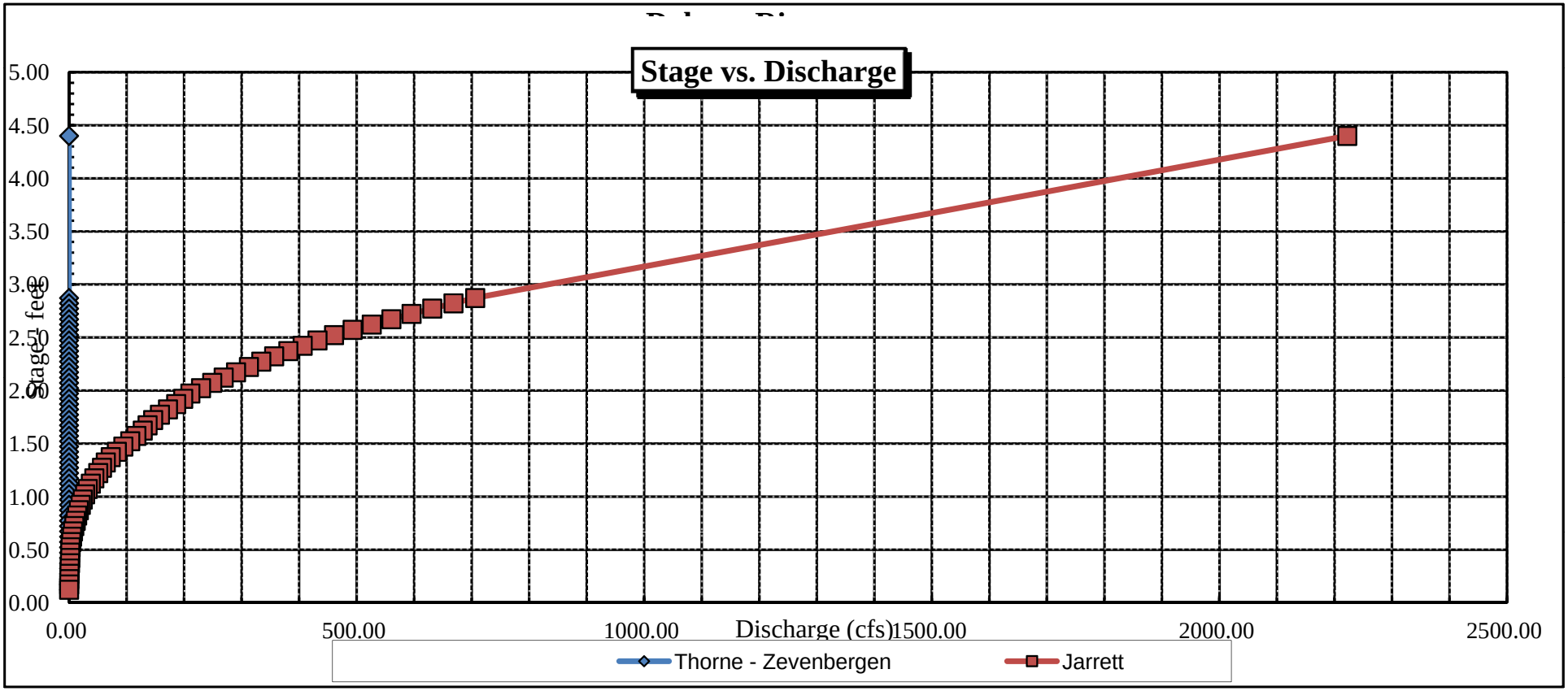
CWCB REVIEW BY: ..…….. DATE:.....


CROSS SECTION DATA ANALYSIS
RS & G
W
LS
G
W
-4.50
-5.50
-6.50
-7.50
-8.50
-9.50
VERTICAL DEPTH (FT)
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
DISTANCE FROM STAKE (FT)
Channel Bottom
Computed Water Line


Percent Wetted Perimeter vs. Discharge
Percent Wetted Perimeter
100.0%
90.0%
80.0%
70.0%
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
0.00
500.00
1000.00
Discharge (cfs)
1500.00
2000.00
2500.00
Mannings N
Thorne - Zevenbergen
Jarrett


Velocity vs. Discharge
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Velocity - ft/sec
0.00
500.00
1000.00
Discharge (cfs)1500.00
2000.00
2500.00
Mannings N
Thorne - Zevenbergen
Jarrett


Average Depth vs. Discharge
Average Depth - feet
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0.00
500.00
1000.00
Discharge (cfs)
1500.00
2000.00
2500.00
Mannings N
Thorne - Zevenbergen
Jarrett


Stage vs. Discharge
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Stage, feet
0.00
500.00
1000.00
1500.00
2000.00
2500.00
Discharge (cfs)
Thorne - Zevenbergen
Jarrett

COLORADO WATER CONSERVATION BOARD

FIELD DATA FOR INSTREAM FLOW DETERMINATIONS

COLORADO DIVISION OF WILDLIFE

LOCATION INFORMATION

STREAM NAME: Dolores River					CROSS-SECTION NO.: 3
CROSS-SECTION LOCATION: Mile Marker 96 GPS Zone 12 683455 4263991					
DATE: 2-27-13	OBSERVERS: R. Smith, D. Graf, E. Rumbold, N. Dieterich				
LEGAL DESCRIPTION	¼ SECTION: SE	SECTION: 17	TOWNSHIP: 49 (N) S	RANGE: 18 E (W)	PM: NM
COUNTY: Mesa	WATERSHED: Dolores	WATER DIVISION: 4	DOW WATER CODE: 39760		
MAP(S):	USGS:				
	USFS:				

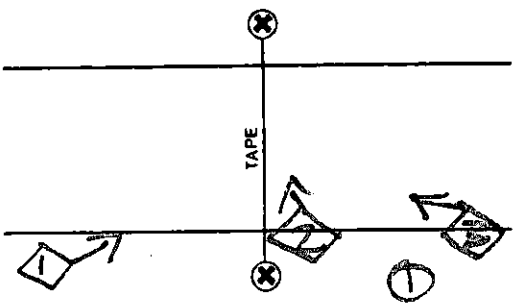
SUPPLEMENTAL DATA

SAG TAPE SECTION SAME AS DISCHARGE SECTION: (YES / NO)	METER TYPE: M-M			
METER NUMBER:	DATE RATED:	CALIB/SPIN. ____ sec	TAPE WEIGHT surveyed ____ lbs/foot	TAPE TENSION: surveyed ____ lbs
CHANNEL BED MATERIAL SIZE RANGE: 2" cobbles to 1-foot boulders	PHOTOGRAPHS TAKEN: (YES/NO)	NUMBER OF PHOTOGRAPHS: 3		

CHANNEL PROFILE DATA

STATION	DISTANCE FROM TAPE (ft)	ROD READING (ft)
(⊗) Tape @ Stake LB	0.0	surveyed
(⊗) Tape @ Stake RB	0.0	surveyed
(1) WS @ Tape LB/RB	0.0	8.90/8.94
(2) WS Upstream	39.0	8.61
(3) WS Downstream	132.5	10.42
SLOPE	1.81 / 171.5 = .0105	

SKETCH



LEGEND:
- Stake (⊗)
- Station (1)
- Photo (1)
- Direction of Flow

AQUATIC SAMPLING SUMMARY

STREAM ELECTROFISHED: YES/NO	DISTANCE ELECTROFISHED ____ ft	FISH CAUGHT YES/NO	WATER CHEMISTRY SAMPLED: YES/NO

LENGTH - FREQUENCY DISTRIBUTION BY ONE-INCH SIZE GROUPS (1.0-1.9, 2.0-2.9, ETC.)

SPECIES (FILL IN)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	>15	TOTAL

AQUATIC INSECTS IN STREAM SECTION BY COMMON OR SCIENTIFIC ORDER NAME:

COMMENTS

DISCHARGE/CROSS SECTION NOTES

STREAM NAME: Dolores River	CROSS-SECTION NO.: 3	DATE: 2-27-13	SHEET ___ OF ___
BEGINNING OF MEASUREMENT	EDGE OF WATER LOOKING DOWNSTREAM: (0.0 AT STAKE) LEFT / RIGHT	Gage Reading: ____ ft	TIME: 12:40 pm.

Features: Stake (S) Grassline (G) Waterline (W) Rock (R)	Distance From Initial Point (ft)	Width (ft)	Total Vertical Depth From Tape/Inst (ft)	Water Depth (ft)	Depth of Obser-vation (ft)	Revolutions	Time (sec)	Velocity (ft/sec) At Point	Velocity (ft/sec) Mean in Vertical	Area (ft^2)	Discharge (cfs)
LS	1.0		4.98								
G	3.0		5.91								
	5.3		7.80								
W	9.0		8.90								
	10		9.15	.25				.43			
	12		9.36	.45				1.08			
	14		9.46	.60				1.81			
	16		9.39	.50				1.98			
	18		10.00	.90				1.91			
	20		10.26	1.5				1.37			
	22		10.29	1.55				2.83			
	24		10.07	1.2				2.36			
	26		10.45	1.6				2.28			
	28		10.53	1.75				1.89			
	30		10.37	1.5				2.29			
	32		10.25	1.3				2.25			
	34		10.38	1.5				2.07			
	36		10.28	1.25				2.2			
	38		9.99	1.1				1.42			
	40		9.84	1.0				1.75			
	42		9.80	0.9				1.92			
	44		9.78	0.9				0.43			
	46		9.95	0.9				2.19			
	48		9.85	0.9				0.83			
	50		9.60	0.75				2.17			
	52		9.88	0.85				1.08			
	54		9.72	0.75				1.75			
	56		9.57	0.75				1.26			
	58		9.24	0.5				0.41			
	60		9.05	0.1				0			
	62		8.94	0				0			
	64		9.19	0.3				1.16			
	66		9.20	0.3				1.28			
	68		9.14	0.1				0			
	70		8.97	0				0			
W	71		8.94	0							
	85		8.52								
	90		7.55								
	92		6.01								
G	93		5.73								
RS	96.6		4.72								
TOTALS:											

End of Measurement	Time	Gage Reading ft	CALCULATIONS PERFORMED BY	CALCULATIONS CHECKED BY

COLORADO WATER CONSERVATION BOARD
INSTREAM FLOW / NATURAL LAKE LEVEL PROGRAM
STREAM CROSS-SECTION AND FLOW ANALYSIS

LOCATION INFORMATION

STREAM NAME:	Dolores River
XS LOCATION:	Mile Marker 96
XS NUMBER:	3
DATE:	27-Feb-13
OBSERVERS:	R. Smith, D. Graf, N. Dieterich, E. Rumbold
1/4 SEC:	SE
SECTION:	17
TWP:	49N
RANGE:	18W
PM:	New Mexico
COUNTY:	Mesa
WATERSHED:	Dolores
DIVISION:	4
DOW CODE:	39760
USGS MAP:	0
USFS MAP:	0

SUPPLEMENTAL DATA

TAPE WT:	0.0106	*** NOTE *** Leave TAPE WT and TENSION at defaults for data collected with a survey level and rod
TENSION:	99999	

CHANNEL PROFILE DATA

SLOPE:	0.0105

INPUT DATA CHECKED BY: .....DATE.....

ASSIGNED TO: ….....…….....DATE.....

STREAM NAME: Dolores River
XS LOCATION: Mile Marker 96
XS NUMBER: 3

DATA POINTS= 41

VALUES COMPUTED FROM RAW FIELD DATA

	FEATURE	DIST	VERT DEPTH	WATER DEPTH	VEL	WETTED PERIM.	WATER DEPTH	AREA (Am)	Q (Qm)	% Q CELL
	LS	1.00	4.98			0.00		0.00	0.00	0.0%
1	G	3.00	5.91			0.00		0.00	0.00	0.0%
		5.30	7.80			0.00		0.00	0.00	0.0%
	W	9.00	8.90	0.00	0.00	0.00		0.00	0.00	0.0%
		10.00	9.15	0.25	0.43	1.03	0.25	0.38	0.16	0.2%
		12.00	9.36	0.45	1.08	2.01	0.45	0.90	0.97	1.0%
		14.00	9.46	0.60	1.81	2.00	0.60	1.20	2.17	2.3%
		16.00	9.39	0.50	1.98	2.00	0.50	1.00	1.98	2.1%
		18.00	10.00	0.90	1.91	2.09	0.90	1.80	3.44	3.7%
		20.00	10.26	1.50	1.37	2.02	1.50	3.00	4.11	4.4%
		22.00	10.29	1.55	2.83	2.00	1.55	3.10	8.77	9.4%
		24.00	10.07	1.20	2.36	2.01	1.20	2.40	5.66	6.1%
		26.00	10.45	1.60	2.28	2.04	1.60	3.20	7.30	7.8%
		28.00	10.53	1.75	1.89	2.00	1.75	3.50	6.62	7.1%
		30.00	10.37	1.50	2.29	2.01	1.50	3.00	6.87	7.4%
		32.00	10.25	1.30	2.25	2.00	1.30	2.60	5.85	6.3%
		34.00	10.38	1.50	2.07	2.00	1.50	3.00	6.21	6.7%
		36.00	10.28	1.25	2.20	2.00	1.25	2.50	5.50	5.9%
		38.00	9.99	1.10	1.42	2.02	1.10	2.20	3.12	3.3%
		40.00	9.84	1.00	1.75	2.01	1.00	2.00	3.50	3.7%
		42.00	9.80	0.90	1.92	2.00	0.90	1.80	3.46	3.7%
		44.00	9.78	0.90	0.43	2.00	0.90	1.80	0.77	0.8%
		46.00	9.95	0.90	2.19	2.01	0.90	1.80	3.94	4.2%
		48.00	9.85	0.90	0.83	2.00	0.90	1.80	1.49	1.6%
		50.00	9.60	0.75	2.17	2.02	0.75	1.50	3.26	3.5%
		52.00	9.88	0.85	1.08	2.02	0.85	1.70	1.84	2.0%
		54.00	9.72	0.75	1.75	2.01	0.75	1.50	2.63	2.8%
		56.00	9.57	0.75	1.26	2.01	0.75	1.50	1.89	2.0%
		58.00	9.24	0.50	0.41	2.03	0.50	1.00	0.41	0.4%
		60.00	9.05	0.10	0.00	2.01	0.10	0.20	0.00	0.0%
		62.00	8.94	0.00	0.00	2.00		0.00	0.00	0.0%
		64.00	9.19	0.30	1.16	2.02	0.30	0.60	0.70	0.7%
		66.00	9.20	0.30	1.28	2.00	0.30	0.60	0.77	0.8%
		68.00	9.14	0.10	0.00	2.00	0.10	0.20	0.00	0.0%
		70.00	8.97	0.00	0.00	2.01		0.00	0.00	0.0%
	W	71.00	8.94	0.00	0.00	0.00		0.00	0.00	0.0%
		85.00	8.52			0.00		0.00	0.00	0.0%
		90.00	7.55			0.00		0.00	0.00	0.0%
		92.00	6.01			0.00		0.00	0.00	0.0%
1	G	93.00	5.73			0.00		0.00	0.00	0.0%
	RS	96.60	4.72			0.00		0.00	0.00	0.0%
	TOTALS ----------					61.37	1.75 (Max.)	51.78	93.38	100.0%

Manning's n = 0.0754
Hydraulic Radius= 0.84370489

STREAM NAME: Dolores River
XS LOCATION: Mile Marker 96
XS NUMBER: 3

WATER LINE COMPARISON TABLE

WATER LINE	MEAS AREA	COMP AREA	AREA ERROR
	51.78	48.56	-6.2%
8.71	51.78	65.03	25.6%
8.73	51.78	63.63	22.9%
8.75	51.78	62.24	20.2%
8.77	51.78	60.87	17.6%
8.79	51.78	59.51	14.9%
8.81	51.78	58.17	12.3%
8.83	51.78	56.84	9.8%
8.85	51.78	55.53	7.2%
8.87	51.78	54.23	4.7%
8.89	51.78	52.94	2.3%
8.91	51.78	51.67	-0.2%
8.92	51.78	51.04	-1.4%
8.93	51.78	50.41	-2.6%
8.94	51.78	49.79	-3.8%
8.95	51.78	49.17	-5.0%
8.96	51.78	48.56	-6.2%
8.97	51.78	47.96	-7.4%
8.98	51.78	47.36	-8.5%
8.99	51.78	46.76	-9.7%
9.00	51.78	46.17	-10.8%
9.01	51.78	45.58	-12.0%
9.03	51.78	44.42	-14.2%
9.05	51.78	43.28	-16.4%
9.07	51.78	42.15	-18.6%
9.09	51.78	41.04	-20.7%
9.11	51.78	39.94	-22.9%
9.13	51.78	38.85	-25.0%
9.15	51.78	37.78	-27.0%
9.17	51.78	36.72	-29.1%
9.19	51.78	35.70	-31.1%
9.21	51.78	34.71	-33.0%

WATERLINE AT ZERO
AREA ERROR = 8.903

STREAM NAME: Dolores River
XS LOCATION: Mile Marker 96
XS NUMBER: 3

Constant Manning's n

GL = lowest Grassline elevation corrected for sag
STAGING TABLE *WL* = Waterline corrected for variations in field measured water surface elevations and sag

	DIST TO WATER (FT)	TOP WIDTH (FT)	AVG. DEPTH (FT)	MAX. DEPTH (FT)	AREA (SQ FT)	WETTED PERIM. (FT)	PERCENT WET PERIM (%)	HYDR RADIUS (FT)	FLOW (CFS)	AVG. VELOCITY (FT/SEC)
GL	5.91	89.36	3.36	4.62	300.41	91.20	100.0%	3.29	1343.49	4.47
	7.90	82.53	1.55	2.63	127.97	83.11	91.1%	1.54	344.72	2.69
	7.95	82.10	1.51	2.58	123.86	82.67	90.6%	1.50	327.59	2.64
	8.00	81.68	1.47	2.53	119.76	82.23	90.2%	1.46	310.84	2.60
	8.05	81.25	1.42	2.48	115.69	81.79	89.7%	1.41	294.47	2.55
	8.10	80.83	1.38	2.43	111.64	81.36	89.2%	1.37	278.48	2.49
	8.15	80.40	1.34	2.38	107.61	80.92	88.7%	1.33	262.87	2.44
	8.20	79.97	1.30	2.33	103.60	80.48	88.2%	1.29	247.64	2.39
	8.25	79.55	1.25	2.28	99.61	80.04	87.8%	1.24	232.80	2.34
	8.30	79.12	1.21	2.23	95.64	79.60	87.3%	1.20	218.35	2.28
	8.35	78.70	1.17	2.18	91.70	79.17	86.8%	1.16	204.30	2.23
	8.40	78.27	1.12	2.13	87.77	78.73	86.3%	1.11	190.64	2.17
	8.45	77.85	1.08	2.08	83.87	78.29	85.8%	1.07	177.38	2.11
	8.50	77.42	1.03	2.03	79.99	77.85	85.4%	1.03	164.52	2.06
	8.55	76.05	1.00	1.98	76.15	76.48	83.9%	1.00	153.37	2.01
	8.60	74.22	0.98	1.93	72.39	74.63	81.8%	0.97	143.28	1.98
	8.65	72.38	0.95	1.88	68.72	72.79	79.8%	0.94	133.60	1.94
	8.70	70.55	0.92	1.83	65.15	70.95	77.8%	0.92	124.33	1.91
	8.75	68.71	0.90	1.78	61.67	69.10	75.8%	0.89	115.46	1.87
	8.80	66.88	0.87	1.73	58.28	67.26	73.8%	0.87	106.99	1.84
	8.85	65.04	0.85	1.68	54.98	65.42	71.7%	0.84	98.91	1.80
WL	8.90	63.21	0.82	1.63	51.77	63.57	69.7%	0.81	91.20	1.76
	8.95	60.99	0.80	1.58	48.66	61.35	67.3%	0.79	84.23	1.73
	9.00	58.54	0.78	1.53	45.68	58.88	64.6%	0.78	77.91	1.71
	9.05	56.46	0.76	1.48	42.81	56.80	62.3%	0.75	71.61	1.67
	9.10	54.75	0.73	1.43	40.03	55.07	60.4%	0.73	65.36	1.63
	9.15	52.73	0.71	1.38	37.33	53.03	58.2%	0.70	59.68	1.60
	9.20	47.88	0.73	1.33	34.79	48.18	52.8%	0.72	56.56	1.63
	9.25	46.93	0.69	1.28	32.42	47.23	51.8%	0.69	50.96	1.57
	9.30	46.16	0.65	1.23	30.09	46.44	50.9%	0.65	45.52	1.51
	9.35	45.38	0.61	1.18	27.80	45.66	50.1%	0.61	40.35	1.45
	9.40	43.72	0.58	1.13	25.57	43.99	48.2%	0.58	35.97	1.41
	9.45	40.82	0.57	1.08	23.45	41.08	45.0%	0.57	32.61	1.39
	9.50	40.03	0.54	1.03	21.44	40.28	44.2%	0.53	28.45	1.33
	9.55	39.57	0.49	0.98	19.45	39.80	43.6%	0.49	24.38	1.25
	9.60	38.81	0.45	0.93	17.49	39.03	42.8%	0.45	20.68	1.18
	9.65	37.22	0.42	0.88	15.59	37.43	41.0%	0.42	17.56	1.13
	9.70	35.63	0.39	0.83	13.77	35.82	39.3%	0.38	14.70	1.07
	9.75	34.07	0.35	0.78	12.02	34.25	37.6%	0.35	12.09	1.01
	9.80	30.08	0.35	0.73	10.39	30.24	33.2%	0.34	10.29	0.99
	9.85	25.90	0.35	0.68	9.00	26.04	28.6%	0.35	8.95	0.99
	9.90	22.95	0.34	0.63	7.78	23.08	25.3%	0.34	7.62	0.98
	9.95	20.64	0.32	0.58	6.70	20.75	22.8%	0.32	6.36	0.95
	10.00	19.88	0.29	0.53	5.68	19.98	21.9%	0.28	4.96	0.87
	10.05	19.15	0.25	0.48	4.71	19.25	21.1%	0.24	3.72	0.79
	10.10	17.94	0.21	0.43	3.78	18.03	19.8%	0.21	2.69	0.71
	10.15	16.50	0.18	0.38	2.92	16.57	18.2%	0.18	1.85	0.63
	10.20	15.05	0.14	0.33	2.13	15.11	16.6%	0.14	1.16	0.55
	10.25	13.50	0.10	0.28	1.41	13.54	14.8%	0.10	0.63	0.45
	10.30	8.60	0.10	0.23	0.86	8.62	9.5%	0.10	0.38	0.44
	10.35	5.73	0.09	0.18	0.51	5.75	6.3%	0.09	0.20	0.40
	10.40	3.83	0.07	0.13	0.28	3.84	4.2%	0.07	0.10	0.35
	10.45	2.87	0.04	0.08	0.11	2.88	3.2%	0.04	0.03	0.23
	10.50	1.00	0.01	0.03	0.01	1.00	1.1%	0.01	0.00	0.11

STREAM NAME: Dolores River
XS LOCATION: Mile Marker 96
XS NUMBER: 3

SUMMARY SHEET

MEASURED FLOW (Qm)=	93.38	cfs
CALCULATED FLOW (Qc)=	91.20	cfs
(Qm-Qc)/Qm * 100 =	2.3	%
MEASURED WATERLINE (WLm)=	8.96	ft
CALCULATED WATERLINE (WLc)=	8.90	ft
(WLm-WLc)/WLm * 100 =	0.6	%
MAX MEASURED DEPTH (Dm)=	1.75	ft
MAX CALCULATED DEPTH (Dc)=	1.63	ft
(Dm-Dc)/Dm * 100	7.0	%
MEAN VELOCITY=	1.76	ft/sec
MANNING'S N=	0.075	
SLOPE=	0.0105	ft/ft
.4 * Qm =	37.4	cfs
2.5 * Qm=	233.5	cfs

RECOMMENDED INSTREAM FLOW:
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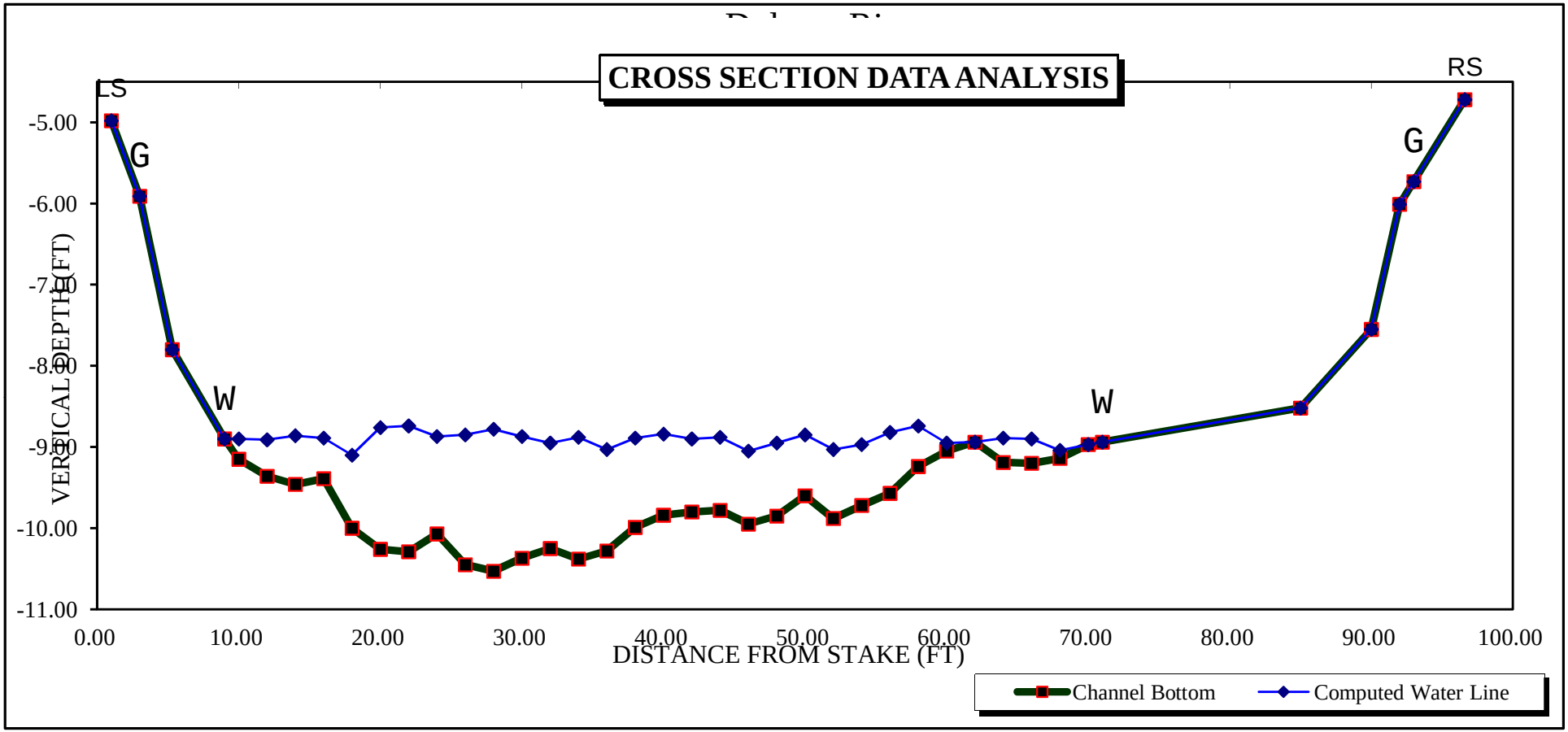
FLOW (CFS)	PERIOD
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_____	_____

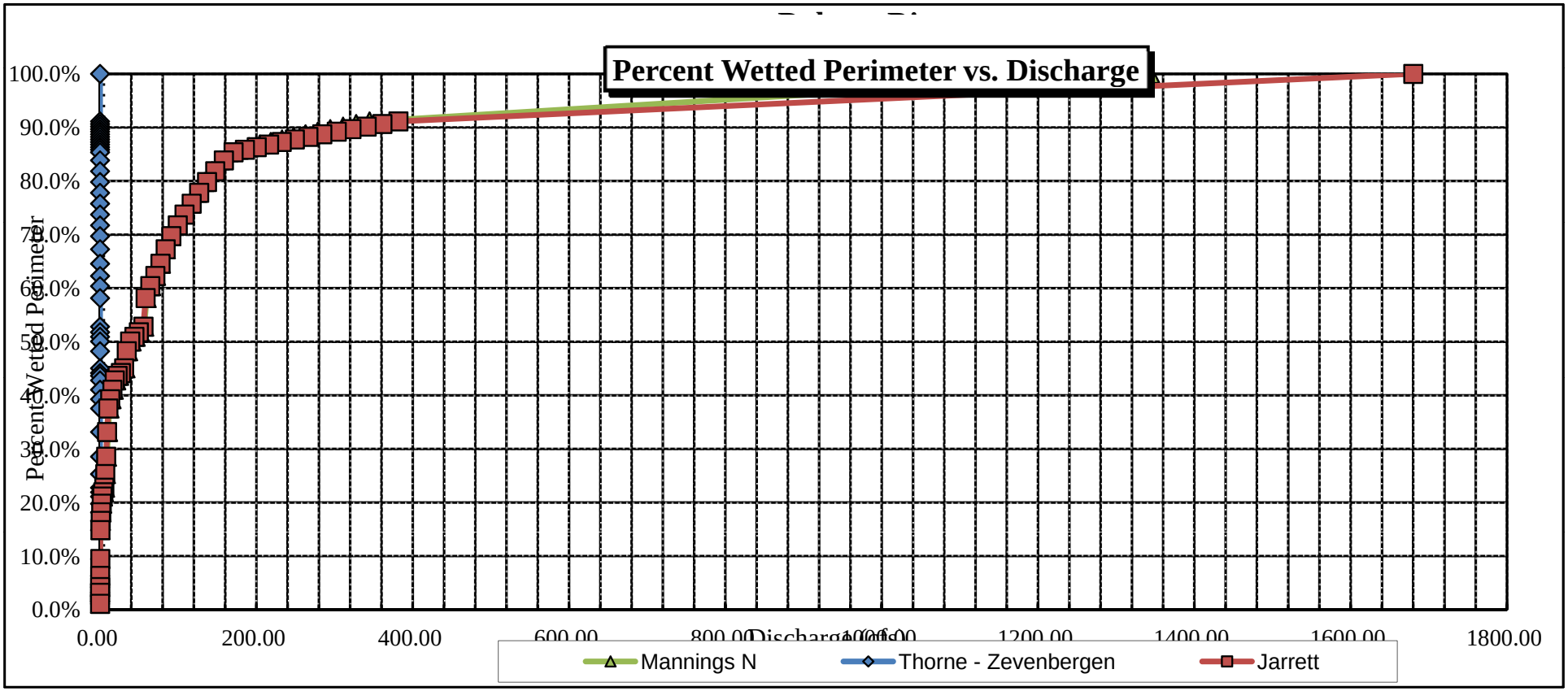
RATIONALE FOR RECOMMENDATION:
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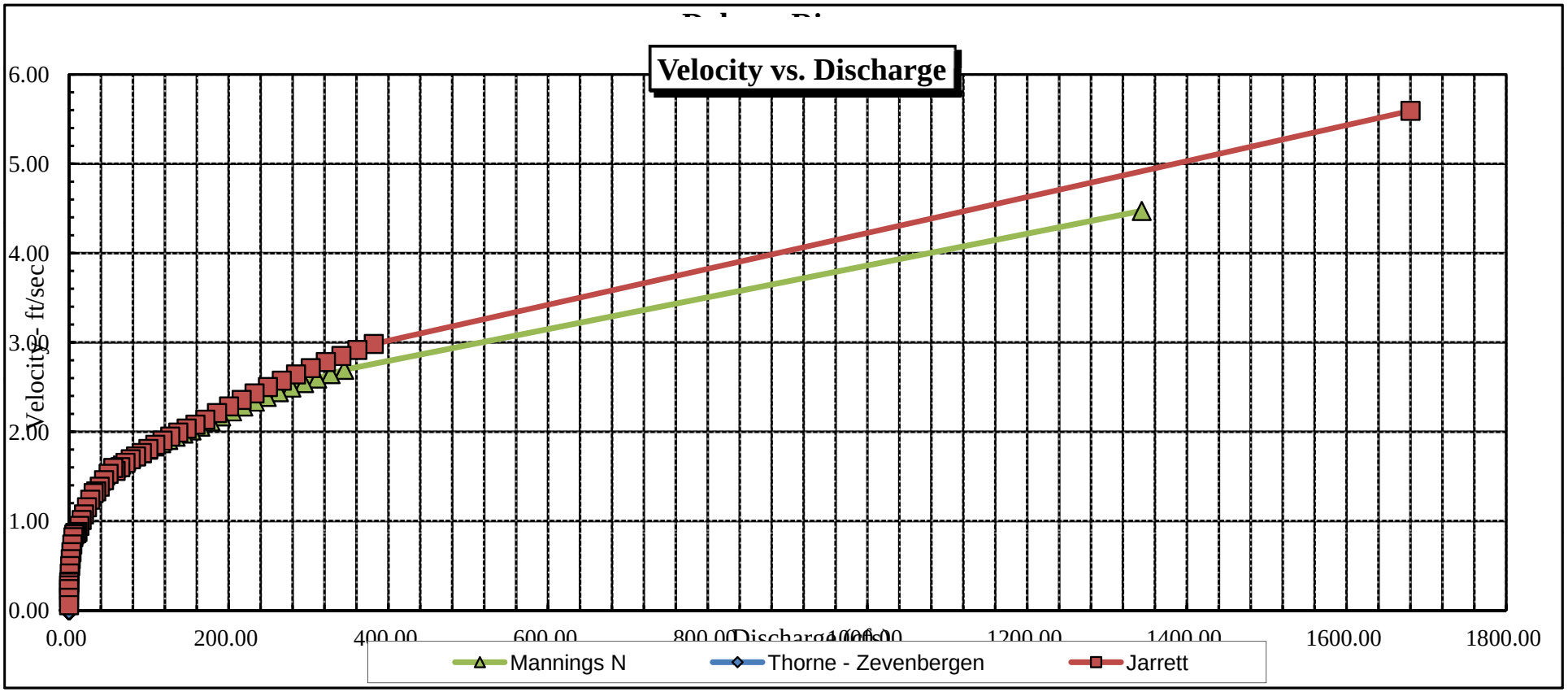
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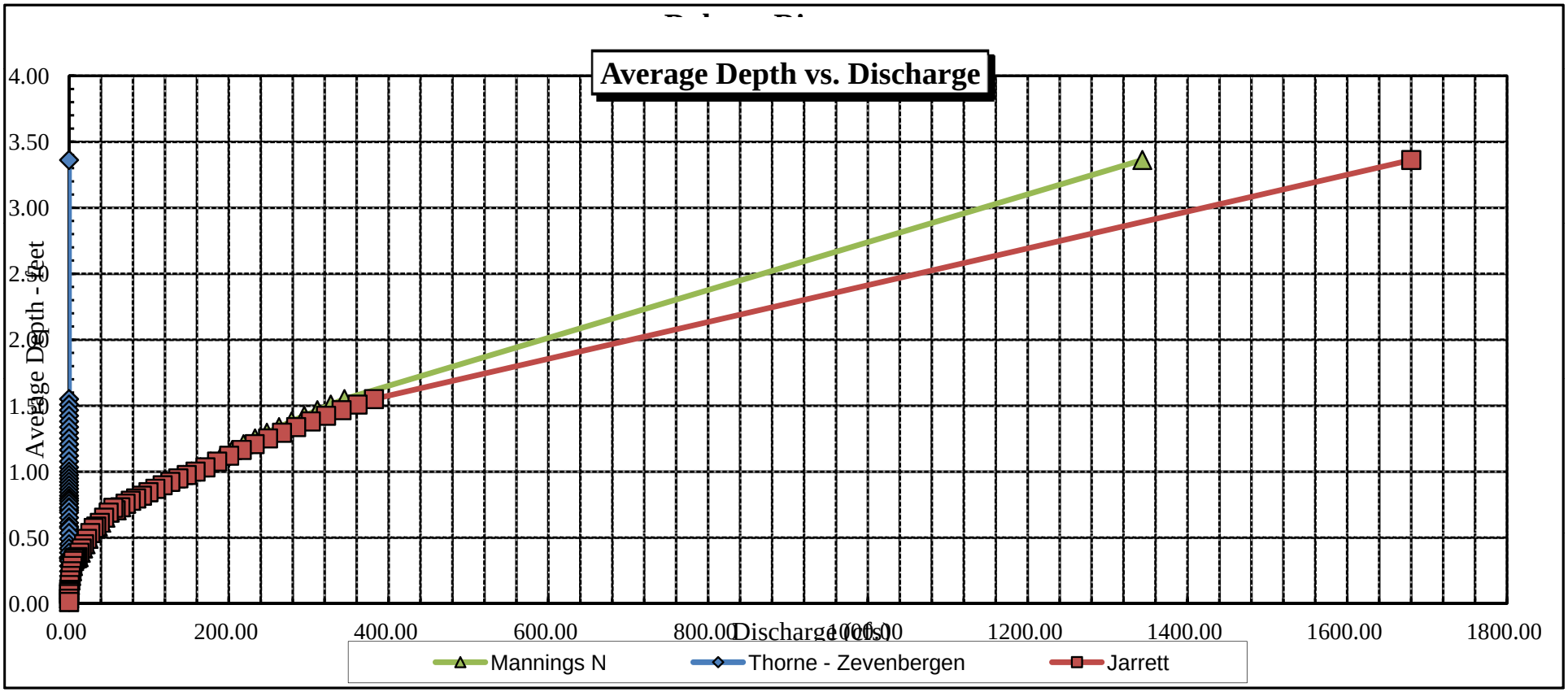
RECOMMENDATION BY: …….. AGENCY..…….. DATE:.....

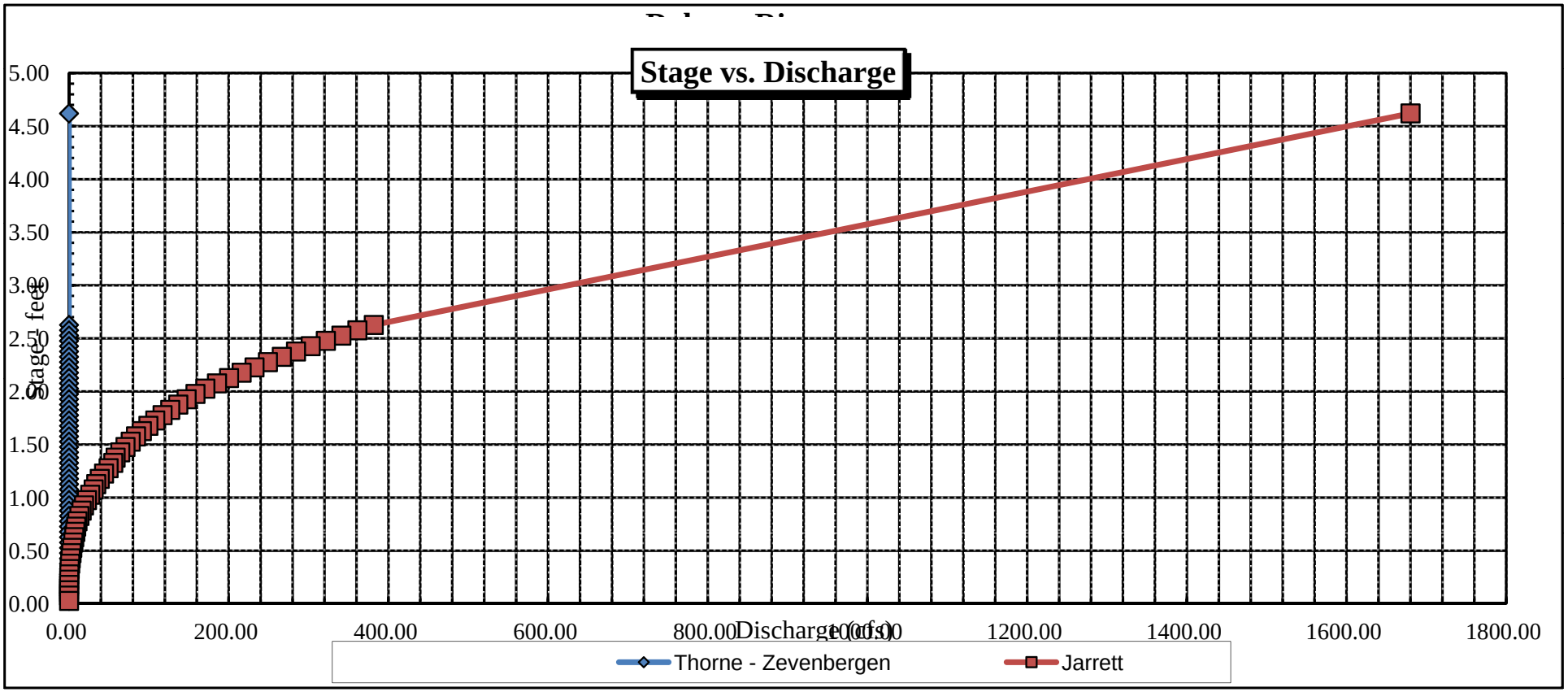
CWCB REVIEW BY: ..…….. DATE:.....


CROSS SECTION DATA ANALYSIS
LS
RS
G
G
W
W
-5.00
-6.00
-7.00
-8.00
-9.00
-10.00
-11.00
VERTICAL DEPTH (FT)
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00
DISTANCE FROM STAKE (FT)
Channel Bottom
Computed Water Line


Percent Wetted Perimeter vs. Discharge
Percent Wetted Perimeter
100.0%
90.0%
80.0%
70.0%
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
0.00
200.00
400.00
600.00
800.00
1000.00
1200.00
1400.00
1600.00
1800.00
Discharge (cfs)
Mannings N
Thorne - Zevenbergen
Jarrett


Velocity vs. Discharge
Velocity - ft/sec
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0.00
200.00
400.00
600.00
800.00
1000.00
1200.00
1400.00
1600.00
1800.00
Mannings N
Thorne - Zevenbergen
Jarrett


Average Depth vs. Discharge
Average Depth - Feet
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0.00
200.00
400.00
600.00
800.00
1000.00
1200.00
1400.00
1600.00
1800.00
Discharge (cfs)
Mannings N
Thorne - Zevenbergen
Jarrett


Stage vs. Discharge
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Stage, feet
0.00
200.00
400.00
600.00
800.00
1000.00
1200.00
1400.00
1600.00
1800.00
Discharge, (cfs)
Thorne - Zevenbergen
Jarrett

COLORADO WATER CONSERVATION BOARD

FIELD DATA FOR INSTREAM FLOW DETERMINATIONS

COLORADO DIVISION OF WILDLIFE

LOCATION INFORMATION

STREAM NAME: Dolores River							CROSS-SECTION NO.: 4
CROSS-SECTION LOCATION: At Montrose - Mesa County Line GPS Zone 12 683745 4263265							
DATE: 2-27-13	OBSERVERS: R. Smith, D. Graf, E. Rumbold, N. Diederich						
LEGAL DESCRIPTION	¼ SECTION: NE	SECTION: 20	TOWNSHIP: 49 (N)S	RANGE: 18 E(W)	PM: NM		
COUNTY: Mesa	WATERSHED: Dolores		WATER DIVISION: 4		DOW WATER CODE: 39760		
MAP(S):	USGS:						
	USFS:						

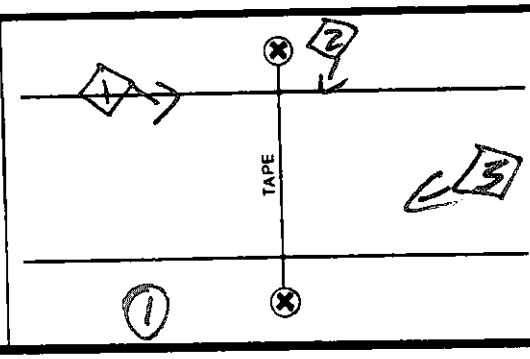
SUPPLEMENTAL DATA

SAG TAPE SECTION SAME AS DISCHARGE SECTION (YES)/NO	METER TYPE: M - M			
METER NUMBER:	DATE RATED:	CALIB/SPIN ____ sec	TAPE WEIGHT surveyed ____ lbs/foot	TAPE TENSION: surveyed ____ lbs
CHANNEL BED MATERIAL SIZE RANGE: 2" cobbles to 2-foot boulders	PHOTOGRAPHS TAKEN: (YES)/NO	NUMBER OF PHOTOGRAPHS: 3		

CHANNEL PROFILE DATA

STATION	DISTANCE FROM TAPE (ft)	ROD READING (ft)
⊗ Tape @ Stake LB	0.0	surveyed
⊗ Tape @ Stake RB	0.0	surveyed
① WS @ Tape LB/RB	0.0	5.36/5.55
② WS Upstream	152.0	3.10
③ WS Downstream	53.0	6.06
SLOPE	2.96/205.0 = .0144	

SKETCH



LEGEND:
Stake ⊗
Station ①
Photo ◇
Direction of Flow

AQUATIC SAMPLING SUMMARY

STREAM ELECTROFISHED: YES/(NO)	DISTANCE ELECTROFISHED: ____ ft	FISH CAUGHT YES/NO	WATER CHEMISTRY SAMPLED: YES/(NO)

LENGTH - FREQUENCY DISTRIBUTION BY ONE-INCH SIZE GROUPS (1.0-1.9, 2.0-2.9, ETC.)

SPECIES (FILL IN)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	>15	TOTAL

AQUATIC INSECTS IN STREAM SECTION BY COMMON OR SCIENTIFIC ORDER NAME:

COMMENTS

DISCHARGE/CROSS SECTION NOTES

STREAM NAME: Dolores River	CROSS-SECTION NO: 4	DATE: 2-27-13	SHEET ___ OF ___
BEGINNING OF MEASUREMENT	EDGE OF WATER LOOKING DOWNSTREAM: (0.0 AT STAKE) LEFT / RIGHT	Gage Reading: ____ ft	TIME: 2:20 pm

Features: Stake (S) Grassline (G) Waterline (W) Rock (R)	Distance From Initial Point (ft)	Width (ft)	Total Vertical Depth From Tape/Inst (ft)	Water Depth (ft)	Depth of Observation (ft)	Revolutions	Time (sec)	Velocity (ft/sec)		Area (ft^2)	Discharge (cfs)
								At Point	Mean in Vertical		
LS	2		2.04								
	5		2.32								
G	9.5		3.68								
	12.5		4.59								
	13		4.98								
W	18		5.36	0				0			
	20		5.30	.15				0			
	23		5.41	.25				0			
	26		5.43	0				0			
	29		5.98	0.7				0.58			
	32		5.84	0.5				0.51			
	35		6.14	0.9				1.22			
	38		5.70	0.4				0.67			
	41		6.48	1.1				1.60			
	44		6.62	1.1				2.45			
	47		6.71	1.1				3.21			
	50		6.48	1.1				0.15			
	53		6.24	0.8				0.78			
	56		6.07	0.75				2.54			
	59		6.42	1.0				1.50			
	62		5.88	0.7				1.67			
	65		6.42	0.9				0.39			
	68		6.74	1.1				0.37			
	71		6.56	1.0				1.22			
	74		6.16	0.6				2.02			
	77		6.90	1.3				1.08			
	80		6.27	0.75				1.40			
	83		7.17	1.3				0.98			
	86		7.42	1.8				0.81			
	89		7.44	1.75				0.53			
	92		7.32	1.95				1.02			
	95		7.42	1.85				1.29			
	98		7.46	1.80				0.55			
	101		7.24	1.40				0.64			
	104		6.45	0.55				1.13			
	107		6.44	0.60				0.58			
	110		6.12	0.40				0.23			
W	113		5.55	0				0			
	117.5		4.25								
G	119.0		3.62								
	122.5		2.26								
RS	124.6		1.88								
TOTALS:											

End of Measurement	Time	Gage Reading ft	CALCULATIONS PERFORMED BY	CALCULATIONS CHECKED BY

COLORADO WATER CONSERVATION BOARD
INSTREAM FLOW / NATURAL LAKE LEVEL PROGRAM
STREAM CROSS-SECTION AND FLOW ANALYSIS

LOCATION INFORMATION

STREAM NAME:	Dolores River
XS LOCATION:	Montrose-Mesa County Line
XS NUMBER:	4
DATE:	27-Feb-13
OBSERVERS:	R. Smith, N. Dieterich,
1/4 SEC:	NE
SECTION:	20
TWP:	49N
RANGE:	18W
PM:	New Mexico
COUNTY:	Montrose
WATERSHED:	Dolores
DIVISION:	4
DOW CODE:	39760
USGS MAP:	0
USFS MAP:	0

SUPPLEMENTAL DATA

		*** NOTE ***
		Leave TAPE WT and TENSION
		at defaults for data collected
TAPE WT:	0.0106	with a survey level and rod
TENSION:	99999	

CHANNEL PROFILE DATA

SLOPE:	0.014

INPUT DATA CHECKED BY: .....DATE.....

ASSIGNED TO: ….....……..…….....DATE.....

STREAM NAME: Dolores River
XS LOCATION: Montrose-Mesa County Line
XS NUMBER: 4

DATA POINTS= 42

VALUES COMPUTED FROM RAW FIELD DATA

FEATURE	DIST	VERT DEPTH	WATER DEPTH	VEL	WETTED PERIM.	WATER DEPTH	AREA (Am)	Q (Qm)	% Q CELL
LS	2.00	2.04			0.00		0.00	0.00	0.0%
	5.00	2.32			0.00		0.00	0.00	0.0%
1 G	9.50	3.68			0.00		0.00	0.00	0.0%
	12.50	4.59			0.00		0.00	0.00	0.0%
	13.00	4.98			0.00		0.00	0.00	0.0%
W	18.00	5.36	0.00	0.00	0.00		0.00	0.00	0.0%
	20.00	5.30	0.15	0.00	2.00	0.15	0.38	0.00	0.0%
	23.00	5.41	0.25	0.00	3.00	0.25	0.75	0.00	0.0%
	26.00	5.43	0.00	0.00	3.00		0.00	0.00	0.0%
	29.00	5.98	0.70	0.58	3.05	0.70	2.10	1.22	1.3%
	32.00	5.84	0.50	0.51	3.00	0.50	1.50	0.77	0.8%
	35.00	6.14	0.90	1.22	3.01	0.90	2.70	3.29	3.4%
	38.00	5.70	0.40	0.67	3.03	0.40	1.20	0.80	0.8%
	41.00	6.48	1.10	1.60	3.10	1.10	3.30	5.28	5.5%
	44.00	6.62	1.10	2.45	3.00	1.10	3.30	8.09	8.4%
	47.00	6.71	1.10	3.21	3.00	1.10	3.30	10.59	11.0%
	50.00	6.48	1.10	0.15	3.01	1.10	3.30	0.50	0.5%
	53.00	6.24	0.80	0.78	3.01	0.80	2.40	1.87	1.9%
	56.00	6.07	0.75	2.54	3.00	0.75	2.25	5.72	6.0%
	59.00	6.42	1.00	1.50	3.02	1.00	3.00	4.50	4.7%
	62.00	5.88	0.70	1.67	3.05	0.70	2.10	3.51	3.7%
	65.00	6.42	0.90	0.39	3.05	0.90	2.70	1.05	1.1%
	68.00	6.74	1.10	0.37	3.02	1.10	3.30	1.22	1.3%
	71.00	6.56	1.00	1.22	3.01	1.00	3.00	3.66	3.8%
	74.00	6.16	0.60	2.02	3.03	0.60	1.80	3.64	3.8%
	77.00	6.90	1.30	1.08	3.09	1.30	3.90	4.21	4.4%
	80.00	6.27	0.75	1.40	3.07	0.75	2.25	3.15	3.3%
	83.00	7.12	1.30	0.98	3.12	1.30	3.90	3.82	4.0%
	86.00	7.42	1.80	0.81	3.01	1.80	5.40	4.37	4.6%
	89.00	7.44	1.75	0.53	3.00	1.75	5.25	2.78	2.9%
	92.00	7.32	1.95	1.02	3.00	1.95	5.85	5.97	6.2%
	95.00	7.42	1.85	1.29	3.00	1.85	5.55	7.16	7.5%
	98.00	7.46	1.80	0.55	3.00	1.80	5.40	2.97	3.1%
	101.00	7.24	1.40	0.64	3.01	1.40	4.20	2.69	2.8%
	104.00	6.45	0.55	1.13	3.10	0.55	1.65	1.86	1.9%
	107.00	6.44	0.60	0.58	3.00	0.60	1.80	1.04	1.1%
	110.00	6.12	0.40	0.23	3.02	0.40	1.20	0.28	0.3%
W	113.00	5.55	0.00	0.00	3.05		0.00	0.00	0.0%
	117.50	4.25			0.00		0.00	0.00	0.0%
1 G	119.00	3.62			0.00		0.00	0.00	0.0%
	122.50	2.26			0.00		0.00	0.00	0.0%
RS	124.60	1.88			0.00		0.00	0.00	0.0%
TOTALS ----------					95.87	1.95 (Max.)	88.73	96.01	100.0%

Manning's n = 0.1543
Hydraulic Radius= 0.92546773

STREAM NAME: Dolores River
XS LOCATION: Montrose-Mesa County Line
XS NUMBER: 4

WATER LINE COMPARISON TABLE

WATER LINE	MEAS AREA	COMP AREA	AREA ERROR
	88.73	90.98	2.5%
5.24	88.73	114.04	28.5%
5.26	88.73	112.09	26.3%
5.28	88.73	110.15	24.1%
5.30	88.73	108.21	22.0%
5.32	88.73	106.30	19.8%
5.34	88.73	104.41	17.7%
5.36	88.73	102.55	15.6%
5.38	88.73	100.72	13.5%
5.40	88.73	98.90	11.5%
5.42	88.73	97.09	9.4%
5.44	88.73	95.34	7.5%
5.45	88.73	94.46	6.5%
5.46	88.73	93.59	5.5%
5.47	88.73	92.72	4.5%
5.48	88.73	91.85	3.5%
5.49	88.73	90.98	2.5%
5.50	88.73	90.11	1.6%
5.51	88.73	89.25	0.6%
5.52	88.73	88.38	-0.4%
5.53	88.73	87.51	-1.4%
5.54	88.73	86.65	-2.3%
5.56	88.73	84.92	-4.3%
5.58	88.73	83.20	-6.2%
5.60	88.73	81.48	-8.2%
5.62	88.73	79.77	-10.1%
5.64	88.73	78.06	-12.0%
5.66	88.73	76.35	-13.9%
5.68	88.73	74.65	-15.9%
5.70	88.73	72.95	-17.8%
5.72	88.73	71.26	-19.7%
5.74	88.73	69.58	-21.6%

WATERLINE AT ZERO
AREA ERROR = 5.516

STREAM NAME: Dolores River
XS LOCATION: Montrose-Mesa County Line
XS NUMBER: 4

Constant Manning's n

GL = lowest Grassline elevation corrected for sag
STAGING TABLE *WL* = Waterline corrected for variations in field measured water surface elevations and sag

	DIST TO WATER (FT)	TOP WIDTH (FT)	AVG. DEPTH (FT)	MAX. DEPTH (FT)	AREA (SQ FT)	WETTED PERIM. (FT)	PERCENT WET PERIM (%)	HYDR RADIUS (FT)	FLOW (CFS)	AVG. VELOCITY (FT/SEC)
GL	3.68	109.36	2.54	3.78	277.23	110.81	100.0%	2.50	582.17	2.10
	4.52	104.32	1.80	2.94	187.82	105.50	95.2%	1.78	314.37	1.67
	4.57	103.98	1.76	2.89	182.62	105.15	94.9%	1.74	300.65	1.65
	4.62	103.70	1.71	2.84	177.42	104.84	94.6%	1.69	287.09	1.62
	4.67	103.46	1.66	2.79	172.25	104.58	94.4%	1.65	273.72	1.59
	4.72	103.23	1.62	2.74	167.08	104.32	94.1%	1.60	260.61	1.56
	4.77	102.99	1.57	2.69	161.92	104.06	93.9%	1.56	247.76	1.53
	4.82	102.75	1.53	2.64	156.78	103.80	93.7%	1.51	235.17	1.50
	4.87	102.51	1.48	2.59	151.65	103.53	93.4%	1.46	222.86	1.47
	4.92	102.28	1.43	2.54	146.53	103.27	93.2%	1.42	210.81	1.44
	4.97	102.04	1.39	2.49	141.42	103.01	93.0%	1.37	199.04	1.41
	5.02	101.37	1.34	2.44	136.33	102.33	92.4%	1.33	188.08	1.38
	5.07	100.54	1.31	2.39	131.28	101.49	91.6%	1.29	177.59	1.35
	5.12	99.71	1.27	2.34	126.28	100.65	90.8%	1.25	167.37	1.33
	5.17	98.88	1.23	2.29	121.31	99.81	90.1%	1.22	157.42	1.30
	5.22	98.05	1.19	2.24	116.39	98.97	89.3%	1.18	147.75	1.27
	5.27	97.22	1.15	2.19	111.51	98.13	88.6%	1.14	138.35	1.24
	5.32	95.42	1.12	2.14	106.67	96.32	86.9%	1.11	130.11	1.22
	5.37	91.84	1.11	2.09	102.00	92.73	83.7%	1.10	123.84	1.21
	5.42	89.56	1.09	2.04	97.45	90.45	81.6%	1.08	116.69	1.20
	5.47	87.09	1.07	1.99	93.07	87.97	79.4%	1.06	110.10	1.18
WL	5.52	86.65	1.02	1.94	88.72	87.51	79.0%	1.01	102.03	1.15
	5.57	86.17	0.98	1.89	84.40	87.03	78.5%	0.97	94.23	1.12
	5.62	85.64	0.94	1.84	80.11	86.48	78.0%	0.93	86.74	1.08
	5.67	85.10	0.89	1.79	75.84	85.94	77.6%	0.88	79.50	1.05
	5.72	84.40	0.85	1.74	71.60	85.22	76.9%	0.84	72.64	1.01
	5.77	83.33	0.81	1.69	67.41	84.13	75.9%	0.80	66.25	0.98
	5.82	82.26	0.77	1.64	63.27	83.04	74.9%	0.76	60.13	0.95
	5.87	80.37	0.74	1.59	59.19	81.14	73.2%	0.73	54.66	0.92
	5.92	77.33	0.71	1.54	55.25	78.07	70.5%	0.71	49.99	0.90
	5.97	74.14	0.69	1.49	51.46	74.84	67.5%	0.69	45.68	0.89
	6.02	71.91	0.66	1.44	47.81	72.58	65.5%	0.66	41.25	0.86
	6.07	70.06	0.63	1.39	44.27	70.70	63.8%	0.63	36.91	0.83
	6.12	67.00	0.61	1.34	40.84	67.62	61.0%	0.60	33.24	0.81
	6.17	64.02	0.59	1.29	37.56	64.61	58.3%	0.58	29.82	0.79
	6.22	60.91	0.57	1.24	34.44	61.47	55.5%	0.56	26.67	0.77
	6.27	57.94	0.54	1.19	31.47	58.47	52.8%	0.54	23.73	0.75
	6.32	54.71	0.52	1.14	28.65	55.19	49.8%	0.52	21.09	0.74
	6.37	51.45	0.51	1.09	26.00	51.89	46.8%	0.50	18.69	0.72
	6.42	48.19	0.49	1.04	23.51	48.58	43.8%	0.48	16.51	0.70
	6.47	42.58	0.50	0.99	21.23	42.94	38.7%	0.49	15.13	0.71
	6.52	39.46	0.49	0.94	19.18	39.78	35.9%	0.48	13.43	0.70
	6.57	36.03	0.48	0.89	17.29	36.32	32.8%	0.48	12.01	0.69
	6.62	32.20	0.48	0.84	15.58	32.46	29.3%	0.48	10.89	0.70
	6.67	27.82	0.51	0.79	14.08	28.05	25.3%	0.50	10.13	0.72
	6.72	23.67	0.54	0.74	12.80	23.86	21.5%	0.54	9.63	0.75
	6.77	22.23	0.52	0.69	11.66	22.40	20.2%	0.52	8.60	0.74
	6.82	21.42	0.49	0.64	10.57	21.57	19.5%	0.49	7.48	0.71
	6.87	20.62	0.46	0.59	9.52	20.74	18.7%	0.46	6.45	0.68
	6.92	19.95	0.43	0.54	8.51	20.05	18.1%	0.42	5.47	0.64
	6.97	19.58	0.38	0.49	7.52	19.67	17.7%	0.38	4.51	0.60
	7.02	19.22	0.34	0.44	6.55	19.29	17.4%	0.34	3.63	0.55
	7.07	18.85	0.30	0.39	5.60	18.91	17.1%	0.30	2.83	0.51
	7.12	18.49	0.25	0.34	4.66	18.53	16.7%	0.25	2.12	0.45
	7.17	17.82	0.21	0.29	3.75	17.86	16.1%	0.21	1.51	0.40
	7.22	17.13	0.17	0.24	2.88	17.16	15.5%	0.17	1.00	0.35
	7.27	16.19	0.13	0.19	2.04	16.21	14.6%	0.13	0.59	0.29

STREAM NAME: Dolores River
XS LOCATION: Montrose-Mesa County Line
XS NUMBER: 4

SUMMARY SHEET

MEASURED FLOW (Qm)=	96.01	cfs
CALCULATED FLOW (Qc)=	102.03	cfs
(Qm-Qc)/Qm * 100 =	-6.3	%
MEASURED WATERLINE (WLm)=	5.49	ft
CALCULATED WATERLINE (WLc)=	5.52	ft
(WLm-WLc)/WLm * 100 =	-0.5	%
MAX MEASURED DEPTH (Dm)=	1.95	ft
MAX CALCULATED DEPTH (Dc)=	1.94	ft
(Dm-Dc)/Dm * 100	0.3	%
MEAN VELOCITY=	1.15	ft/sec
MANNING'S N=	0.154	
SLOPE=	0.014	ft/ft
.4 * Qm =	38.4	cfs
2.5 * Qm=	240.0	cfs

RECOMMENDED INSTREAM FLOW:
==========

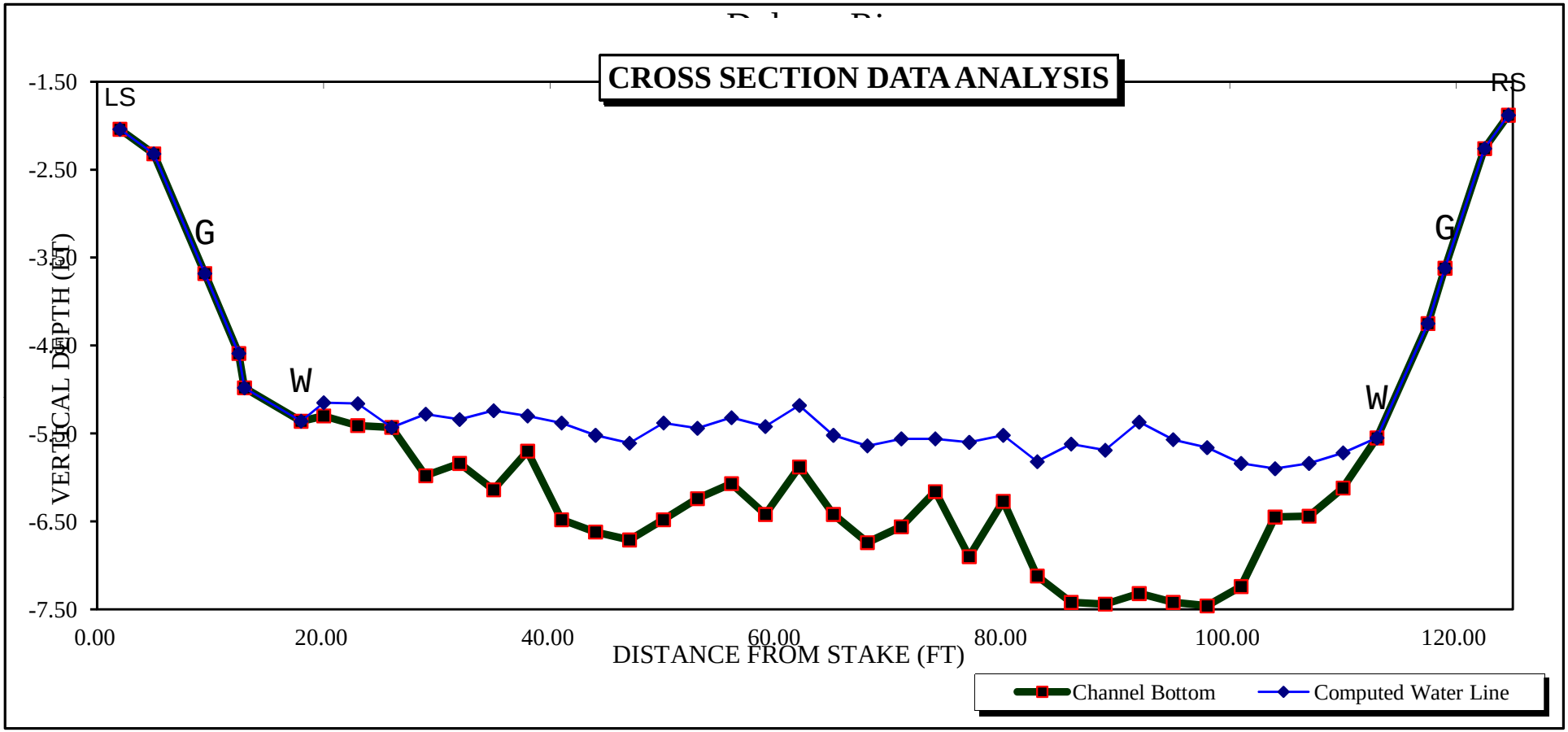
FLOW (CFS)	PERIOD
==========	========
_____	_____
_____	_____
_____	_____
_____	_____

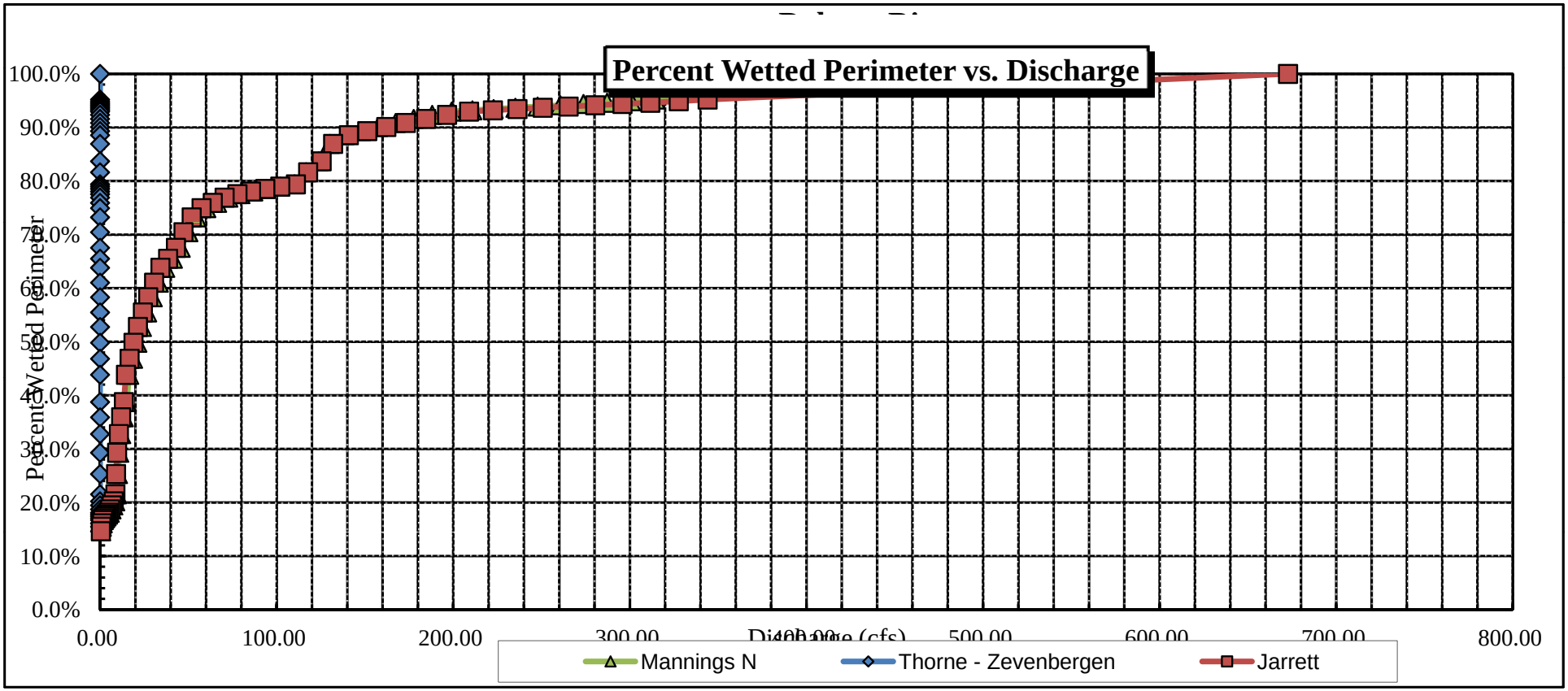
RATIONALE FOR RECOMMENDATION:
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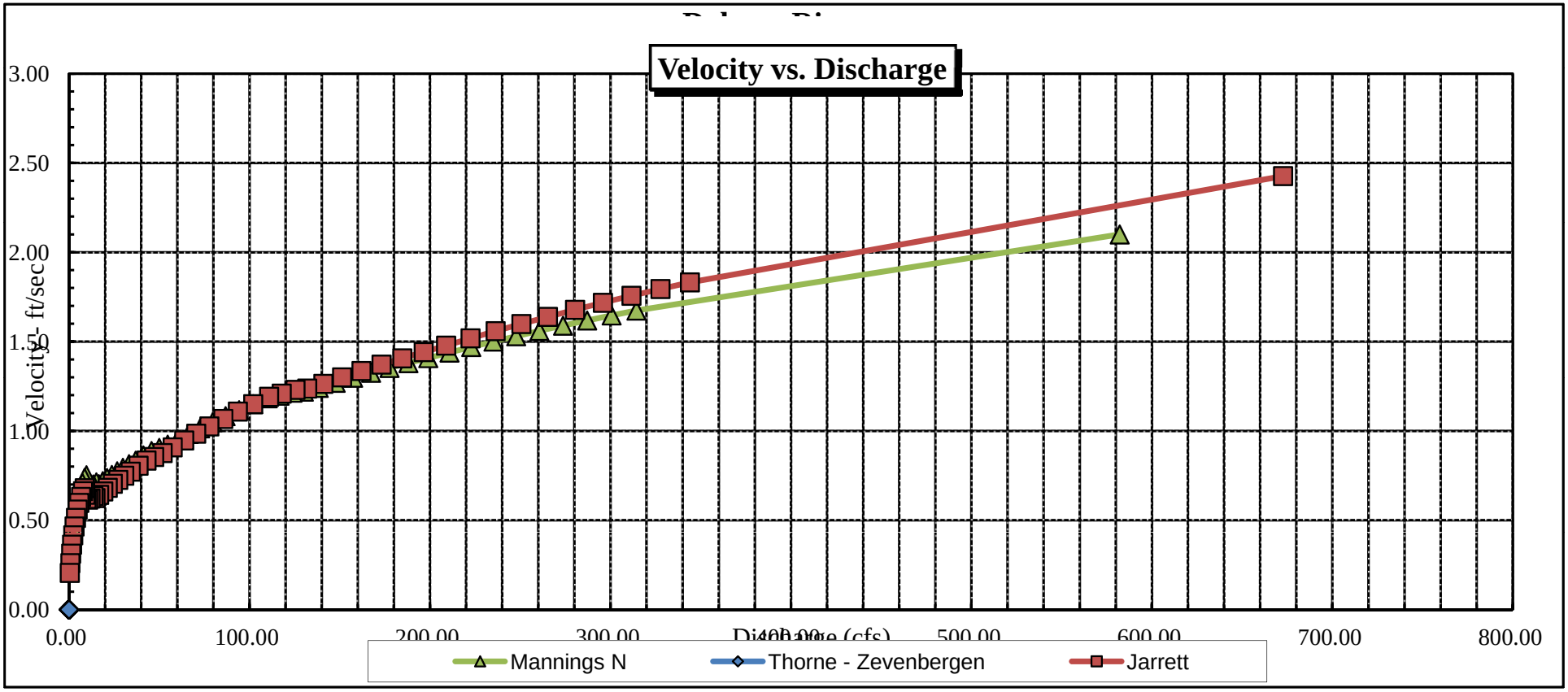
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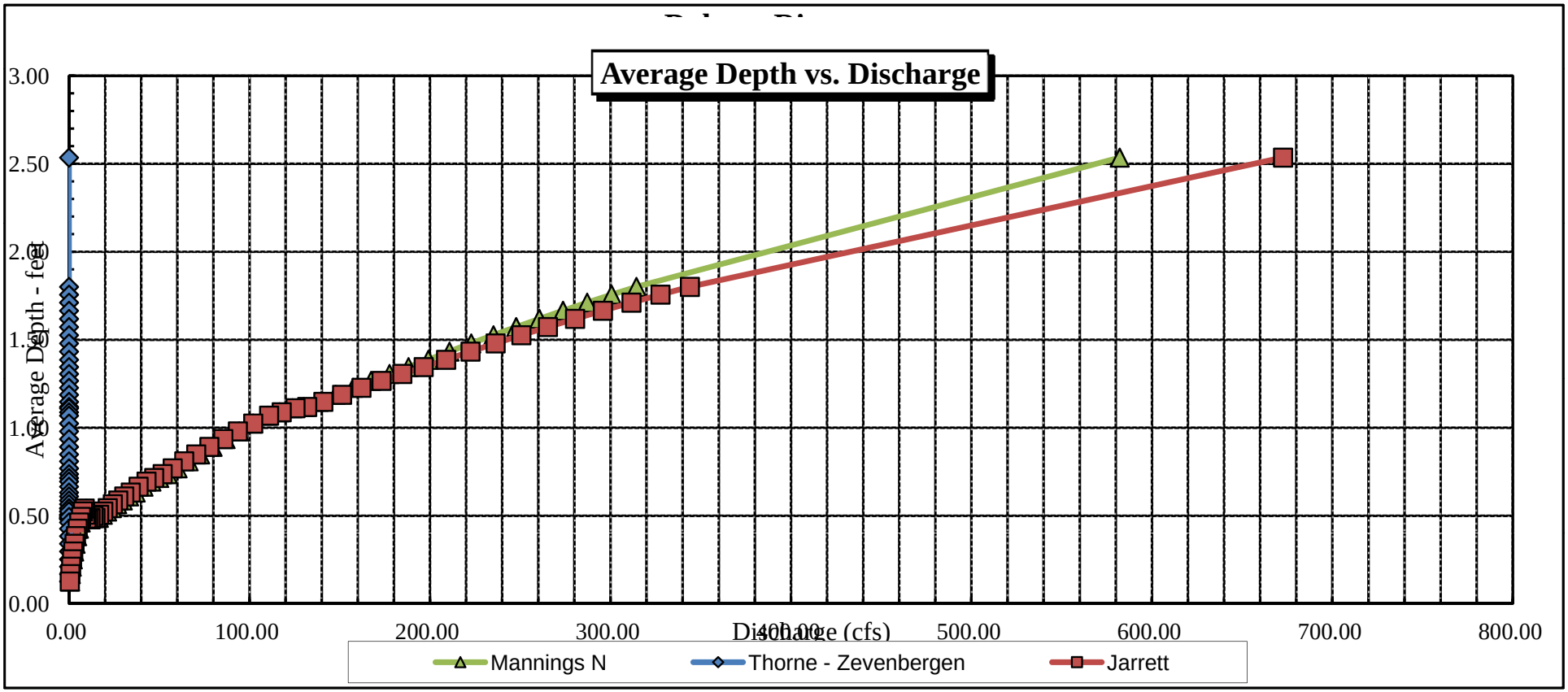
RECOMMENDATION BY: ..... AGENCY..... DATE:.....

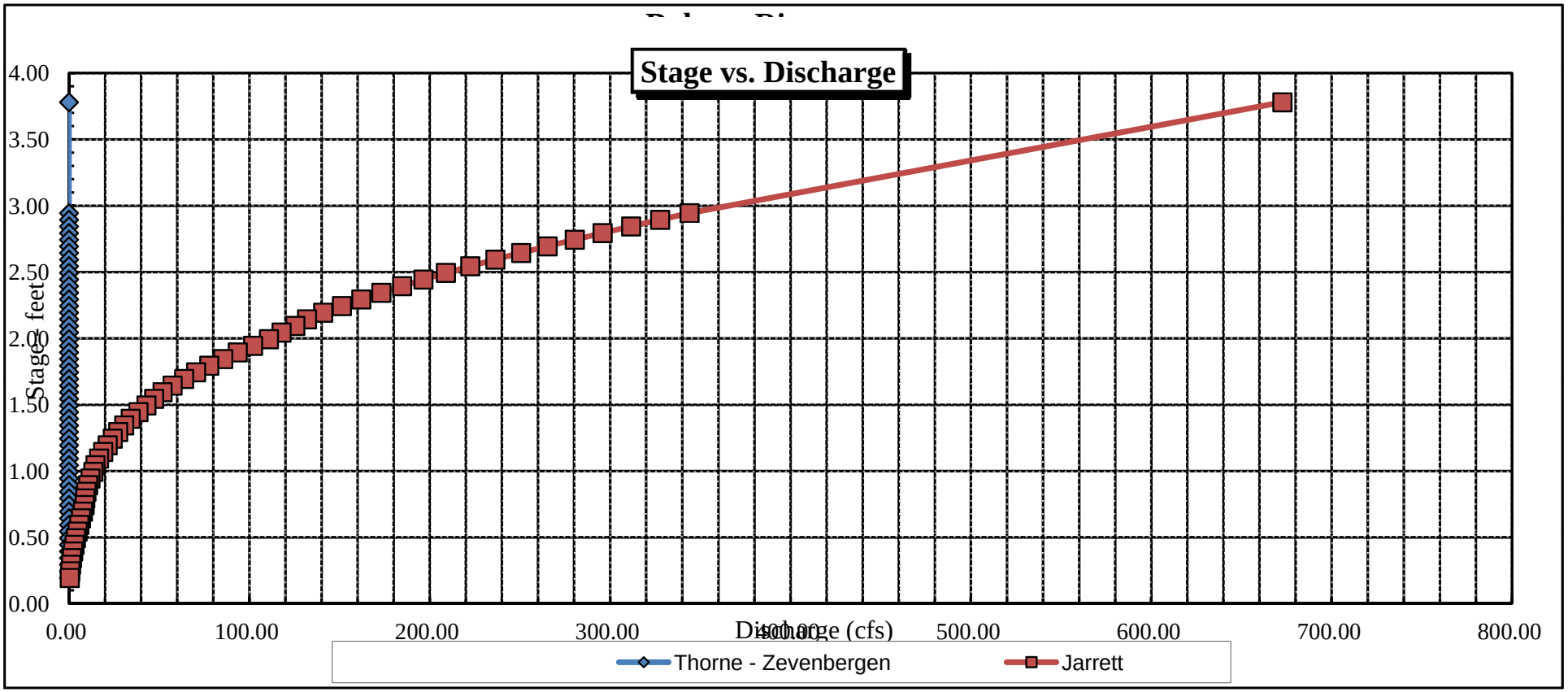
CWCB REVIEW BY: ..... DATE:.....


CROSS SECTION DATA ANALYSIS
LS
RS
G
W
W
G
-1.50
-2.50
-3.50
-4.50
-5.50
-6.50
-7.50
VERTICAL DEPTH (FT)
0.00
20.00
40.00
60.00
80.00
100.00
120.00
DISTANCE FROM STAKE (FT)
Channel Bottom
Computed Water Line


Percent Wetted Perimeter vs. Discharge
Percent Wetted Perimeter
100.0%
90.0%
80.0%
70.0%
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
0.00
100.00
200.00
300.00
500.00
600.00
700.00
800.00
Mannings N
Thorne - Zevenbergen
Jarrett


Velocity vs. Discharge
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0.00
100.00
200.00
300.00
500.00
600.00
700.00
800.00
Mannings N
Thorne - Zevenbergen
Jarrett


Average Depth vs. Discharge
Average Depth - feet
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0.00
100.00
200.00
300.00
400.00
500.00
600.00
700.00
800.00
Discharge (cfs)
Mannings N
Thorne - Zevenbergen
Jarrett


Stage vs. Discharge
Stage - feet
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0.00
100.00
200.00
300.00
400.00
500.00
600.00
700.00
800.00
Discharge (cfs)
Thorne - Zevenbergen
Jarrett

COLORADO WATER CONSERVATION BOARD

FIELD DATA FOR INSTREAM FLOW DETERMINATIONS

COLORADO DIVISION OF WILDLIFE

LOCATION INFORMATION

STREAM NAME: Dolores River					CROSS-SECTION NO.: 1
CROSS-SECTION LOCATION: PHABSIM Reach - Cross Section 1 UTM = 4272581 m N 680671 m E					
DATE: 8-11-2011	OBSERVERS: K. Smith, B. Graf, M. Uppendahl				
LEGAL DESCRIPTION	¼ SECTION:	SECTION:	TOWNSHIP: N/S	RANGE: E/W	PM:
COUNTY: Mesa	WATERSHED: Dolores	WATER DIVISION: 4	DOW WATER CODE: 39760		
MAP(S): USGS:					
USFS:					

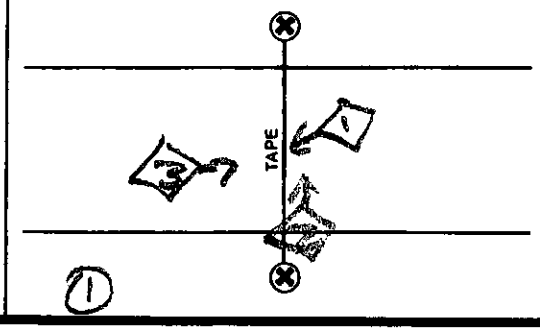
SUPPLEMENTAL DATA

SAG TAPE SECTION SAME AS DISCHARGE SECTION: (YES) / NO	METER TYPE: M-M			
METER NUMBER:	DATE RATED:	CALIB/SPIN: _____ sec	TAPE WEIGHT: surveyed _____ lbs/foot	TAPE TENSION: surveyed _____ lbs
CHANNEL BED MATERIAL SIZE RANGE: 4" cobbles to 2-foot boulders	PHOTOGRAPHS TAKEN: (YES) / NO	NUMBER OF PHOTOGRAPHS: 3		

CHANNEL PROFILE DATA

STATION	DISTANCE FROM TAPE (ft)	ROD READING (ft)
⊗ Tape @ Stake LB	0.0	Surveyed
⊗ Tape @ Stake RB	0.0	
① WS @ Tape LB/RB	0.0	
② WS Upstream	see cross section documentation + PHABSIM notes	
③ WS Downstream		
SLOPE	0.05 ft	

SKETCH



LEGEND:
Stake ⊗
Station ①
Photo ◇→
Direction of Flow

AQUATIC SAMPLING SUMMARY

STREAM ELECTROFISHED: YES/NO	DISTANCE ELECTROFISHED: _____ ft	FISH CAUGHT: YES/NO	WATER CHEMISTRY SAMPLED: YES/NO

LENGTH - FREQUENCY DISTRIBUTION BY ONE-INCH SIZE GROUPS (1.0-1.9, 2.0-2.9, ETC.)

SPECIES (FILL IN)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	>15	TOTAL

AQUATIC INSECTS IN STREAM SECTION BY COMMON OR SCIENTIFIC ORDER NAME:

COMMENTS

This data was also used for PHABSIM Cross Section #1.

u/s RIFFLE

DISCHARGE/CROSS SECTION NOTES

STREAM NAME: Dolores River	CROSS-SECTION NO.: #1	DATE: 11/8/11	SHEET ___ OF ___
BEGINNING OF MEASUREMENT	EDGE OF WATER LOOKING DOWNSTREAM: (0.0 AT STAKE) (LEFT / RIGHT)	Gage Reading: _____ ft	TIME:

Features: Stake (S) Grassline (G) Waterline (W) Rock (R)	Distance From Initial Point (ft)	Width (ft)	Total Vertical Depth From Tape/Inst (ft)	Water Depth (ft)	Depth of Observation (ft)	Revolutions	Time (sec)	Velocity (ft/sec) At Point	Velocity (ft/sec) Mean in Vertical	Area (ft^2)	Discharge (cfs)
TP	0.3		3.84								
BP	0.3		4.25								
	4.0		4.62								
	8.0		5.30								
	11.0		6.44								
	13.0		8.13								
	15.0		10.55								
SWL	18.5		10.85	0							
	23.0		10.85	0							
	29.0		10.85	0				0			
	32.0		11.25	.45				0.47			
	38.0		11.85	1.10				0.81			
	44.5		11.75	.90				0.52			
	50.5		11.65	.80				1.46			
	55.0		11.8	.90				0.70			
	61.0		12.0	1.20				2.00			
	64.0		11.95	.90				1.07			
	68.0		11.75	.60				.08			
	75.5		11.55	.70				.45			
	81.5		11.70	.90				.83			
	85.5		11.50	.75				1.27			
	88.5		11.55	.60				2.83			
	91.5		11.85	1.00				0.30			
	95.0		11.85	1.00				1.50			
	101.0		11.80	.80				2.28			
	104.0		11.90	.80				1.91			
	108.		11.90	1.00				2.27			
	111.		11.90	.80				2.98			
	113.5		11.95	.90				3.47			
	116		11.80	.80				1.26			
	119		11.95	1.00				1.30			
	122		12.05	1.00				2.62			
	124		12.45	1.50				2.23			
	126.5		12.80	1.90				3.28			
	128.5		12.95	1.80				2.89			
	129.5		13.20	2.25				2.53			
	131.7		13.25	2.30				2.94			
	134		13.20	2.20				3.66			
	136		12.90	2.10				1.98			
	138		12.75	1.75				3.73			
	140		12.05	1.40				3.31			
	142		12.00	0.90				3.76			
TOTALS:											

End of Measurement	Time:	Gage Reading: _____ ft	CALCULATIONS PERFORMED BY:	CALCULATIONS CHECKED BY:

U/S Riffle

DISCHARGE/CROSS SECTION NOTES

STREAM NAME: Dolores River	CROSS-SECTION NO.: #1	DATE: 11/8/11	SHEET 2 OF 2
BEGINNING OF MEASUREMENT	EDGE OF WATER LOOKING DOWNSTREAM: (0.0 AT STAKE) (LEFT) RIGHT	Gage Reading: _____ ft	TIME:

Features: Stake (S), Grassline (G), Waterline (W), Rock (R)	Distance From Initial Point (ft)	Width (ft)	Total Vertical Depth From Tape/Inst (ft)	Water Depth (ft)	Depth of Observation (ft)	Revolutions	Time (sec)	Velocity (ft/sec) At Point	Velocity (ft/sec) Mean in Vertical	Area (ft^2)	Discharge (cfs)
	144.5		12.10	1.05				2.93			
	148.0		11.90	.70				.68			
	150		11.60	.55				.50			
SWL @	150		11.03	0				0			
	151.5		11.50	.30				.56			
SWL	151.6		11.03	0				0			
Bkset↑	153		10.45								
	155.5		8.71								
	157.		7.45								
	158		5.45								
	159		4.85								
BPin	160.9		4.56								
Top Pin	160.9		4.13								
TOTALS:											

End of Measurement	Time:	Gage Reading: _____ ft	CALCULATIONS PERFORMED BY:	CALCULATIONS CHECKED BY:

COLORADO WATER CONSERVATION BOARD
INSTREAM FLOW / NATURAL LAKE LEVEL PROGRAM
STREAM CROSS-SECTION AND FLOW ANALYSIS

LOCATION INFORMATION

STREAM NAME:	DOLORES RIVER - XS#1 - 11/08/11
XS LOCATION:	UPSTREAM RIFFLE
XS NUMBER:	01_110811
DATE:	11-Aug-11
OBSERVERS:	CPW & BLM
1/4 SEC:	0
SECTION:	0
TWP:	0
RANGE:	0
PM:	0
COUNTY:	MESA
WATERSHED:	DOLORES RIVER
DIVISION:	0
DOW CODE:	0
USGS MAP:	0
USFS MAP:	0

SUPPLEMENTAL DATA

TAPE WT:	0.0106
TENSION:	99999

*** NOTE ***
Leave TAPE WT and TENSION at defaults for data collected with a survey level and rod

CHANNEL PROFILE DATA

SLOPE:	0.05

INPUT DATA CHECKED BY: .....DATE.....

ASSIGNED TO: ….....……..…….....DATE.....

STREAM NAME: DOLORES RIVER - XS#1 - 11/08/11
XS LOCATION: UPSTREAM RIFFLE
XS NUMBER: 01_110811

DATA POINTS= 54

VALUES COMPUTED FROM RAW FIELD DATA

	FEATURE	DIST	VERT DEPTH	WATER DEPTH	VEL	WETTED PERIM.	WATER DEPTH	AREA (Am)	Q (Qm)	% Q CELL
	TOP PIN	0.30	3.84			0.00		0.00	0.00	0.0%
1	BASE PIN	0.31	4.25			0.00		0.00	0.00	0.0%
		4.00	4.62			0.00		0.00	0.00	0.0%
		8.00	5.30			0.00		0.00	0.00	0.0%
		11.00	6.44			0.00		0.00	0.00	0.0%
		13.00	8.13			0.00		0.00	0.00	0.0%
		15.00	10.55			0.00		0.00	0.00	0.0%
	SWL	18.50	10.85	0.00	0.00	0.00		0.00	0.00	0.0%
		23.00	10.85	0.00	0.00	0.00		0.00	0.00	0.0%
		29.00	10.85	0.00	0.00	0.00		0.00	0.00	0.0%
		32.00	11.25	0.45	0.47	3.03	0.45	2.03	0.95	0.4%
		38.00	11.85	1.10	0.81	6.03	1.10	6.88	5.57	2.5%
		44.50	11.75	0.90	0.52	6.50	0.90	5.63	2.93	1.3%
		50.50	11.65	0.80	1.46	6.00	0.80	4.20	6.13	2.7%
		55.00	11.80	0.90	0.70	4.50	0.90	4.73	3.31	1.5%
		61.00	12.00	1.20	2.00	6.00	1.20	5.40	10.80	4.8%
		64.00	11.95	0.90	1.07	3.00	0.90	3.15	3.37	1.5%
		68.00	11.75	0.60	0.08	4.00	0.60	3.45	0.28	0.1%
		75.50	11.55	0.70	0.45	7.50	0.70	4.73	2.13	0.9%
		81.50	11.70	0.90	0.83	6.00	0.90	4.50	3.74	1.7%
		85.50	11.50	0.75	1.27	4.00	0.75	2.63	3.33	1.5%
		88.50	11.55	0.60	2.83	3.00	0.60	1.80	5.09	2.3%
		91.50	11.85	1.00	0.30	3.01	1.00	3.25	0.98	0.4%
		95.00	11.85	1.00	1.50	3.50	1.00	4.75	7.13	3.2%
		101.00	11.80	0.80	2.28	6.00	0.80	3.60	8.21	3.6%
		104.00	11.90	0.80	1.91	3.00	0.80	2.80	5.35	2.4%
		108.00	11.90	1.00	2.27	4.00	1.00	3.50	7.95	3.5%
		111.00	11.90	0.80	2.98	3.00	0.80	2.20	6.56	2.9%
		113.50	11.95	0.90	3.47	2.50	0.90	2.25	7.81	3.5%
		116.00	11.80	0.80	1.26	2.50	0.80	2.20	2.77	1.2%
		119.00	11.95	1.00	1.30	3.00	1.00	3.00	3.90	1.7%
		122.00	12.05	1.00	2.62	3.00	1.00	2.50	6.55	2.9%
		124.00	12.45	1.50	2.23	2.04	1.50	3.38	7.53	3.3%
		126.50	12.80	1.90	3.28	2.52	1.90	4.28	14.02	6.2%
		128.50	12.95	1.80	2.89	2.01	1.80	2.70	7.80	3.5%
		129.50	13.20	2.25	2.53	1.03	2.25	3.60	9.11	4.0%
		131.70	13.25	2.30	2.94	2.20	2.30	5.18	15.21	6.8%
		134.00	13.20	2.20	3.66	2.30	2.20	4.73	17.31	7.7%
		136.00	12.90	2.10	1.98	2.02	2.10	4.20	8.32	3.7%
		138.00	12.75	1.75	3.73	2.01	1.75	3.50	13.06	5.8%
		140.00	12.05	1.40	3.30	2.12	1.40	2.80	9.24	4.1%
		142.00	12.00	0.90	3.76	2.00	0.90	2.03	7.61	3.4%
		144.50	12.10	1.05	2.93	2.50	1.05	3.15	9.23	4.1%
		148.00	11.90	0.70	0.68	3.51	0.70	1.93	1.31	0.6%
		150.00	11.60	0.55	0.50	2.02	0.55	0.96	0.48	0.2%
		151.50	11.50	0.30	0.56	1.50	0.30	0.24	0.13	0.1%
	SWL	151.60	11.03	0.00	0.00	0.48		0.00	0.00	0.0%
		153.00	10.45			0.00		0.00	0.00	0.0%
		155.50	8.71			0.00		0.00	0.00	0.0%
		157.00	7.45			0.00		0.00	0.00	0.0%
		158.00	5.45			0.00		0.00	0.00	0.0%
		159.00	4.85			0.00		0.00	0.00	0.0%
1	BASE PIN	160.90	4.56			0.00		0.00	0.00	0.0%
	TOP PIN	160.91	4.13			0.00		0.00	0.00	0.0%
	TOTALS ----------					123.37	2.3 (Max.)	121.81	225.17	100.0%

Manning's n = 0.1782
Hydraulic Radius= 0.987338605

STREAM NAME: DOLORES RIVER - XS#1 - 11/08/11
XS LOCATION: UPSTREAM RIFFLE
XS NUMBER: 01_110811

WATER LINE COMPARISON TABLE

WATER LINE	MEAS AREA	COMP AREA	AREA ERROR
	121.81	120.33	-1.2%
10.69	121.81	152.91	25.5%
10.71	121.81	150.19	23.3%
10.73	121.81	147.49	21.1%
10.75	121.81	144.78	18.9%
10.77	121.81	142.09	16.6%
10.79	121.81	139.40	14.4%
10.81	121.81	136.71	12.2%
10.83	121.81	134.03	10.0%
10.85	121.81	131.36	7.8%
10.87	121.81	128.90	5.8%
10.89	121.81	126.45	3.8%
10.90	121.81	125.22	2.8%
10.91	121.81	124.00	1.8%
10.92	121.81	122.77	0.8%
10.93	121.81	121.55	-0.2%
10.94	121.81	120.33	-1.2%
10.95	121.81	119.11	-2.2%
10.96	121.81	117.89	-3.2%
10.97	121.81	116.67	-4.2%
10.98	121.81	115.45	-5.2%
10.99	121.81	114.23	-6.2%
11.01	121.81	111.80	-8.2%
11.03	121.81	109.37	-10.2%
11.05	121.81	106.95	-12.2%
11.07	121.81	104.53	-14.2%
11.09	121.81	102.11	-16.2%
11.11	121.81	99.70	-18.2%
11.13	121.81	97.29	-20.1%
11.15	121.81	94.88	-22.1%
11.17	121.81	92.47	-24.1%
11.19	121.81	90.07	-26.1%

WATERLINE AT ZERO
AREA ERROR = 10.928

STREAM NAME: DOLORES RIVER - XS#1 - 11/08/11
XS LOCATION: UPSTREAM RIFFLE
XS NUMBER: 01_110811 Constant Manning's n

GL = lowest Grassline elevation corrected for sag
STAGING TABLE *WL* = Waterline corrected for variations in field measured water surface elevations and sag

	DIST TO WATER (FT)	TOP WIDTH (FT)	AVG. DEPTH (FT)	MAX. DEPTH (FT)	AREA (SQ FT)	WETTED PERIM. (FT)	PERCENT WET PERIM (%)	HYDR RADIUS (FT)	FLOW (CFS)	AVG. VELOCITY (FT/SEC)
GL	4.56	157.50	6.60	8.69	1039.82	162.85	100.0%	6.39	6672.56	6.42
	9.93	139.26	1.85	3.32	258.25	140.62	86.3%	1.84	722.06	2.80
	9.98	139.15	1.81	3.27	251.29	140.47	86.3%	1.79	690.42	2.75
	10.03	139.04	1.76	3.22	244.33	140.31	86.2%	1.74	659.34	2.70
	10.08	138.92	1.71	3.17	237.39	140.16	86.1%	1.69	628.84	2.65
	10.13	138.81	1.66	3.12	230.44	140.01	86.0%	1.65	598.92	2.60
	10.18	138.70	1.61	3.07	223.50	139.86	85.9%	1.60	569.58	2.55
	10.23	138.59	1.56	3.02	216.57	139.70	85.8%	1.55	540.84	2.50
	10.28	138.47	1.51	2.97	209.65	139.55	85.7%	1.50	512.69	2.45
	10.33	138.36	1.47	2.92	202.73	139.40	85.6%	1.45	485.15	2.39
	10.38	138.25	1.42	2.87	195.81	139.25	85.5%	1.41	458.21	2.34
	10.43	138.13	1.37	2.82	188.90	139.09	85.4%	1.36	431.90	2.29
	10.48	137.99	1.32	2.77	182.00	138.92	85.3%	1.31	406.26	2.23
	10.53	137.83	1.27	2.72	175.10	138.72	85.2%	1.26	381.29	2.18
	10.58	137.37	1.22	2.67	168.22	138.24	84.9%	1.22	357.47	2.13
	10.63	136.66	1.18	2.62	161.37	137.52	84.4%	1.17	334.69	2.07
	10.68	135.96	1.14	2.57	154.55	136.80	84.0%	1.13	312.55	2.02
	10.73	135.25	1.09	2.52	147.77	136.09	83.6%	1.09	291.05	1.97
	10.78	134.55	1.05	2.47	141.03	135.37	83.1%	1.04	270.20	1.92
	10.83	133.85	1.00	2.42	134.32	134.66	82.7%	1.00	249.99	1.86
	10.88	122.76	1.04	2.37	127.93	123.56	75.9%	1.04	244.11	1.91
WL	10.93	122.26	1.00	2.32	121.81	123.05	75.6%	0.99	225.56	1.85
	10.98	121.77	0.95	2.27	115.71	122.54	75.2%	0.94	207.62	1.79
	11.03	121.27	0.90	2.22	109.63	122.03	74.9%	0.90	190.30	1.74
	11.08	120.88	0.86	2.17	103.58	121.60	74.7%	0.85	173.52	1.68
	11.13	120.50	0.81	2.12	97.54	121.17	74.4%	0.81	157.37	1.61
	11.18	120.11	0.76	2.07	91.53	120.74	74.1%	0.76	141.87	1.55
	11.23	119.72	0.71	2.02	85.53	120.31	73.9%	0.71	127.02	1.49
	11.28	119.27	0.67	1.97	79.56	119.81	73.6%	0.66	112.89	1.42
	11.33	118.76	0.62	1.92	73.61	119.26	73.2%	0.62	99.48	1.35
	11.38	118.25	0.57	1.87	67.68	118.70	72.9%	0.57	86.76	1.28
	11.43	117.74	0.52	1.82	61.78	118.15	72.5%	0.52	74.76	1.21
	11.48	117.23	0.48	1.77	55.91	117.60	72.2%	0.48	63.49	1.14
	11.53	114.09	0.44	1.72	50.09	114.44	70.3%	0.44	53.84	1.07
	11.58	108.08	0.41	1.67	44.53	108.42	66.6%	0.41	45.87	1.03
	11.63	101.69	0.39	1.62	39.29	102.01	62.6%	0.39	38.77	0.99
	11.68	92.98	0.37	1.57	34.40	93.30	57.3%	0.37	32.97	0.96
	11.73	83.93	0.36	1.52	29.99	84.24	51.7%	0.36	28.09	0.94
	11.78	76.57	0.34	1.47	25.98	76.86	47.2%	0.34	23.51	0.90
	11.83	64.31	0.35	1.42	22.40	64.60	39.7%	0.35	20.62	0.92
	11.88	50.08	0.39	1.37	19.62	50.35	30.9%	0.39	19.51	0.99
	11.93	36.06	0.48	1.32	17.47	36.32	22.3%	0.48	20.00	1.14
	11.98	28.81	0.55	1.27	15.86	29.07	17.8%	0.55	19.73	1.24
	12.03	22.62	0.64	1.22	14.58	22.87	14.0%	0.64	20.13	1.38
	12.08	18.72	0.72	1.17	13.56	18.96	11.6%	0.72	20.22	1.49
	12.13	17.39	0.73	1.12	12.67	17.62	10.8%	0.72	18.97	1.50
	12.18	17.00	0.70	1.07	11.81	17.21	10.6%	0.69	17.14	1.45
	12.23	16.60	0.66	1.02	10.97	16.80	10.3%	0.65	15.40	1.40
	12.28	16.21	0.63	0.97	10.15	16.40	10.1%	0.62	13.75	1.35
	12.33	15.82	0.59	0.92	9.35	15.99	9.8%	0.58	12.19	1.30
	12.38	15.42	0.56	0.87	8.57	15.58	9.6%	0.55	10.73	1.25
	12.43	15.03	0.52	0.82	7.81	15.18	9.3%	0.51	9.35	1.20
	12.48	14.58	0.48	0.77	7.07	14.71	9.0%	0.48	8.08	1.14
	12.53	14.08	0.45	0.72	6.35	14.20	8.7%	0.45	6.93	1.09
	12.58	13.58	0.42	0.67	5.66	13.69	8.4%	0.41	5.86	1.03
	12.63	13.08	0.38	0.62	4.99	13.18	8.1%	0.38	4.88	0.98
	12.68	12.58	0.35	0.57	4.35	12.67	7.8%	0.34	3.98	0.91

STREAM NAME: DOLORES RIVER - XS#1 - 11/08/11
XS LOCATION: UPSTREAM RIFFLE
XS NUMBER: 01_110811

SUMMARY SHEET

MEASURED FLOW (Qm)=	225.17	cfs
CALCULATED FLOW (Qc)=	225.56	cfs
(Qm-Qc)/Qm * 100 =	-0.2	%
MEASURED WATERLINE (WLm)=	10.94	ft
CALCULATED WATERLINE (WLc)=	10.93	ft
(WLm-WLc)/WLm * 100 =	0.1	%
MAX MEASURED DEPTH (Dm)=	2.30	ft
MAX CALCULATED DEPTH (Dc)=	2.32	ft
(Dm-Dc)/Dm * 100	-1.0	%
MEAN VELOCITY=	1.85	ft/sec
MANNING'S N=	0.178	
SLOPE=	0.05	ft/ft
.4 * Qm =	90.1	cfs
2.5 * Qm=	562.9	cfs

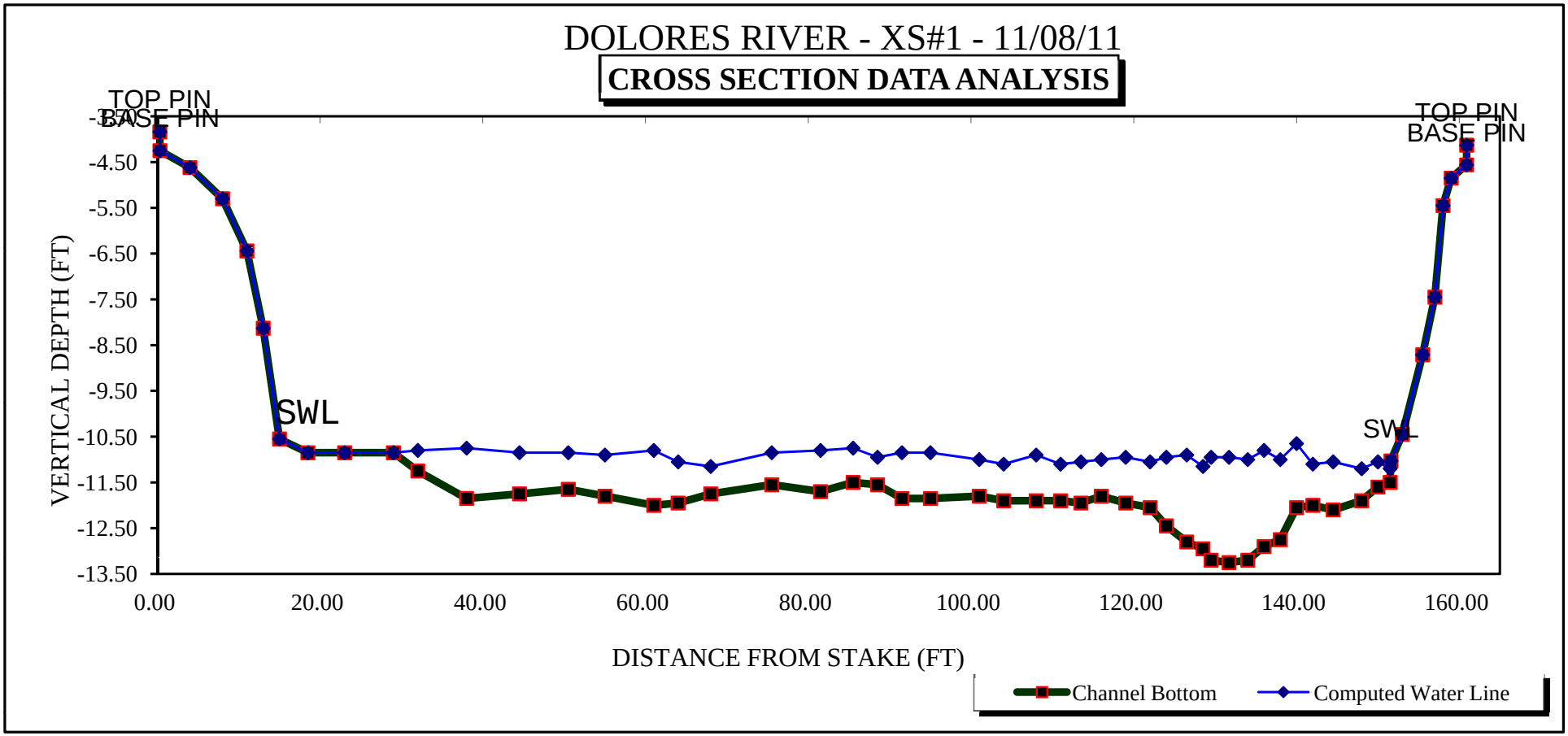
RECOMMENDED INSTREAM FLOW:
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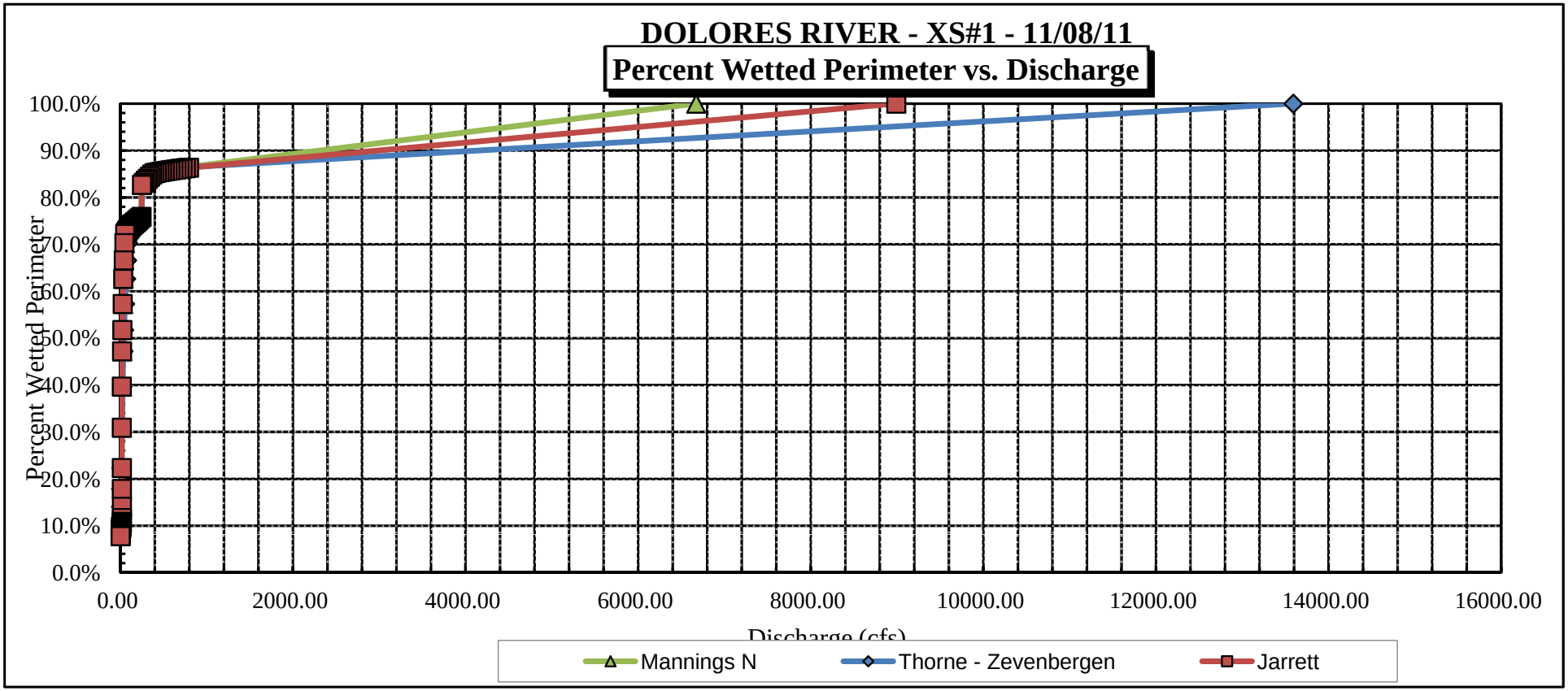
FLOW (CFS)	PERIOD
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_____	_____
_____	_____
_____	_____
_____	_____

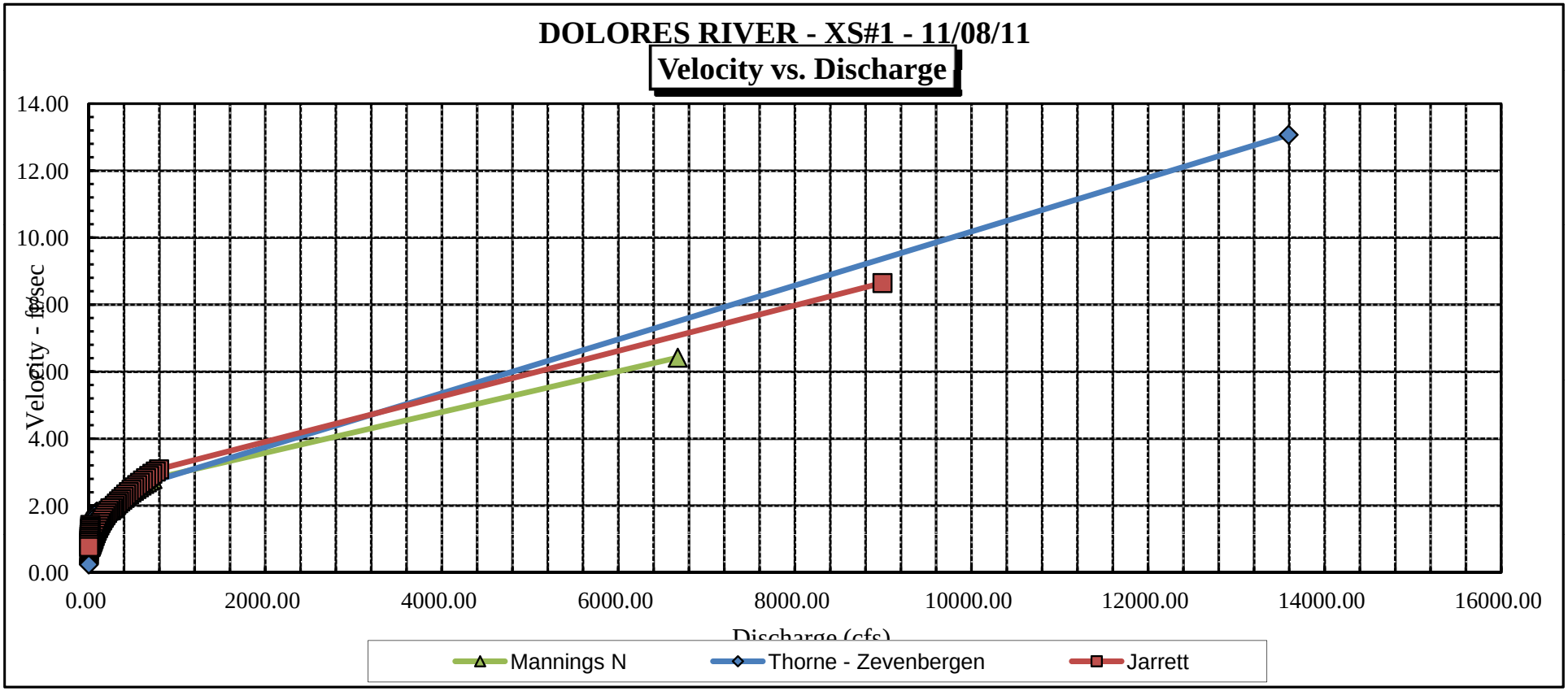
RATIONALE FOR RECOMMENDATION:
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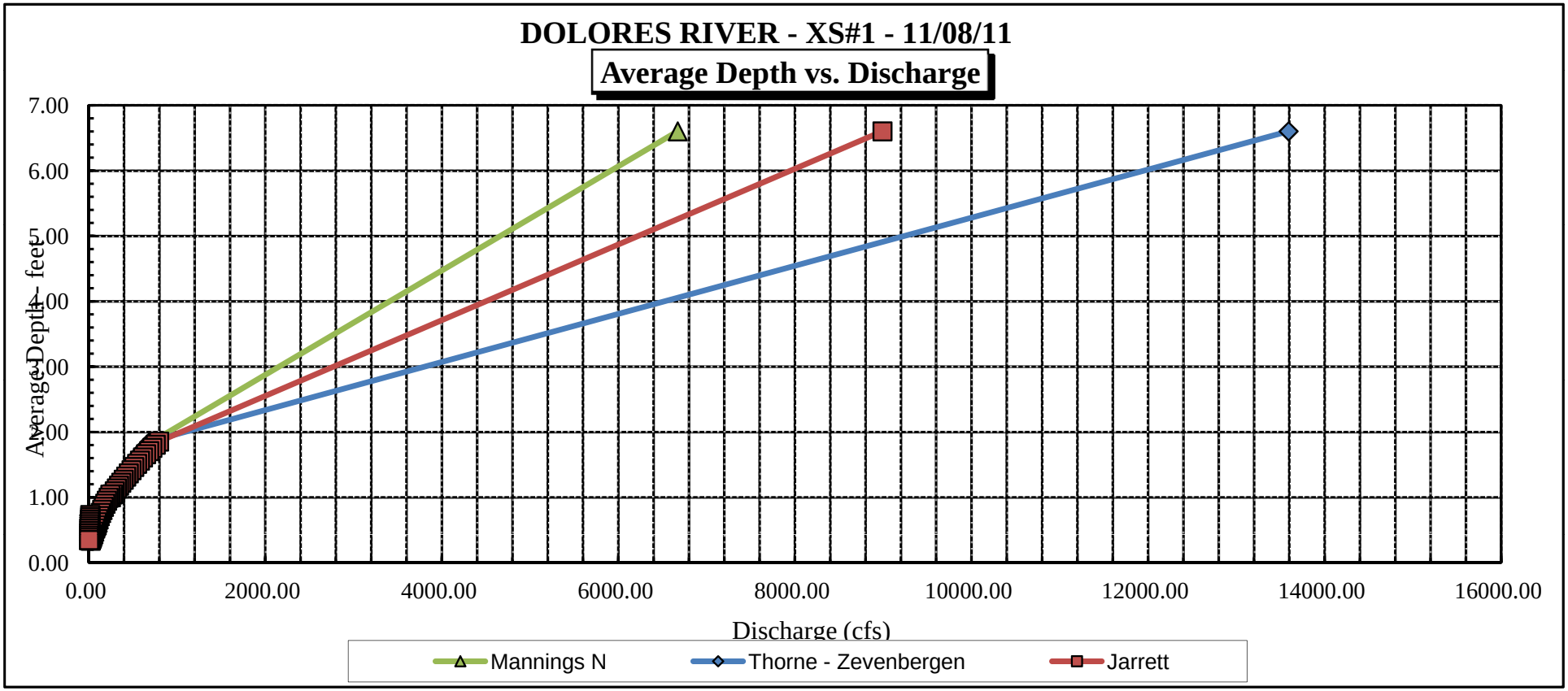
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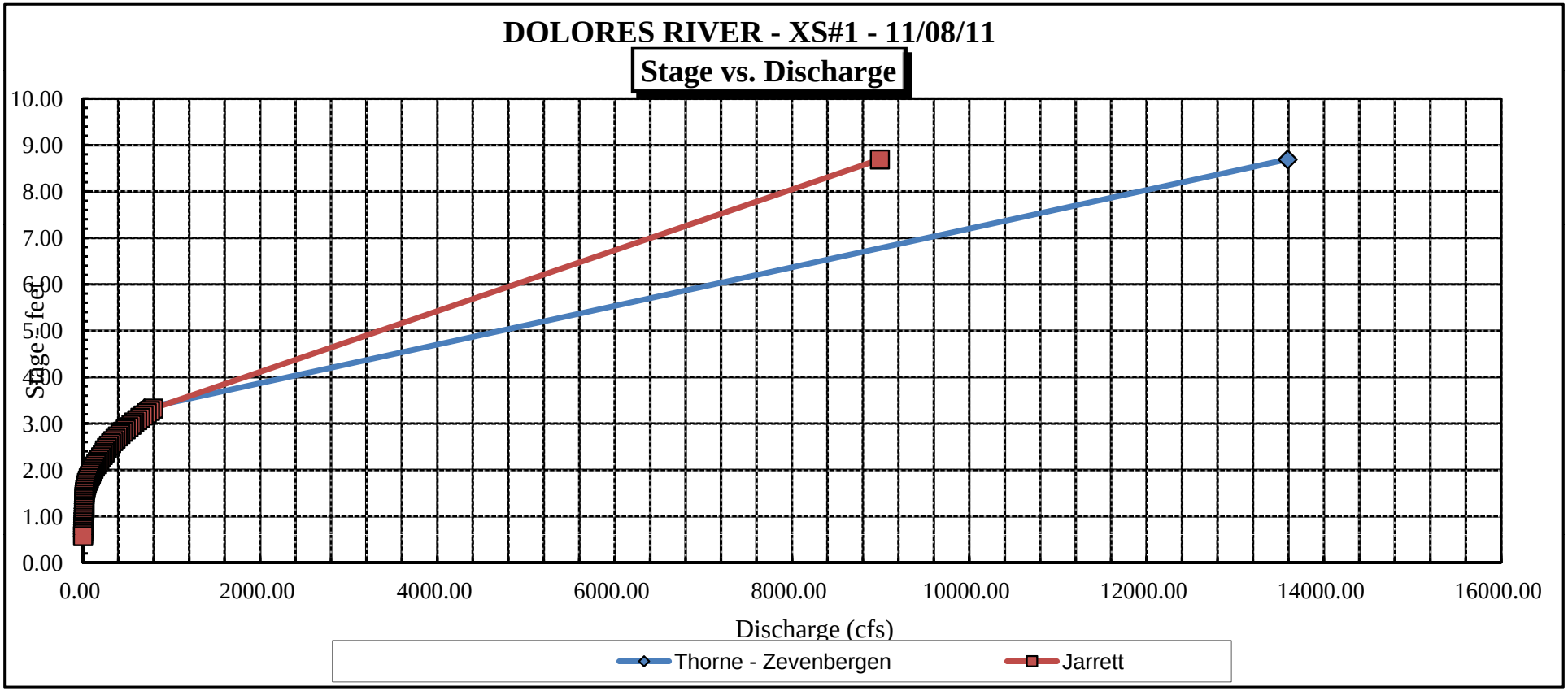
RECOMMENDATION BY: …….....…….....…….....…


DOLORES RIVER - XS#1 - 11/08/11
CROSS SECTION DATA ANALYSIS
TOP PIN
BASE PIN
SWL
TOP PIN
BASE PIN
SWL
-4.50
-5.50
-6.50
-7.50
-8.50
-9.50
-10.50
-11.50
-12.50
-13.50
VERTICAL DEPTH (FT)
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
DISTANCE FROM STAKE (FT)
Channel Bottom
Computed Water Line


DOLORES RIVER - XS#1 - 11/08/11
Percent Wetted Perimeter vs. Discharge
Percent Wetted Perimeter
100.0%
90.0%
80.0%
70.0%
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
0.00
2000.00
4000.00
6000.00
8000.00
10000.00
12000.00
14000.00
16000.00
Discharge (cfs)
Mannings N
Thorne - Zevenbergen
Jarrett


DOLORES RIVER - XS#1 - 11/08/11
Velocity vs. Discharge
Velocity - ft/sec
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0.00
2000.00
4000.00
6000.00
8000.00
10000.00
12000.00
14000.00
16000.00
Discharge (cfs)
Mannings N
Thorne - Zevenbergen
Jarrett

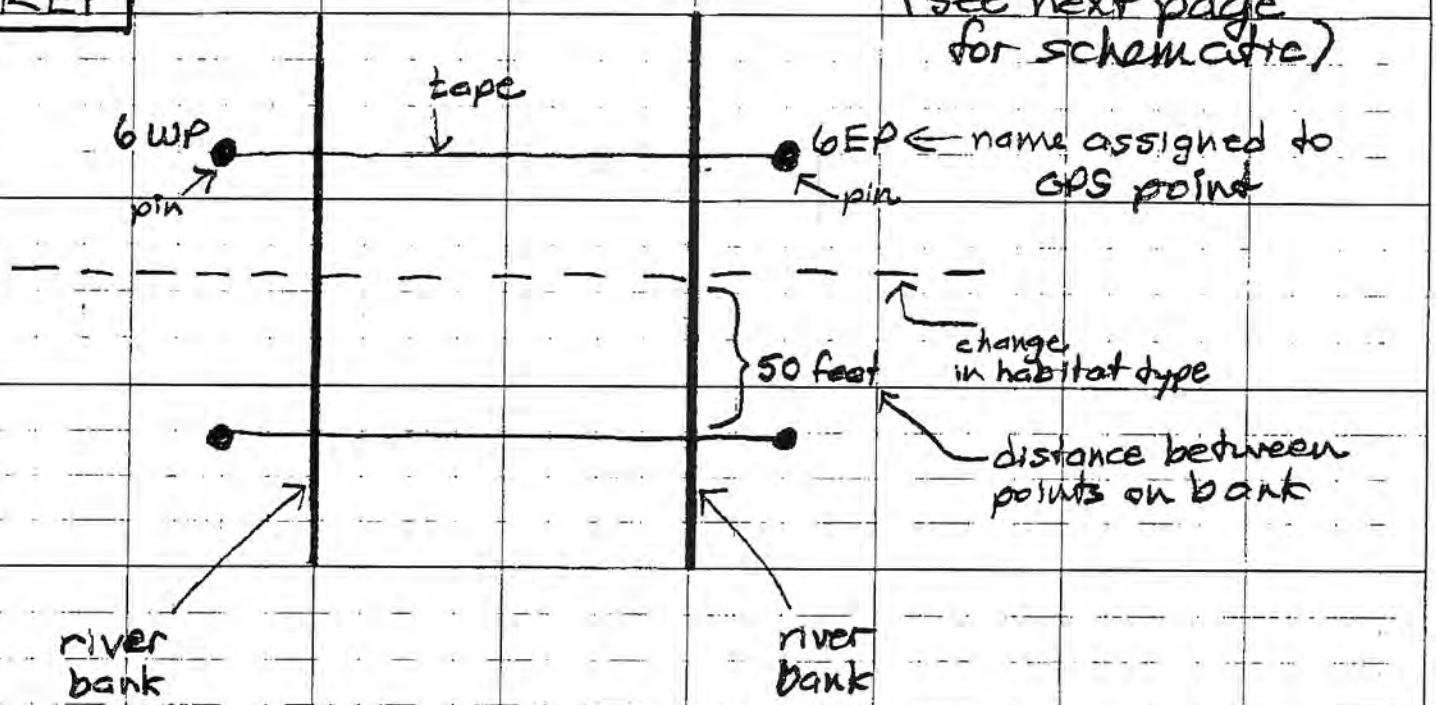

DOLORES RIVER - XS#1 - 11/08/11
Average Depth vs. Discharge
Average Depth - feet
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0.00
2000.00
4000.00
6000.00
8000.00
10000.00
12000.00
14000.00
16000.00
Discharge (cfs)
Mannings N
Thorne - Zevenbergen
Jarrett

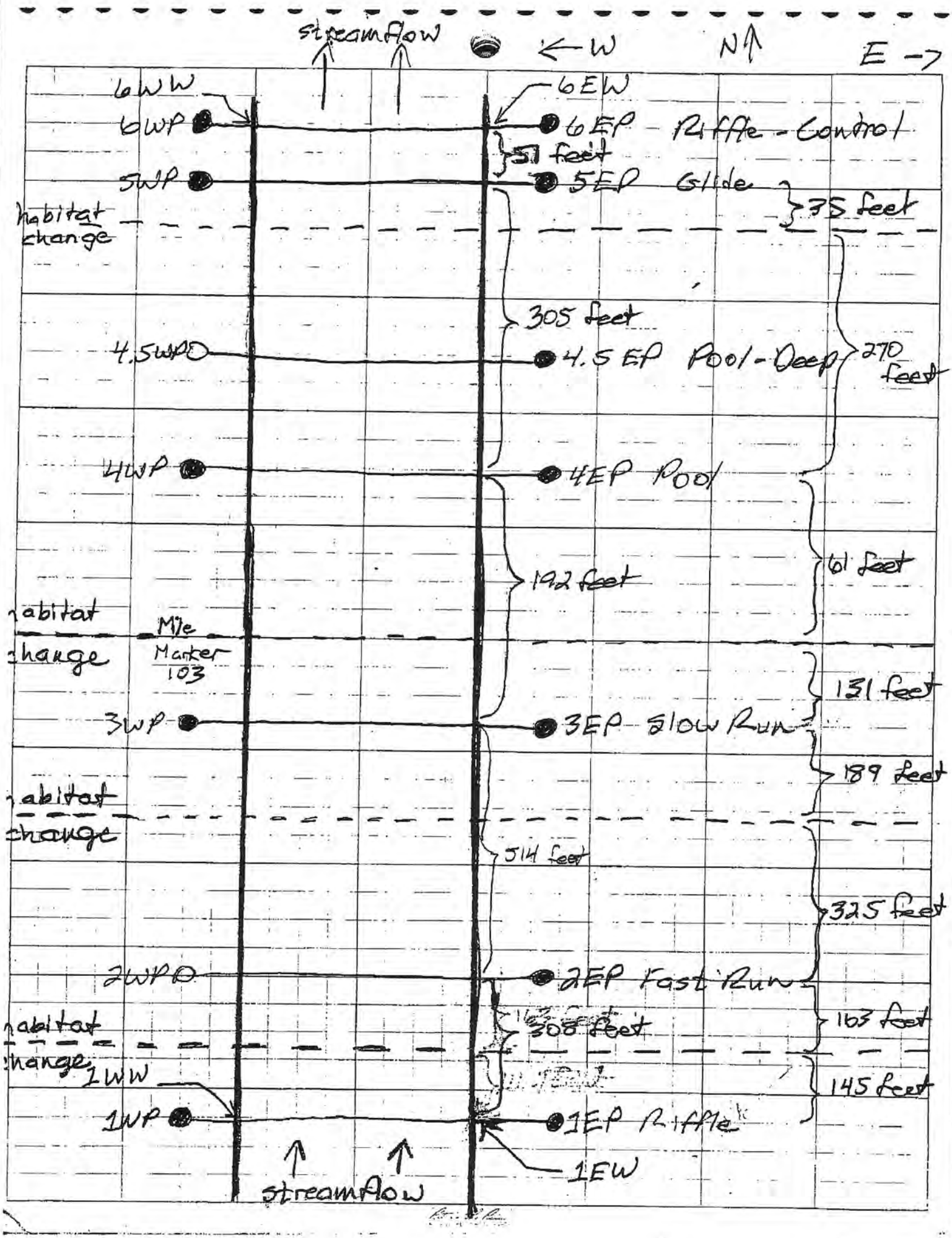

DOLORES RIVER - XS#1 - 11/08/11
Stage vs. Discharge
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Stage, feet
0.00
2000.00
4000.00
6000.00
8000.00
10000.00
12000.00
14000.00
16000.00
Discharge (cfs)
Thorne - Zevenbergen
Jarrett

Dolores River Instream Flow Modeling Reach Schematic

KEY

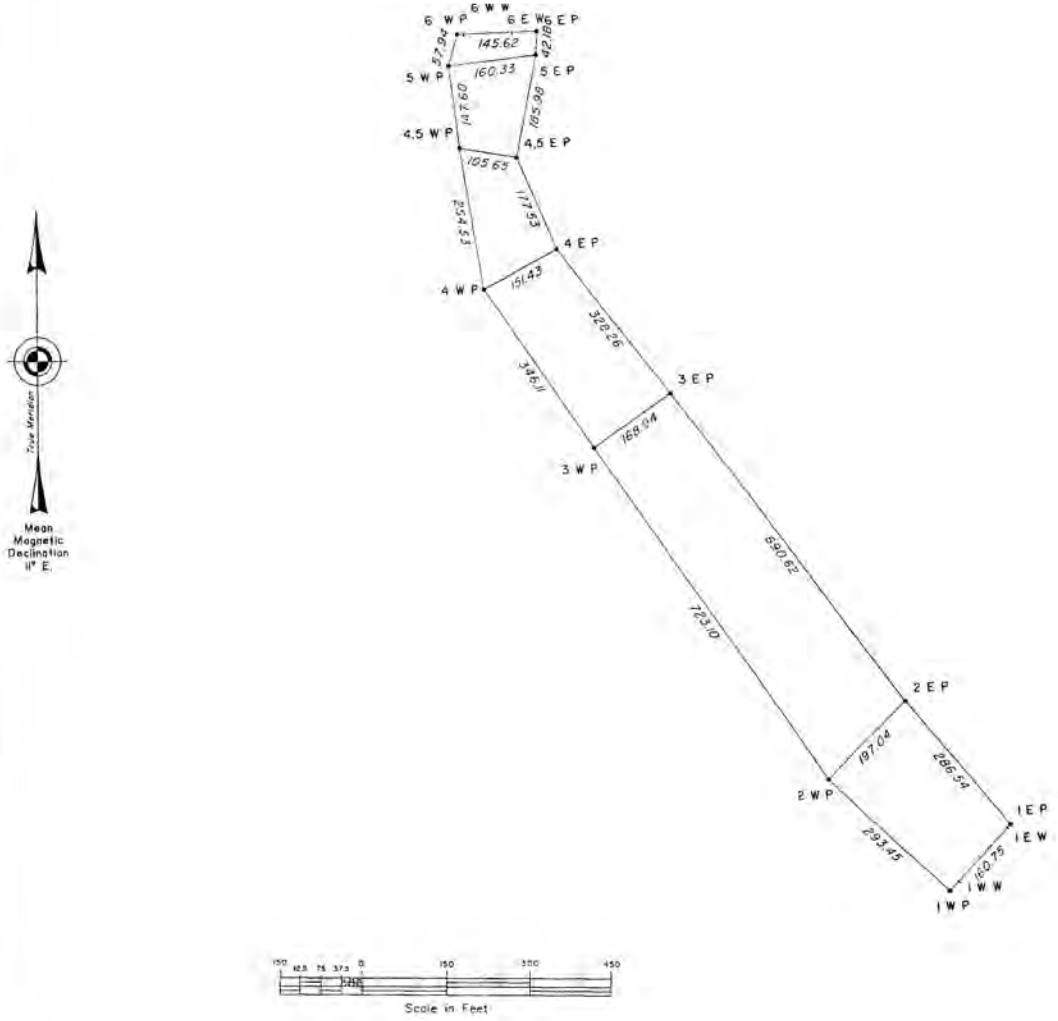
(see next page for schematic)




streamflow
W
N
E
6WW
6WP
6EW
6EP
Riffle - Control
51 feet
5WP
5EP
Glide
35 feet
habitat change
305 feet
4.5WPO
4.5 EP
Pool - Deep
270 feet
4WP
4EP
Pool
192 feet
61 feet
habitat change
Mile Marker 103
131 feet
3WP
3EP
Slow Run
189 feet
habitat change
514 feet
325 feet
2WPO
2EP
Fast Run
163 feet
308 feet
habitat change
1WW
145 feet
1WP
1EP
Riffle
1EW
streamflow

TOWNSHIP 50 NORTH, RANGE 19 WEST, OF THE NEW MEXICO PRINCIPAL MERIDIAN, COLORADO.

LOCATION DIAGRAM



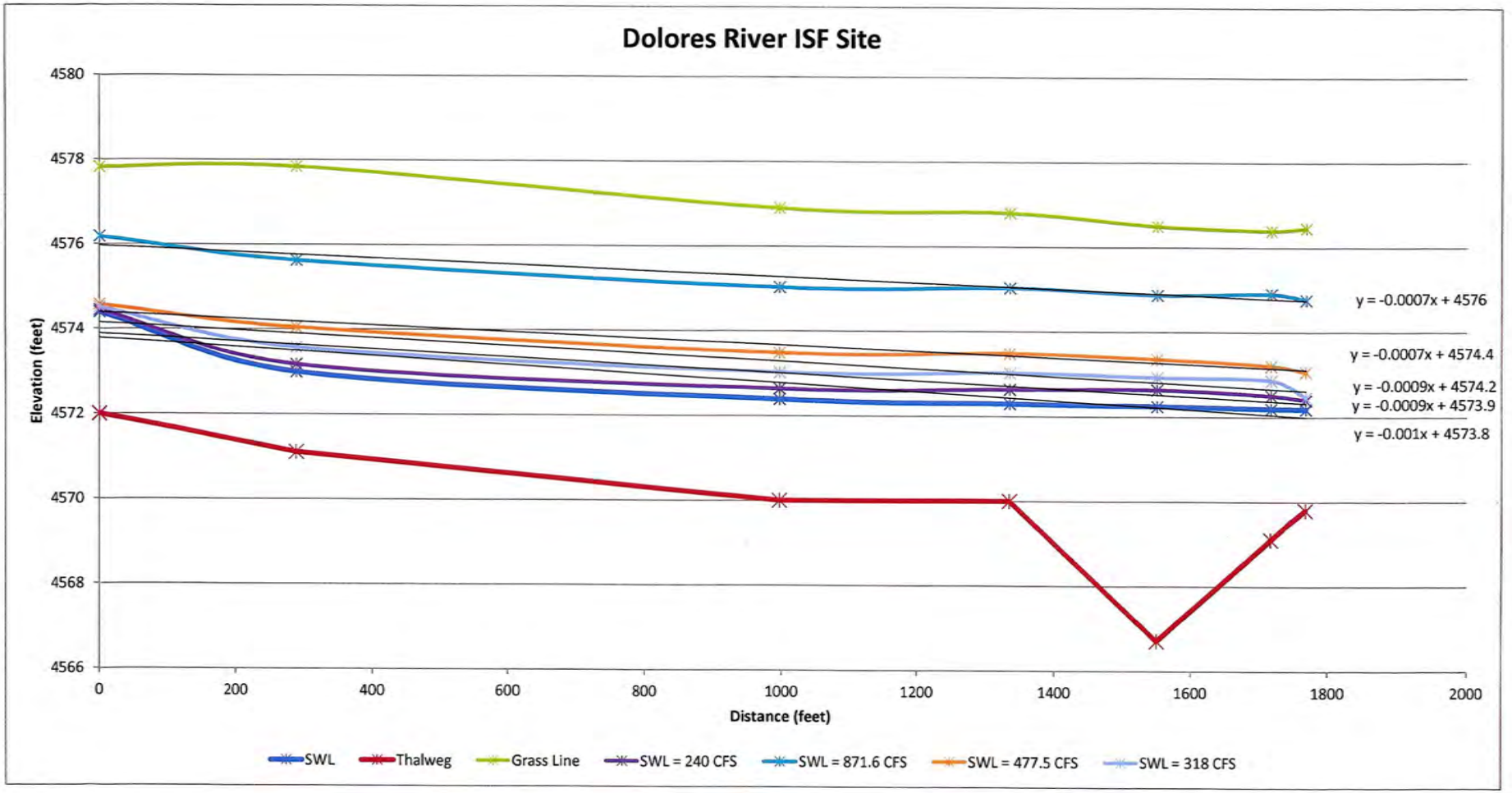
This location diagram depicts the location of the iron rebar set for the Delores River Model Project located south of Gateway, Colorado on Hwy. 141. The distances returned on this diagram are in feet and measure across and up the Delores River.

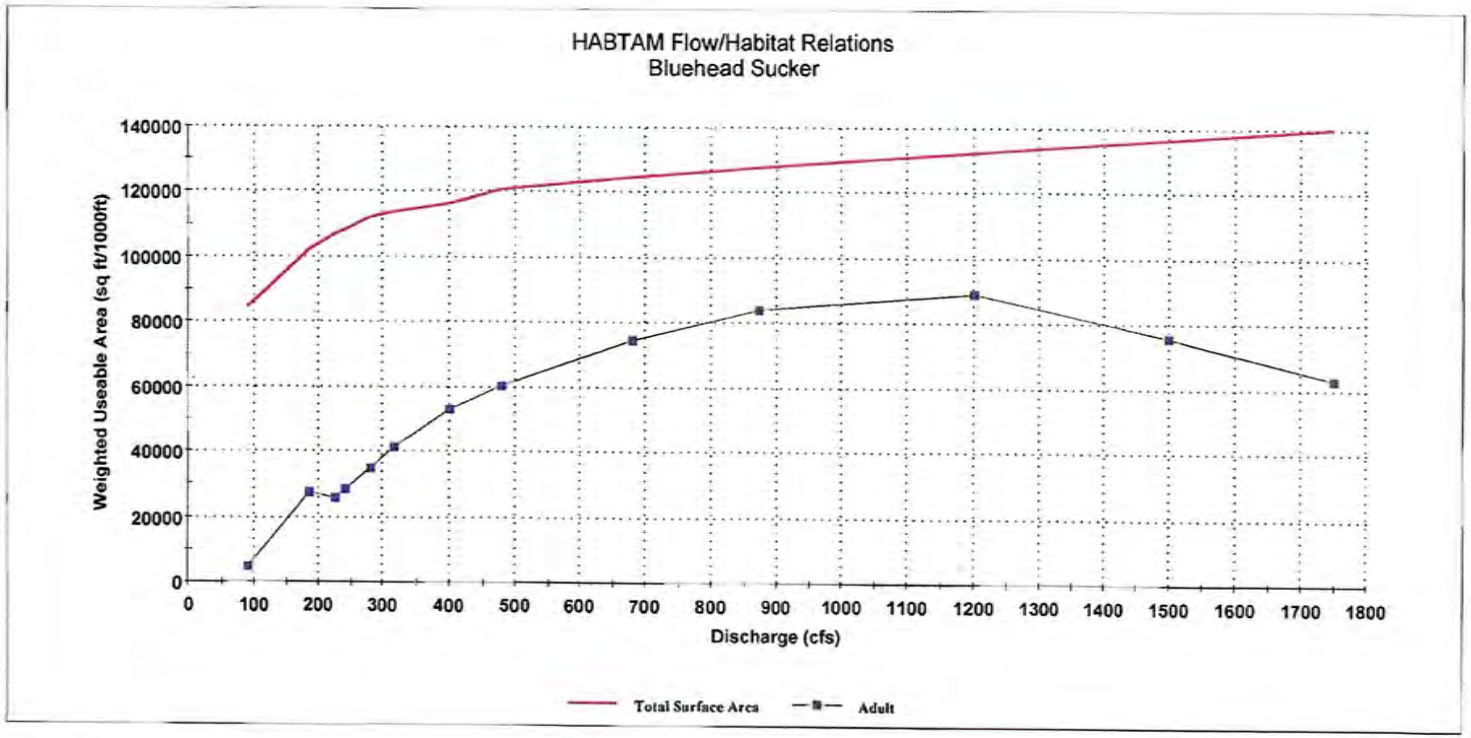
UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT

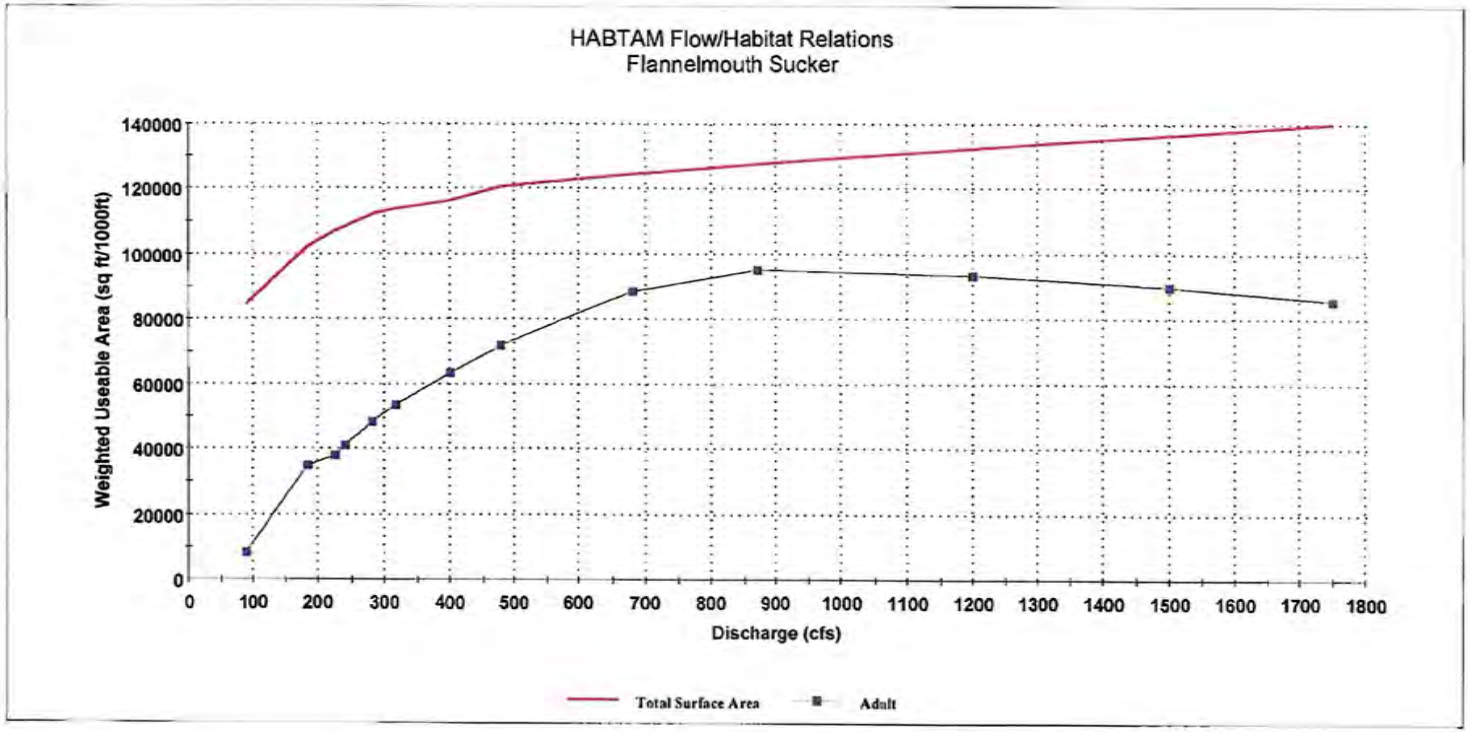
Denver, Colorado Nov. 9, 2011

R. M. Bruns

T. 50 N., R. 19 W., N. M. P.M.


Dolores River ISF Site
Elevation (feet)
4580
4578
4576
4574
4572
4570
4568
4566
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Distance (feet)
y = -0.0007x + 4576
y = -0.0007x + 4574.4
y = -0.0009x + 4574.2
y = -0.0009x + 4573.9
y = -0.001x + 4573.8
SWL
Thalweg
Grass Line
SWL = 240 CFS
SWL = 871.6 CFS
SWL = 477.5 CFS
SWL = 318 CFS


HABTAM Flow/Habitat Relations
Bluehead Sucker
Weighted Useable Area (sq ft/1000ft)
140000
120000
100000
80000
60000
40000
20000
0
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Discharge (cfs)
Total Surface Area
Adult


HABTAM Flow/Habitat Relations
Flannelmouth Sucker
Weighted Useable Area (sq ft/1000ft)
140000
120000
100000
80000
60000
40000
20000
0
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
Discharge (cfs)
Total Surface Area
Adult

Dolores River Water Availability Technical Memo

Flow Modification

The proposed instream flow reach on the Dolores River receives water from the Dolores River, the San Miguel River, and a number of small tributaries. The Dolores and San Miguel Rivers each have historical municipal and irrigation water uses that alter the nature flow of the system (CWCB, 2005). There are also a number of reservoirs that affect flow conditions such as Gurley, Miramonte, Trout Lake, and Lake Hope on the San Miguel and Groundhog, McPhee, Summit, and Narraguinnep on the Dolores River. Many of these reservoirs are part of large water projects such as the Montezuma Valley Irrigation Company (MVIC), the Summit Reservoir System, and the Dolores Project (CWCB, 2012).

The Dolores Project, which includes McPhee Dam and nearly 200 miles of canals, tunnels, pipelines and laterals, significantly alters the flow regime in the proposed instream flow (ISF) reach. The Dolores Project was developed by the United States Bureau of Reclamation (USBR) and supplies an average annual volume of 90,900 acre-feet to Dove Creek, Towaoc, and the Montezuma Valley (USBR website). Many of these are transbasin diversions that export water from the Dolores River system to the San Juan River system. The majority of decreed water uses occur upstream from McPhee Reservoir. The exceptions are a fish pool, some senior downstream water rights, and flows necessary for the salinity control project in the Paradox Valley.

Construction of McPhee Dam started in 1980 and was completed in 1984 (Voggesser, 2001). Other portions of the project were completed later, such as the Great Cut Pumping Plant in 1987 and the McPhee Powerplant in 1993. The Dove Creek Canal and Towaoc Canal were completed in 1987 and 1993 respectively. The USBR declared the Dolores Project, "substantially complete" in 1995 with "final completion" in September 1998 after correcting minor design and construction deficiencies in laterals and canals (Voggesser, 2001). The full Dolores Project was online and in use by 1999 or 2000, with 2000 the typical date given (Ken Curtis – Dolores Water Conservancy District, personal communication). This history of changing use can be divided into three primary time frames:

1. Pre-McPhee which includes historical water depletions, prior to 1984
2. Post-McPhee, when McPhee Dam was complete but not necessarily the entire Dolores Project, 1984 to present
3. Post-Dolores Project when the entire Dolores Project was operational and utilized, 2000 to present.

Analysis Methods

The Dolores River and water development projects in the basin represent a complex system that has changed through time as different projects have been implemented. Given changes in historical use and available data, there are a number of time-frames and methods that can be used to analyze and determine water availability. Staff examined three principal means of evaluating water availability for

the proposed Dolores River instream flow. First, the gage data for the Dolores River near Bedrock and the San Miguel River near Uravan were combined to estimate flow entering the proposed reach from 1984 to 2012. This time frame represents post-McPhee conditions but not the full implementation of the Dolores Project. Second, the Colorado River Decision Support System (CDSS) Statemod model historical simulation was used to evaluate the historical use at the downstream terminus from 1984 to 2006. This time frame also represents post-McPhee conditions, but ends at the last year modeled by Statemod. Lastly, the Statemod model baseline simulation was used to evaluate the current management practices of the Dolores Project with historical hydrology from 1974 to 2006. These analyses and results are detailed below.

Gage Data

Several different gages have operated in the vicinity of the proposed instream flow reach, each with different periods of record. Relatively long term and continuous gage data is available for both the San Miguel River at Uravan (09177000) and the Dolores River near Bedrock (USGS 09171100) gages starting in 1973. The Uravan gage is located approximately 6.7 miles upstream from the proposed upper terminus at the confluence. The Bedrock gage is located approximately 3.5 miles upstream from the proposed upper terminus. A historical gage on the Dolores River at Gateway (09179500), located downstream from the proposed lower terminus, operated for less than twenty years in the 1930s to 1950s. Approximately 22 miles downstream from the lower terminus, the Dolores River at Cisco (0918000) gage has the longest continuous record operating from 1950 to present.

Gage Name	Gage ID	Start of record	End of record
Dolores River at Bedrock	09169500	10-1-1917 8-1-1971	9-30-1922 Present
Dolores River near Bedrock	09171100	8-1-1971	Present
San Miguel River at Uravan	0917700	8-1-1954 10-1-1973	9-30-1962 Present
Dolores River at Gateway	09179500	10-1-1936	9-30-1954
Dolores at Cisco	0918000	12-1-1950	Present

In order to estimate the flow that historically entered the proposed instream flow reach, gage data from the San Miguel at Uravan (09177000) and the Dolores River near Bedrock (USGS 09171100) were added together. Concurrent data at both gages is available from 10-1-1973 to the present, but only 10-1-1984 to 9-30-2012 was used in the analysis. 10-1-1984 is the date the USGS uses to analyze data for the post-McPhee period and 9-30-2012 represents the last complete water year with approved USGS data at the time of analysis.

Before adding the gages together, the data were analyzed to determine if the measured flows would meet on the same day at the confluence or if there would be a lag from one or the other gages. The field measurements for the Bedrock and Uravan gages were downloaded and a relationship between discharge and average velocity for each gage was developed. The distance between each gage and the

confluence of the two rivers was measured and travel times were calculated. The estimated travel times for both gages indicate that for all discharges measured, flow from the two different gages would reach the confluence on the same day. Therefore, it does not appear to be necessary to lag either gage before combining the datasets.

Once the gage data from 10-1-1984 to 9-30-2012 were added, a number of statistics were calculated. The median, or the flow that occurs at least 50% of the time, was calculated for each day. In addition, 95% confidence intervals for the median were calculated. Typically the Board considers water to be available if the proposed ISF flow rate is at or below the median value, but can consider ISF flow rates that are below the upper 95% confidence interval.

CDSS

Statemod is a modeling system developed by the CWCB for water supply planning purposes as part of the Colorado Decision Support System (CDSS). This model uses streamflow data, diversion records, water rights, reservoir contents, operating rules, return flow estimates, and consumptive use estimates among other datasets. The model simulates streamflow, native flow, and other information at specific locations in a basin for either monthly or daily time-steps. The model can be used to simulated different types of conditions including: 1) Historic simulations that use historic hydrology based on historic operations of reservoirs and diversion; and 2) baseline simulations that use historic hydrology, but current operating rules and practices. Typically, baseline simulations use diversion demand (the amount of water the crops actually need, limited by the water rights) rather than the diversion record.

The San Juan Statemod model contains the Dolores River and simulates flow from 1974 to 2006. This model was updated in 2010 as part of Colorado River Water Availability Study (CRWAS) and includes the operating procedures for the Dolores Project at that time. The San Juan model was modified to provide additional detail in the area near the proposed instream flow reach. Specifically, nodes representing the upstream and downstream instream flow termini were added; a node was added to explicitly model Casto (WDID630578); diversions on tributaries to the Dolores River instream flow reach were aggregated; and other diversions on the mainstem Dolores in the instream flow reach were aggregated. A number of other modifications and corrections were applied to improve simulations in this area. The modifications are summarized below.

- Created instream flow nodes to represent the upstream and downstream termini.
- Disaggregated the existing aggregate node (63_ADS_023) into four smaller aggregates that represent: structures physically and hydrologically located above the Uravan gage; structures on tributaries to the Dolores River within the proposed ISF reach; structures on the mainstem Dolores River within the proposed ISF reach; structures located downstream from the ISF reach.
- Removed Foster Miner Ditch (6300524) from model due to no diversion records and incorrectly assigned irrigated acreage.
- Disaggregated the existing aggregate node on West Creek (63_ADS_024) into five smaller aggregate structures.
- Created a new diversion node for Casto Ditch (WDID 630578) and assigned return flows to 63_ADS_Blw located below the lower terminus.

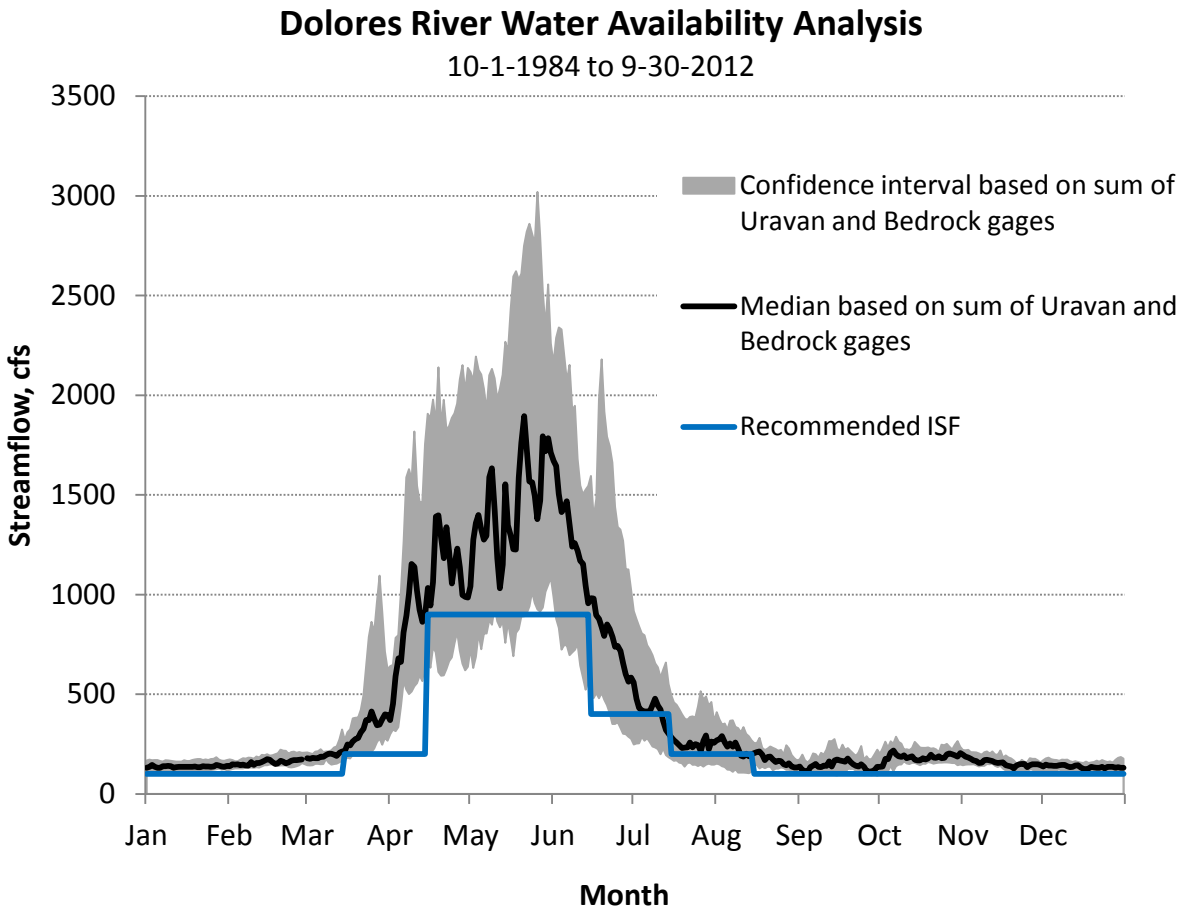
- Red Cross Ditch returns flows were assigned to 63_ADS_Blw located below the lower terminus.
- Set irrigation efficiencies for created Dolores River aggregate nodes and Casto to the efficiencies originally computed for the 63_ADS_023 aggregate.
- Set irrigation efficiencies for created West Creek aggregate nodes to the efficiencies originally computed for the 63_ADS_024 aggregate.
- Extended the gage record for the Dolores at Gateway using regression with the Dolores at Cisco gage.
- Revised daily pattern gage to use the Dolores at Cisco for the Dolores near Bedrock, Dolores at Gateway, and West Creek diversions.
- Revised the native flow calculation approach for West Creek from the neighboring gage approach to the gain approach (CDSS, 2010).
- Revised drainage basin area and precipitation values to better match values measured by StreamStats (Capesius and Stephens, 2009). Precipitation on West Creek was increased by 1 inch to improve calibration.
- Turned on use diversion comments when filling diversion records.

These modifications involved changes to the network and all necessary input files. New native flow calculations and daily historic and baseline simulations were performed. The simulated daily streamflow at the lower terminus was then used to determine the median and 95% confidence intervals for both the historical and baseline simulations.

Water Availability Results

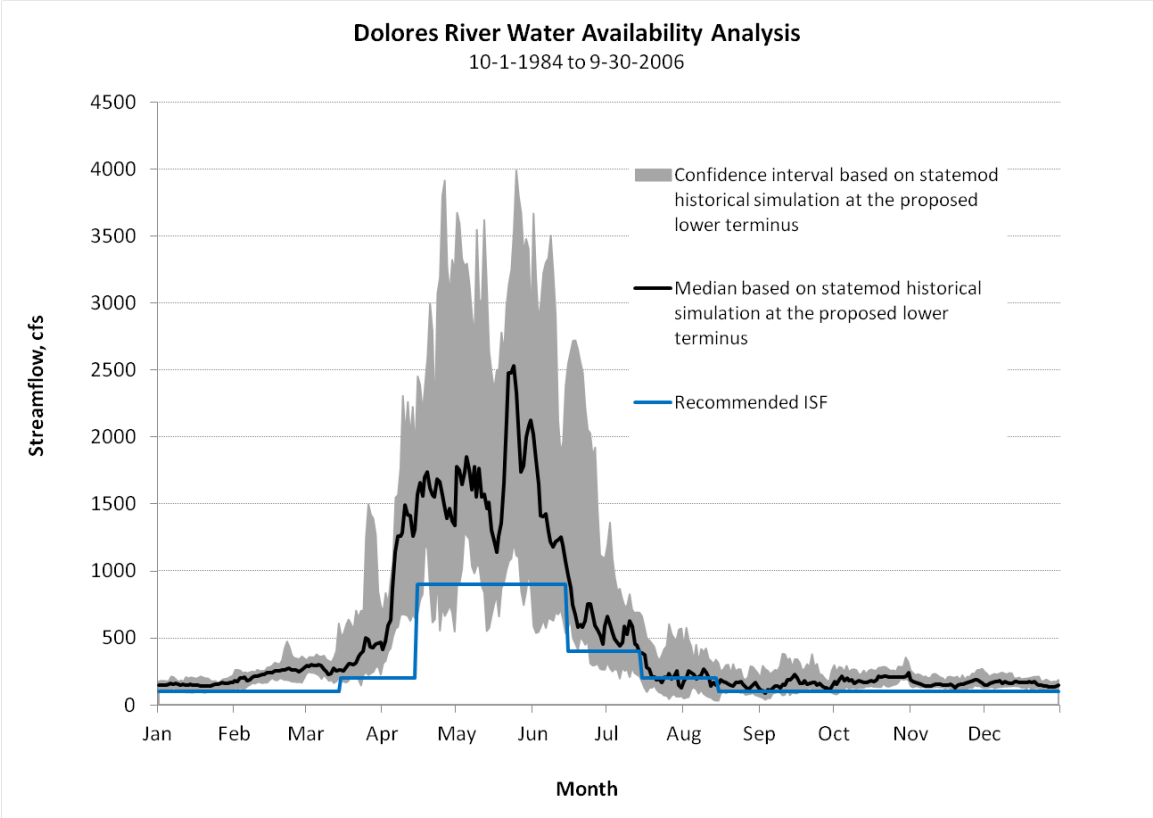
Historical Gage Analysis

The combined flow of the Dolores River at Bedrock and the San Miguel River at Uravan indicates that water has been available to meet the proposed ISF rate at the upper terminus from 10-1-1984 to 9-30-2012. The proposed ISF is below the median for 357 of 365 days. The proposed ISF is higher than the median for 3 days in July and 5 days in August. The ISF is below the upper 95% confidence interval for all days of the year.



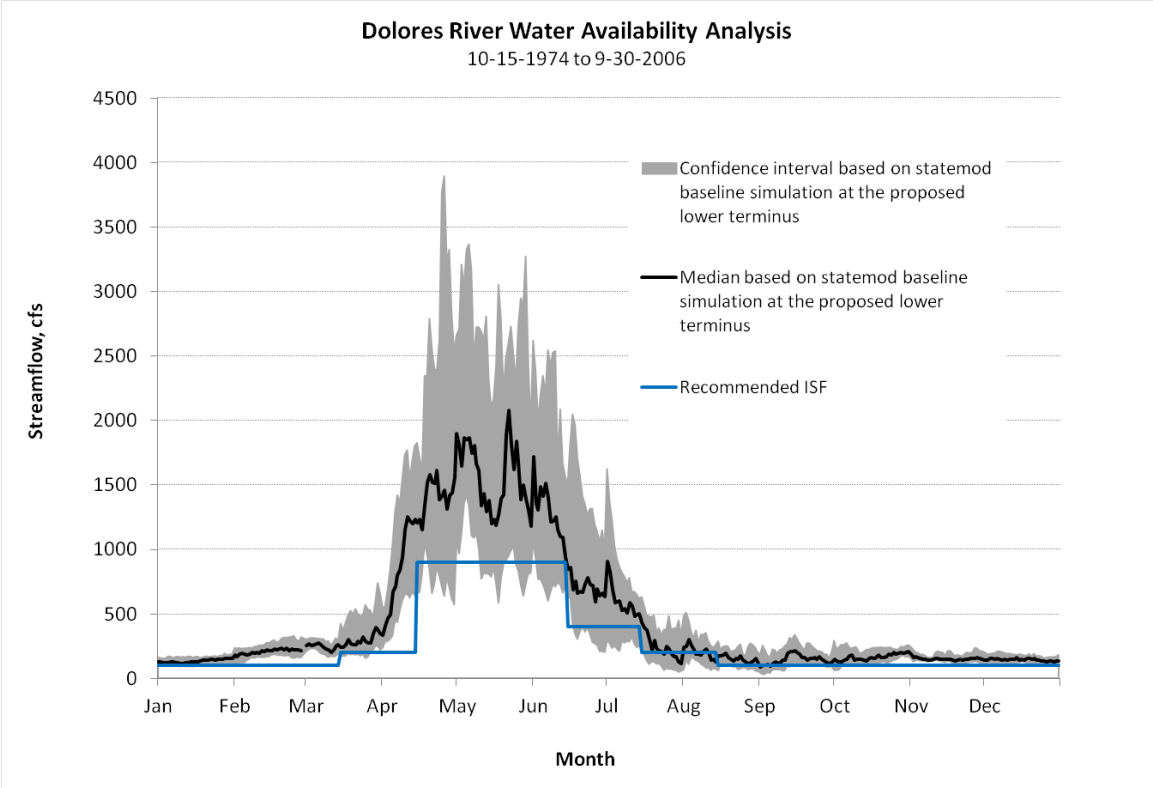
Historical Statemod Analysis

The historical Statemod results at the proposed lower terminus are similar to the historical gage analysis. These results are similar despite a change in the period of record (ending in 2006 not 2012) and a change in the location analyzed (upper versus lower terminus). The proposed ISF is below the median for 351 of 365 days. The proposed ISF is higher than the median for 8 days in July, 5 days in August, and 1 days in September. The ISF is below the upper 95% confidence interval for all days of the year.



Baseline Statemod Analysis

The baseline Statemod results at the proposed lower terminus are similar to the historical gage analysis. This occurs even though the analysis period for the baseline simulation is slightly longer. In this case analysis started on 10-15-1974 through 9-30-2006. The proposed ISF is below the median for 351 of 365 days. The proposed ISF is higher than the median for 6 days in July, 6 days in August, and 2 days in September. The ISF is below the upper 95% confidence interval for all days of the year.



Summary

Based on all three methods and time-frames of analysis, water is available to support the proposed instream flow rates for the Dolores River. The Statemod baseline simulation result is the most conservative estimate of streamflow because it simulates current operation of McPhee Dam including the completed Dolores Project. The final median hydrology used to evaluate water availability for the proposed instream flow on the Dolores River is based on the Statemod baseline results. This model was selected for the final hydrology because it represents the best available data and analysis method for the Dolores River.

Citations

Capesius, J.P. and V.C. Stephens, 2009, Regional regression equations for estimation of natural streamflow statistics in Colorado, Scientific Investigations Report 2009-5136.
CWCB, 2005, San Juan and Dolores River Basin Information, p 89.

CWCB, 2009, San Juan / Dolores River Basin Water Resources Planning Model User's Manual, p 296.

CWCB, 2010, StateDMI, p 996.

CWCB, 2012, Colorado River Water Availability Study, p 189.

Voggesser, Garrit, 2001, The Dolores Project, Bureau of Reclamation History, p 46.
http://www.usbr.gov/projects//ImageServer?imgName=Doc_1303397411306.pdf

USBR, Dolores Project. Updated 3-12-2009, accessed 10-22-2013 at
http://www.usbr.gov/projects/Project.jsp?proj_Name=Dolores%20Project



















Stream: Dolores River

Executive Summary

Water Division: 4
Water District: 63
CPW#: 39760
CWCB ID: 14/4/A-006

Segment: CONFLUENCE SAN MIGUEL RIVER TO CONFLUENCE WEST CREEK

Upper Terminus: CONFLUENCE SAN MIGUEL RIVER AT
UTM North: 4254788.25 UTM East: 167728.07

Lower Terminus: CONFLUENCE WEST CREEK AT
UTM North: 4288483.48 UTM East: 154090.30

Watershed: Lower Dolores (HUC #: 14030004)
Counties: Mesa, Montrose
Length: 34.21 miles
USGS Quad(s): Gateway, Juanita Arch, Red Canyon, Roc Creek
Flow Recommendation: 900 cfs (4/15 – 6/14)
400 cfs (6/15 – 7/15)
200 cfs (7/16 – 8/14)
100 cfs (8/15 – 3/15
200 cfs (3/16 – 4/14)



Staff Analysis and Recommendation

Summary

The information contained in this report and the associated supporting data and analyses (located at http://cwcb.state.co.us/environment/instream-flow-program/Pages/2014ProposedInstreamFlowAppropriations.aspx) form the basis for staff's instream flow recommendation to be considered by the Board. It is staff's opinion that the information contained in this report is sufficient to support the findings required by ISF Rule 5.40.

Colorado's Instream Flow Program was created in 1973 when the Colorado State Legislature recognized "the need to correlate the activities of mankind with some reasonable preservation of the natural environment" (see 37-92-102 (3) C.R.S.). The statute vests the CWCB with the exclusive authority to appropriate and acquire instream flow and natural lake level water rights. In order to encourage other entities to participate in Colorado's Instream Flow Program agencies., the statute directs the CWCB to request instream flow recommendations from other state and federal The Bureau of Land Management (BLM) and Colorado Parks and Wildlife (CPW) jointly recommended this segment of Dolores River to the CWCB for a water right under the Instream Flow Program. The Dolores River is being considered because it has a natural environment that can be preserved to a reasonable degree with an instream flow water right.

The Dolores River is approximately 189 miles long and originates in the San Juan National Forest near Bolam Pass at an elevation of 11,640 feet. It flows in a southwesterly direction as it drops to an elevation of 4,560 feet where it crosses the Colorado - Utah border. Sixty-one percent of the land on the 34.21 mile segment addressed by this report is publicly owned (see Table 1). The recommended segment of the Dolores River is located within Mesa and Montrose Counties and the total drainage area of the river is approximately 4,400 square miles.

The subject of this report is a segment of Dolores River from the confluence with the San Miguel River extending downstream to the confluence with West Creek. The proposed segment is located immediately upstream of the Town of Gateway. The BLM and CPW both have submitted recommendations for this segment to Staff, which are discussed below.

Instream Flow Recommendation

BLM and CPW recommended flows of 900 cfs (4/15 – 6/14), 400 cfs (6/15 – 7/15), 200 cfs (7/16 – 8/14), 100 cfs (8/15 – 3/15 and 200 cfs (3/16 – 4/14), based on data collection and modeling efforts.

Land Status Review

Table 1. Summary of land ownership data in the vicinity of the proposed ISF on the Dolores River.

Upper Terminus	Lower Terminus	Total Length (miles)	Land Ownership	
			% Private	% Public
Confluence with San Miguel River	Confluence with West Creek	34.21	39%	61%

All of the public lands in this segment are managed by the BLM.

Biological Data

Fisheries

Fishery surveys taken during 2007 and 2009 by the Colorado Division of Wildlife indicate that the stream environment supports bluehead sucker (*Catostomus discobolus*), flannelmouth sucker *Catostomus latipinnis*, roundtail chub (*Gila robusta*), and speckled dace (*Rhinichthys osculus*). The surveys indicated that 89% of the fish captured were native species, and that all of these species were represented by individuals of multiple age classes. This reach of the Dolores River appears to be one of the best populations of native fish within Colorado.

Roundtail chub (*Gila robusta*) is recognized by the State of Colorado as a species of special concern. CPW's Administrative Directive W-7 (2007) describes the process and criteria for placing species into this management status. In short, vulnerable species can either be listed as state threatened or endangered or as a species of special concern. There are a number of factors that might lead to this management classification, but in the case of the roundtail chub, this species is known to be in decline in its historic range and there are biotic and abiotic threats (habitat degradation and non-native competition) to the chub's continued survival.

The roundtail chub, flannelmouth sucker (*Catostomus latipinnis*) and bluehead sucker (*Catostomus discobolus*) are considered sensitive species by the BLM. Criteria that apply to BLM sensitive species include the following: 1) species under status review by the U.S. Fish and Wildlife Service; or 2) species with numbers declining so rapidly that federal listing may become necessary; or 3) species with typically small and widely dispersed populations; or 4) species inhabiting ecological refugia or other specialized or unique habits.

The CPW, BLM, numerous state wildlife agencies, federal agencies, and others have developed a "Range-Wide Conservation Agreement and Strategy" to direct management for these species. This plan provides direction and goals for research, monitoring, and overall management of the three species. The success of management strategies will depend upon the voluntary implementation of these strategies by the signatories. Special attention will need to be given to habitat degradation and influence of non-native species interactions within the native range of these species. The intention of these plans is to increase populations and distribution of the identified species, thereby assisting in the long-term

persistence of the species. The habitat protection that is afforded by an instream flow water right fits into the range of actions that the signatories agreed to pursue under this agreement. The success of such plans could potentially curtail the need for federal listing of these species under the Endangered Species Act (ESA). These species are not currently federally listed.

Macroinvertebrates

The BLM performed macroinvertebrate surveys during July 2013. The BLM utilized a sampling protocol developed by the National Aquatic Monitoring Center (NAMC), designed to generate data sufficient to characterize the status and trend of aquatic macroinvertebrate assemblages, including quantifying the effects of human disturbances and/or restoration actions. The BLM will provide these results to the CWCB, along with its analysis of the health and status of the macroinvertebrate community.

Riparian Community

The Dolores River riparian community has been heavily impacted by invasion of non-native tamarisk. Depending upon the location, the tamarisk component of the riparian community can range from 10 to 80% of vegetation cover. However, there are still extensive occurrences of native species, including Rio Grande Cottonwood, Narrow-leaf Cottonwood, Box Elder, Coyote Willow, Skunkbrush, and New Mexico Privet. In many locations, tamarisk dominates the zone immediately adjacent to the river channel and native species dominate the first terrace that is slightly elevated above the river channel. Even with the tamarisk impact, the river banks are in stable condition and excessive erosion does not appear to be impacting the aquatic community.

The Dolores River Restoration Partnership is making a major investment in treating the invasive species along the river. The Partnership's objective is to increase the vigor and extent of native riparian species, including Rio Grande Cottonwood, Narrow-leaf Cottonwood, Box Elder, Coyote Willow, New Mexico Privet, and Skunkbrush. For the river corridor to successfully transition back to a vegetation community dominated by native species, a supporting hydrologic regime will be required that provides periodic flooding and maintains groundwater levels within the root zone of the riparian community.

While the proposed instream flow water right does not protect the highest flood flows, BLM and CPW believe that the proposed seasonal variations in flow rates will provide good support for groundwater levels in near-stream alluvial deposits. This support is accomplished by protecting stream flow during the snowmelt runoff period which is the flow that recharges near-stream alluvial deposits. In addition, by protecting base flows during seasonally dry periods, groundwater levels in near-stream alluvial deposits can be maintained during high temperature and high evapotranspiration periods. Maintenance of groundwater levels in near-stream alluvial deposits during both periods will sustain the health and vigor of the riparian community.

Flow Quantification Methodology

PHABSIM and R2Cross Methodology

The CPW and BLM evaluated all of the data collected to date and determined that the best flow recommendation would be derived from a combination of methods. PHABSIM (Physical Habitat Simulation) is a widely accepted method for quantifying the suitable versus unsuitable hydraulic habitat attributes of selected species and life stages as a function of discharge. R2CROSS is best suited for identifying flows with specific hydraulic criteria across riffle type habitats. The State of Colorado has used R2CROSS extensively in the past to appropriate instream flow water rights. PHABSIM is widely used in North America to quantify instream flow requirements.

CPW and BLM determined that exclusive use of the standard R2CROSS method would not be appropriate for this reach of the Dolores River due to its large width (over 100 feet wide in most places), type of fish species present (warm/cool water species) and its big river channel morphology that includes extensive run, pool, and glide habitat. In addition, only a very small percentage of the fish habitat in this reach is comprised of riffles. For these reasons, CPW and BLM decided to utilize PHABSIM results to develop flow recommendation for the snowmelt runoff months between March and August. This is the portion of the year when the three sensitive species are using run, pool, glide, and riffle habitat to complete important parts of their life cycles, such as spawning and recruitment of young of the year. Habitat availability is critical during this period for maintaining the biomass and age diversity of the three sensitive fish species.

CPW and BLM decided to use the R2Cross methodology to develop flow recommendations during the base flow portions of the year from August through March. This is the period when there is substantial competition between individuals for physical habitat space, foraging areas, and limited food supplies. During this period, it is critical for the three species to be able to move between habitat areas to make full use of the limited physical habitat. Riffles are the first location where low flows can limit passage between habitat types, so it as appropriate to develop flow recommendations that focus on the fish passage function.

To select an appropriate location for PHABSIM modeling, CPW and BLM staff conducted reconnaissance throughout the 34-mile reach to identify its typical habitat characteristics, including channel widths, substrate types, depths, and velocities. The CPW and BLM staff then selected an 1,800-foot reach of stream, located approximately seven miles upstream from the Town of Gateway, as a location that could represent the full variety of habitat types found within the 34-mile reach. The CPW and BLM staff established and monumented seven transects that incorporate different mesohabitat types, including riffles, runs, pools and glides. These seven different cross-sections formed the basis for the PHABSIM/RHABSIM study conducted by the CPW and BLM.

BLM and CPW staff also ran data from the seven cross-sections through the R2Cross model. Since the seven cross-sections include only one cross-section of riffle habitat, CPW and BLM staff also collected data from four additional representative riffle cross-sections at other locations on the river. The additional cross-section data collection was designed to increase the reliability of the R2Cross model in predicting hydraulic characteristics that would be experienced at various flow rates within the 34-mile reach.

The initial recommendations based on the PHABSIM and R2CROSS modeling are designed to address the unique biologic requirements of this stream reach without regard to water availability. In addition to the criteria developed using the PHABSIM methodology and RHABSIM software, the three standard instream flow hydraulic parameters used in R2CROSS (average depth, percent wetted perimeter and average velocity) were also used to calculate and inform the biologic instream flow recommendations.

Application of Habitat Suitability Criteria

Habitat suitability criteria (HSC) were developed by CPW Aquatic Researcher Richard Anderson, in collaboration with Gregory Stewart from the Department of Geosciences Oregon State University (Anderson and Stewart, 2003). The basis for this study was a 1999 request from the CWCB for the CPW to provide biologically justified instream flow recommendations for the Yampa and Colorado Rivers based on habitat and flow requirements for non-endangered native fish. Anderson and Stewart used two–dimensional (2D) modeling to develop habitat suitability criteria for bluehead and flannelmouth suckers, two native species. Their methods and results are more fully described in Anderson and Stewart (2003), Stewart et al. (2005), Stewart and Anderson (2007), and Anderson and Stewart (2007).

The bluehead and flannelmouth sucker habitat suitability criteria were used to develop specific hydraulic criteria that were incorporated into a PHABSIM/RHABSIM analysis. Stewart and Anderson determined that "Abundance of bluehead sucker was a reliable indicator for instream flows and habitat maintenance for the native fish assemblage. In the Colorado, Gunnison and Yampa Rivers, bluehead sucker habitat peaked at flows of 600 to 1,200 cfs. This flow range also resulted in high habitat diversity and high native fish biomass." Their assumption that flows that maintained adequate bluehead sucker abundance (about 25% of fish over 15 cm) would also maintain adequate flannelmouth sucker and roundtail chub habitat was validated by this study.

CPW and BLM determined that the flannelmouth sucker and bluehead sucker would be the primary indicator species for the biologically based instream flow recommendation. The reason for considering the needs of both species is that they have somewhat different habitat preferences. Flannelmouth sucker have stronger preference for pool, glide, and run habitats, while bluehead sucker abundance is directly related to availability and quality of riffle habitats. Roundtail chub primarily utilize habitats with slower velocities, typically found in pools. CPW and BLM determined that if sufficient flows were protected

for flannelmouth sucker and bluehead sucker needs, there would also be sufficient water to maintain pool habitats relied upon by roundtail chub.

When developing recommendations for flow rates to support flannelmouth sucker and bluehead sucker, BLM and CPW personnel examined tables and graphs produced by the PHABSIM model that show amounts of "weighted usable area" (suitable habitat) available at various flow rates for each of the two species. The BLM and CPW then identified the most "efficient" flow rate for providing habitat protection. In this case, the most "efficient" flow rate is defined as the minimum flow rate that protects at least 90 percent of the habitat that is potentially available within the stream channel for both species. For example, if a PHABSIM modeling run showed that an equal amount of weighted usable area was available at either of two different flow rates, then the lower flow rate was identified for protection because it is more efficient. In addition, when identifying minimum flow rates, BLM and CPW personnel also considered the amount of time weighted usable area is available, specifically the number of days within a calendar year. CPW and BLM considered this factor because much of the potential habitat in the Dolores River is available during only a very short time period during the peak of snowmelt runoff.

Application of R2Cross Criteria

The primary objective of most cross section methodologies, including R2CROSS, is to maintain quality riffles. Riffles are the habitat most vulnerable to dewatering, and are important for invertebrate productivity. As noted previously, riffles comprise only a very small portion of the total habitat area in this stream reach, so the importance of maintaining riffle habitats is magnified even further. BLM and CPW performed a reconnaissance to identify the various types of riffles within this stream reach, based upon width, substrate, and average water velocity. The two agencies then selected four representative riffles for further R2CROSS analysis.

BLM and CPW personnel applied the following criteria in evaluating the R2CROSS modeling runs:

• Maintain 70% of wetted perimeter, given that the channel width typically exceeds 60 feet. This follows R2Cross criteria based on Nehring (1979).

• Maintain 1.3 feet per second average velocity and maintain 1.0 average depth. BLM and CPW altered the Nehring (1979) criteria for average velocity and average depth to be more species specific to the habitat needs for flannelmouth sucker and bluehead sucker. This criteria is recommended by Anderson and Steward (2003) to maintain marginally suitable habitat for flannelmouth sucker and bluehead sucker.

The R2CROSS model provides reliable predictive results for flows that are up to 250% of the flow measured during the data collection effort. It also provides reliable predictive results for flows down to 40% of the flow measured during the data collection effort. This range, from 40% to 250% of flows measured during the data collection, is referred to as the "confidence interval" for R2CROSS modeling.

When the flow rate that meets the instream flow criteria fell outside of this confidence interval, data from that cross section were not used to develop instream flow recommendations. The results from cross sections with usable results (inside the confidence interval) were averaged to develop the recommended flow rates.

Biological Flow Recommendations

Overview of Recommended Flow Rates

The recommended flow values were determined using the best professional judgment of CPW and BLM biologists and hydrologists. The CPW and BLM professionals reviewed and evaluated the results of the Physical Habitat Simulation (PHABSIM) Methodology and RHABSIM software PHABSIM/RHABSIM analysis. They also reviewed the R2CROSS analysis, using the criteria set forth above in this executive summary. These initial flow recommendations were based on the physical and biological data collected to date and do not incorporate any water availability constraints.

The PHABSIM/RHABSIM data analysis shows that the maximum amount of usable habitat for bluehead suckers is produced at a flow of 1200 cfs and for flannelmouth suckers at a flow of 875 cfs. BLM and CPW staff determined that a flow rate of 900 cfs would adequately protect the flannelmouth sucker habitat while protecting more than 90% of the usable habitat for bluehead sucker. BLM and CPW staff also noted that this usable habitat is typically available for only two months of the year. Accordingly, the initial biological recommendation for the snowmelt period between March 15 and August 14 is 900 cfs.

The R2CROSS analysis indicated that a fall/winter flow rate of approximately 100 cfs was necessary to meet two out of the three of the critical hydraulic criteria in the cross - section selected by the BLM and CPW. This flow rate is an average of the R2Cross results collected in five different riffles. BLM and CPW personnel also determined that a flow of 100 cfs would also protect other habitat types, such as pools and glides, during the base flow period. According, the initial biological recommendation for the base flow period between August 15 and March 14 is 100 cfs.

Consideration of Water Availability

After developing initial flow recommendations based exclusively upon maintenance of usable habitat and hydraulic characteristics, BLM and CPW reviewed the initial recommendations in light of water available during various times of the year. The BLM and CPW consideration of water availability was based upon an initial water availability analysis conducted by the CWCB staff. Consideration of water availability is very important for this recommendation because the amount of time (number of days in a calendar year) that habitat is available for the critical life functions of fish directly affects the health and viability of those populations.

After considering water availability, the initial flow recommendations were further modified as follows:

Time Period	% of 365-day year	Recommended Flow Rate	% of Weighted Usable Area Protected		Number of R2Cross Criteria Met
			Bluehead Sucker	Flannel-mouth Sucker	
April 15 to June 14 (61 days)	16.7%	900 cfs	94%	100%	3 of 3
June 15 to July 14 (30 days)	8.2 %	400 cfs	59%	66%	3 of 3
July 15 to August 14 (31 days)	8.5 %	200 cfs	30%	38%	3 of 3
August 15 to March 14 (212 days)	58%	100 cfs	8%	12%	2 of 3
March 15 to April 14 (31 days)	8.5%	200 cfs	30%	38%	3 of 3

The initial water availability analysis demonstrated that 900 cfs is available at least 50% of the time between April 15 and June 14, so no water availability adjustment was required during that time period. The biological flow recommendation of 900 cfs was reduced to 400 cfs for the June 15 through July 14 time period because of water availability concerns. The biological flow recommendation of 900 cfs flow was further reduced to 200 cfs during the July 15 to August 14 period because of water availability concerns. The recommendation for the June 15 to July 14 and July 15 to August 14 time periods are designed to maintain as much bluehead sucker and flannelmouth sucker habitat as possible during a period of the year when flows are rapidly declining. The descending limb of the hydrograph occurs at the warmest time of the year when the species are most active and are attempting to put on weight to survive limited food availability during winter.

The biological flow recommendation of 900 cfs was also reduced to 200 cfs for the March 15 to April 14 period because of water availability concerns. Protection of higher flows associated with the beginning of snowmelt runoff is warranted during this period because it is the beginning of the portion of the year when the sensitive fishes complete critical parts of their life cycles, including the commencement of spawning activities in early spring.

The R2CROSS Method suggests that fall/winter flows should be maintained at 100 cfs, which meets two of the three of the identified critical hydraulic criteria. The flow rate of 100 cfs was not reduced to address water availability concerns, because the initial water availability analysis performed by the CWCB suggests that 100 cfs is available at least 50% of the time during the time period between August 15 and March 14.

Hydrologic Data and Analysis

CWCB staff conducts hydrologic analyses for each recommended instream flow (ISF) appropriation to provide the Board with a basis for making the determination that water is available. Each recommended ISF reach has a unique flow regime that depends on variables such as the timing, magnitude, and location of water inputs (such as rain, snow, and snowmelt) and water losses (such as diversions, reservoirs, evaporation and transpiration, groundwater recharge, etc). Although extensive

and time consuming investigations of all variables may be possible, staff takes a pragmatic and cost-effective approach to analyze water availability. This approach focuses on streamflows and the influence of flow alterations, such as diversions, to understand how much water is physically available in the recommended reach.

Staff's hydrologic analysis is data-driven, meaning that staff gathers and evaluates the best available data and uses the best available analysis method for that data. Whenever possible, long-term stream gage data (period of record 20 or more years) will be used to evaluate streamflow. Other streamflow information such as short-term gages, temporary gages, spot streamflow measurements, diversion records, and StreamStats will be used when long-term gage data is not available. StreamStats, a statistical hydrologic program, uses regression equations developed by the USGS (Capesius and Stephens, 2009) to estimate mean flows for each month based on drainage basin area and average drainage basin precipitation. Diversion records will also be used to evaluate the effect of surface water diversions when necessary. Interviews with water commissioners, landowners, and ditch or reservoir operators can provide additional information. A range of analytical techniques may be employed to extend gage records, estimate streamflow in ungaged locations, and estimate the effects of diversions. The goal is to obtain the most detailed and reliable estimate of actual hydrology using the most efficient analysis technique.

The final product of the hydrologic analysis to determine water availability is a hydrograph, which shows streamflow and the proposed ISF rate over the course of one year. The hydrograph will show median daily values when daily data is available; otherwise, mean-monthly streamflow values will be presented.

Background Information

The proposed instream flow reach on the Dolores River receives water from the Dolores River, the San Miguel River, and a number of small tributaries that enter the reach between the confluence of the Dolores and San Miguel Rivers and the proposed lower terminus. The Dolores and San Miguel Rivers each have historical municipal and irrigation water uses that alter the nature flow of the system (CWCB, 2005). However, hydrology on the Dolores and San Miguel Rivers have been altered to different degrees.

Dolores River

The Dolores River has experienced significant changes in hydrology. There are a number of reservoirs on the system upstream from the proposed instream flow reach: Groundhog, McPhee, Summit, and Narraguinnep. Many of these reservoirs are part of large water projects such as the Montezuma Valley Irrigation Company (MVIC), the Summit Reservoir System, and the Dolores Project (CWCB, 2012).

The Dolores Project, which includes McPhee Dam and nearly 200 miles of canals, tunnels, pipelines and laterals, significantly alters the flow regime in the proposed instream flow (ISF) reach. The Dolores Project was developed by the United States Bureau of Reclamation (USBR) and supplies an average

annual volume of 90,900 acre-feet to Dove Creek, Towaoc, and the Montezuma Valley (USBR, 2012). Many of these are transbasin diversions that export water from the Dolores River system to the San Juan River system. The majority of decreed water uses occur upstream from McPhee Reservoir. The exceptions are a fish pool, senior downstream water rights, and flows necessary for a salinity control project in the Paradox Valley.

Construction of McPhee Dam started in 1980 and was completed in 1984 (Voggesser, 2001). Other portions of the project were completed later, such as the Great Cut Pumping Plant in 1987 and the McPhee Powerplant in 1993. The Dove Creek Canal and Towaoc Canal were completed in 1987 and 1993 respectively. The USBR declared the Dolores Project "substantially complete" in 1995 with "final completion" in September 1998 after correcting minor design and construction deficiencies in laterals and canals (Voggesser, 2001). The full Dolores Project was online and in use by 1999 or 2000, with 2000 the typical date given (Ken Curtis - Dolores Water Conservancy District, personal communication).

Operation of McPhee Dam and the Dolores Project in conjunction with natural flow conditions results in variable hydrology from year to year. In some years, no appreciable spill is released from McPhee Dam. In other years, there are substantial releases from McPhee Dam that resemble snow-melt runoff hydrology.

San Miguel River

The San Miguel is also influenced by storage reservoirs and irrigation diversions. Reservoirs include Gurley, Miramonte, Trout Lake, and Lake Hope. The United States Geological Survey (USGS) estimates 28,000 acres of irrigated lands upstream from the Uravan gage (USGS, 2013). Although streamflow on the San Miguel has been altered, it has not been impacted to the same degree as the Dolores River. The hydrograph for the San Miguel River exhibits more natural hydrology that follows patterns more typical of snow-melt driven systems.

Analysis Method

The upper Dolores River basin represents a complex system that has changed through time as different water projects were implemented. Given changes in use and available gage and diversion data, there are a number of time-frames and methods that could be used to analyze and determine water availability in the proposed instream flow reach. These range from relatively simple analysis of gage records to more comprehensive modeling efforts. Because of the complexities in this system, the final analysis is based on the Colorado Decision Support System (CDSS) Statemod model. This model has the capacity to simulate current operations of the Dolores River project using historical hydrology data. This model was selected for the final water availability analysis because staff believes it represents the best available data and analysis method for the Dolores River. This analysis method also aims to address concerns expressed during public outreach that water availability analyses reflect the full implementation of the Dolores Project.

CDSS

Statemod is a modeling system developed by the CWCB for water supply planning purposes, as part of the Colorado Decision Support System (CDSS). This model uses streamflow data, diversion records, water rights, reservoir contents, operating rules, return flow estimates, and consumptive use estimates among other datasets. The model simulates streamflow, native flow, and other information at specific locations in a basin (called nodes) for either monthly or daily time-steps. The model can be used to simulate different conditions including: 1) historic simulations that use historic hydrology based on historic operations of reservoirs and diversions; and 2) baseline simulations that use historic hydrology, but current operating rules and practices. The baseline simulation was used in staff's final water availability analysis because it had the ability to account for the completed Dolores River project.

The San Juan Statemod model contains the Dolores River and simulates flow from 1974 to 2006. This model was updated in 2010 as part of Colorado River Water Availability (CRWAS) Study and includes the operating procedures for the Dolores Project. Staff refined the San Juan model in the vicinity of the proposed instream flow reach. Nodes were added to the model to simulate flow conditions at the proposed upstream and downstream instream termini. Other modifications were made to improve accounting for irrigation diversions, return flows, and gains and losses within the reach due to tributary inflow, groundwater seepage, and other processes. More detailed information about the model modifications is available in the Dolores River Water Availability Technical Memo. Once modifications were complete, the daily baseline simulation was recalculated.

Water Availability Results

The simulated daily streamflow at the lower terminus was exported from the model and imported into Excel for analysis. The median streamflow, and upper and lower confidence intervals for the median streamflows were calculated. Statistically, there is 95% confidence that the true value of the median is located within the confidence interval. The hydrograph (see Figure 1) shows that the proposed instream flow rate is below the median daily streamflow for 351 of 365 days. The proposed ISF is higher than the median for 6 days in July, 6 days in August, and 2 days in September. The ISF is below the upper 95% confidence interval for all days of the year. Based on this analysis, staff concludes that water is available for appropriation.

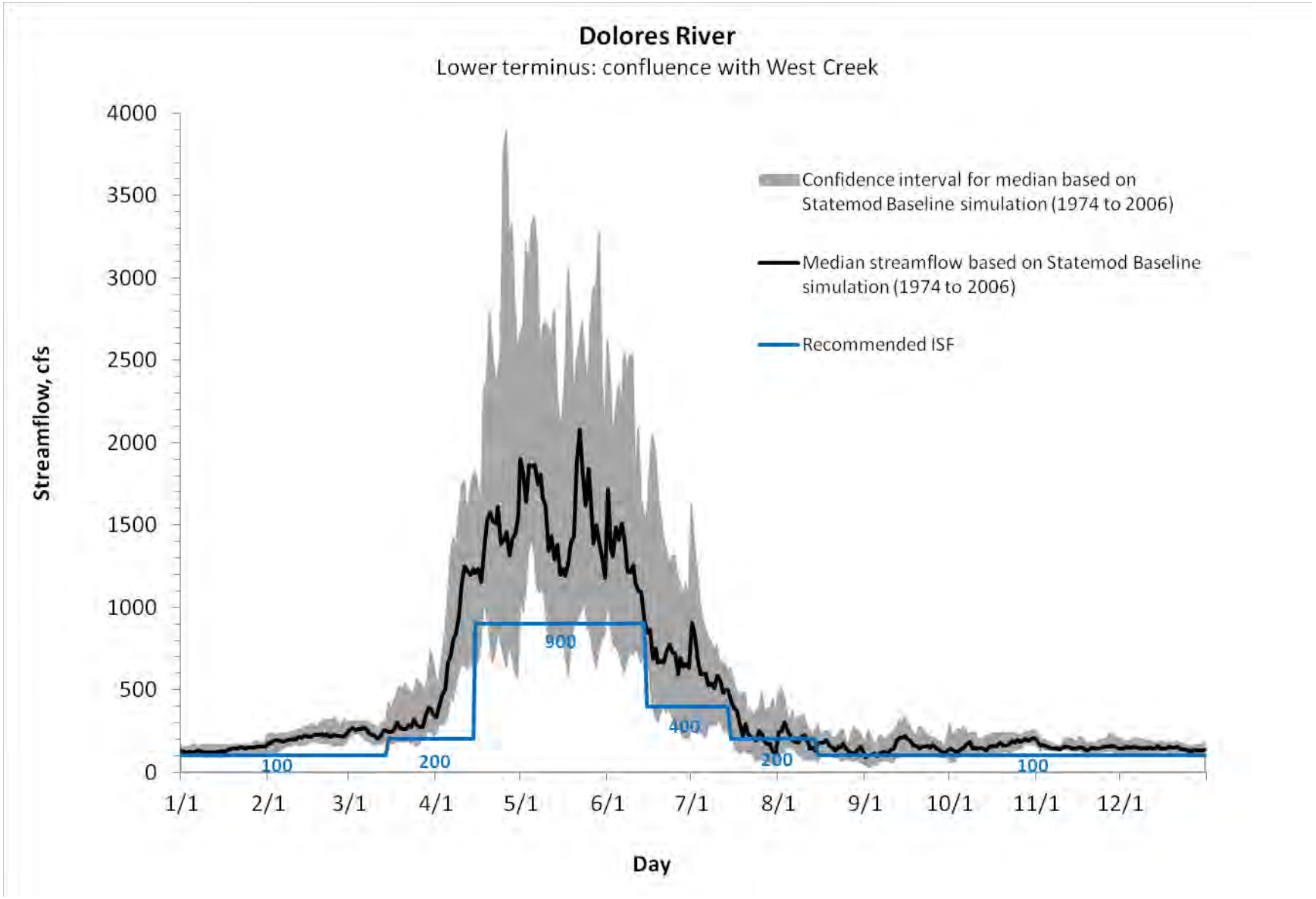


Figure 1. Hydrograph showing streamflow data and the proposed ISF rate on the Dolores River.

Citations

Anderson, R. & Stewart, G., 2007, Fish-Flow Investigation II. Impacts of stream flow alterations on the native fish assemblage and their habitat availability as determined by 2D modeling and the use of fish population data to support instream flow recommendations for the sections of the Yampa, Colorado, Gunnison and Dolores rivers in Colorado. In Special Report No. 80. Colorado Division of Wildlife. http://wildlife.state.co.us/NR/rdonlyres/778159B8-1EA2-443C-A0AF-A8DAB3F41473/0/SpecialReportpart2.pdf

CWCB, 2005, San Juan and Dolores River Basin Information, p 89.

CWCB, 2009, San Juan / Dolores River Basin Water Resources Planning Model User's Manual, p 296.

CWCB, 2010, StateDMI, p 996.

CWCB, 2012, Colorado River Water Availability Study, p 189.

Nehring, R., 1979, Evaluation of instream flow methods and determination of water quantity needs for streams in the State of Colorado. Colorado Division of Wildlife.

Steward, G., Anderson, R., and Wohl, E., 2005, Two-dimensional modeling of habitat suitability as a function of discharge on two Colorado rivers, River Research and Applications, Vol 21, Issue 10, pg 1061-1074. Doi:10.1002/rra.868/

Stewart, G. & Anderson, R., 2007, Fish-Flow Investigation I. Two-dimensional modeling for predicting fish biomass in western Colorado. In Special Report Number 80. Colorado Division of Wildlife. http://wildlife.state.co.us/NR/rdonlyres/1F5A5F31-DDCB-4478-B810-1B37B129627F/0/SpecialReportpart1.pdf

Voggesser, G., 2001, The Dolores Project, Bureau of Reclamation History, p 46. http://www.usbr.gov/projects//ImageServer?imgName=Doc_1303397411306.pdf

USBR, Dolores Project. Updated 3-12-2009, accessed 10-22-2013 at http://www.usbr.gov/projects/Project.jsp?proj_Name=Dolores%20Project

USGS, 2013, Water-resources data for the United States, Water Year 2012: U.S. Geological Survey Water-Data Report WDR-US-2012, site 09177000, accessed at: http://wdr.water.usgs.gov/wy2012/pdfs/09177000.2012.pdf

Existing Water Rights

Staff has analyzed the water rights tabulation and determined that there are seven decreed absolute surface diversions within this reach of stream: Ben Ames Ditch, Case No. CA4952 for 4.10 cfs with a 3/1/1930 appropriation date; Castro Pumping Plant; Case No. W0637 for 4.5 cfs with a 10/11/1922 appropriation date; Foster Miner Ditch Point A, Case No. W0143 for 5.65 cfs with a 10/11/1922 appropriation date; Red Cross Ditch, Case No. CA4952 for 10.09 cfs with a 6/15/1918 appropriation date; Red Cross Ditch Point A, Case No. W0724, for 2.21 cfs and a 9/25/1922 appropriation date; Roc Creek Diversion, Case No. 07CW220, for 1.43 cfs with a 7/10/2006 appropriation date; and Sheep Shed Canyon Ditch, Case No. W3386 for 3 cfs with a 5/15/1906 appropriation date. Staff has concluded that a new junior appropriation of water rights on the Dolores River can exist to preserve the natural environment to a reasonable degree without limiting or foreclosing the exercise of valid existing water rights.

CWCB Staff's Instream Flow Recommendation

Staff recommends that the Board form its intent to appropriate on the following stream reach:

Segment: CONFLUENCE SAN MIGUEL RIVER TO CONFLUENCE WEST CREEK

Upper Terminus: CONFLUENCE SAN MIGUEL RIVER AT
UTM North: 4254788.25 UTM East: 167728.07
(Latitude 38° 22' 46.6"N) (Longitude 108° 48' 12.89"W)
SW SE Section 25, Township 48 North, Range 18 West NM PM
2,126' West of the East Section Line; 285' North of the South Section Line

Lower Terminus: CONFLUENCE WEST CREEK AT
UTM North: 4288483.48 UTM East: 154090.30
(Latitude 38° 40' 38.57"N) (Longitude 108° 58' 33.67"W)
NE NW Section 22, Township 51 North, Range 19 West NM PM
1,563' East of the West Section Line; 388' South of the North Section Line

Watershed: Lower Dolores (HUC #: 14030004)
Counties: Mesa, Montrose
Length: 34.21 miles
USGS Quad(s): Gateway, Juanita Arch, Red Canyon, Roc Creek
Flow Recommendation: 900 cfs (4/15 – 6/14)
400 cfs (6/15 – 7/15)
200 cfs (7/16 – 8/14)
100 cfs (8/15 – 3/15
200 cfs (3/16 – 4/14)

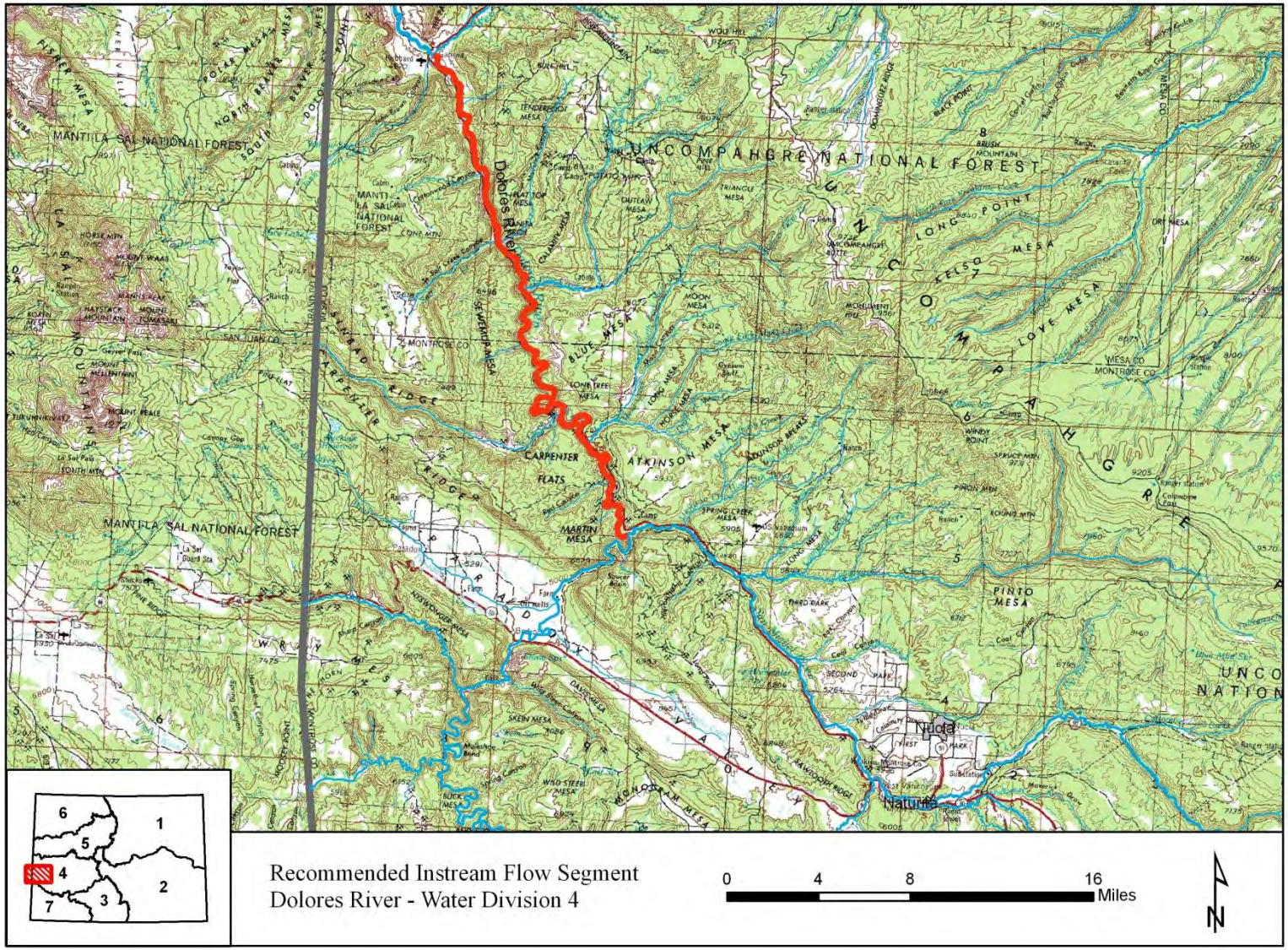
Metadata Descriptions:

a) The UTM, PLSS and Lat/Long locations for the upstream and downstream termini were derived from CWCB GIS using the National Hydrography Dataset (NHD).

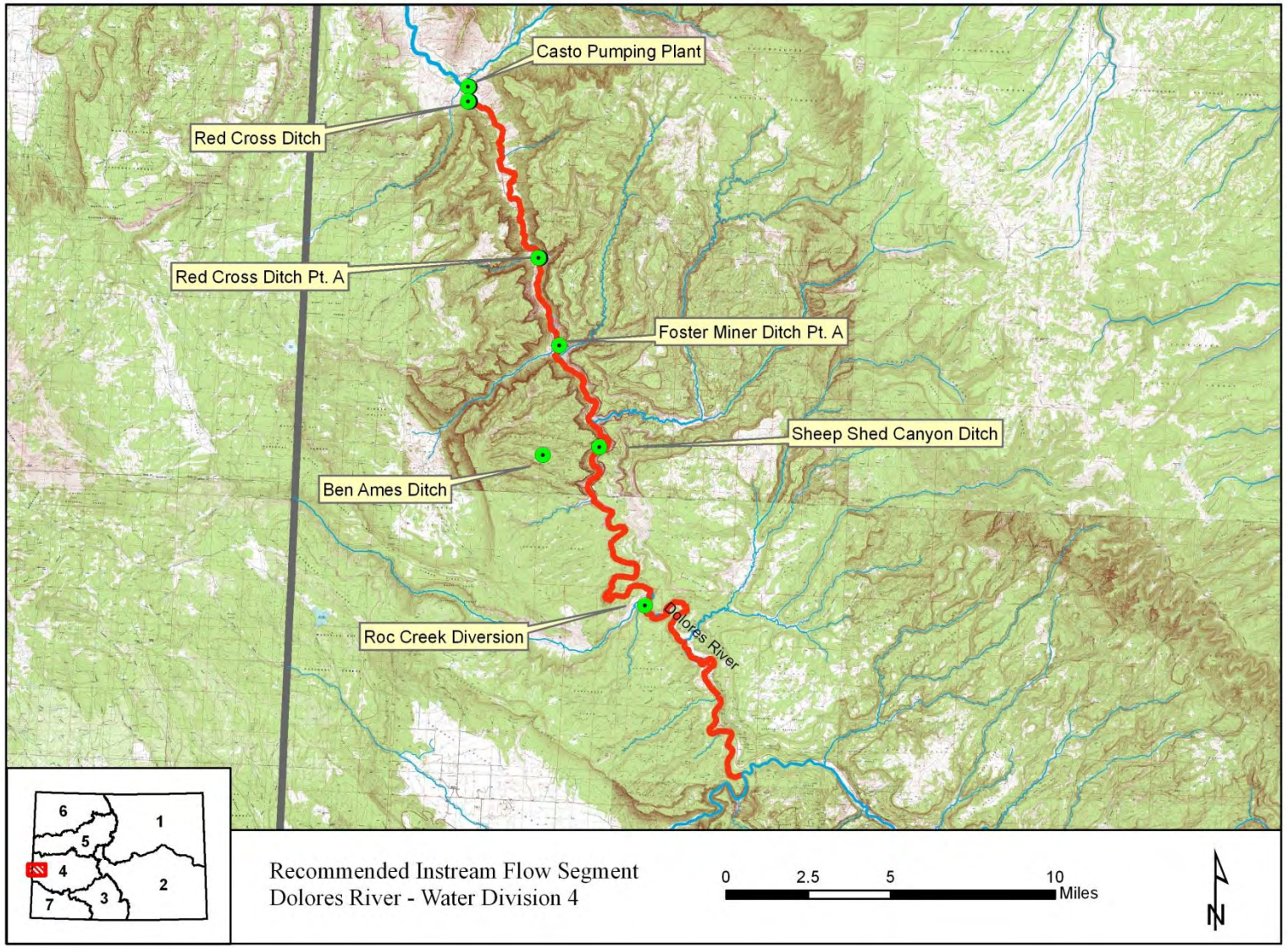
b) The PLSS locations were derived from CWCB GIS using 2005 PLSS data from the U.S. Bureau of Land Management's Geographic Coordinate Database

c) Projected Coordinate System: NAD 1983 UTM Zone 13N

Vicinity Map



Water Rights Map



Land Use Map

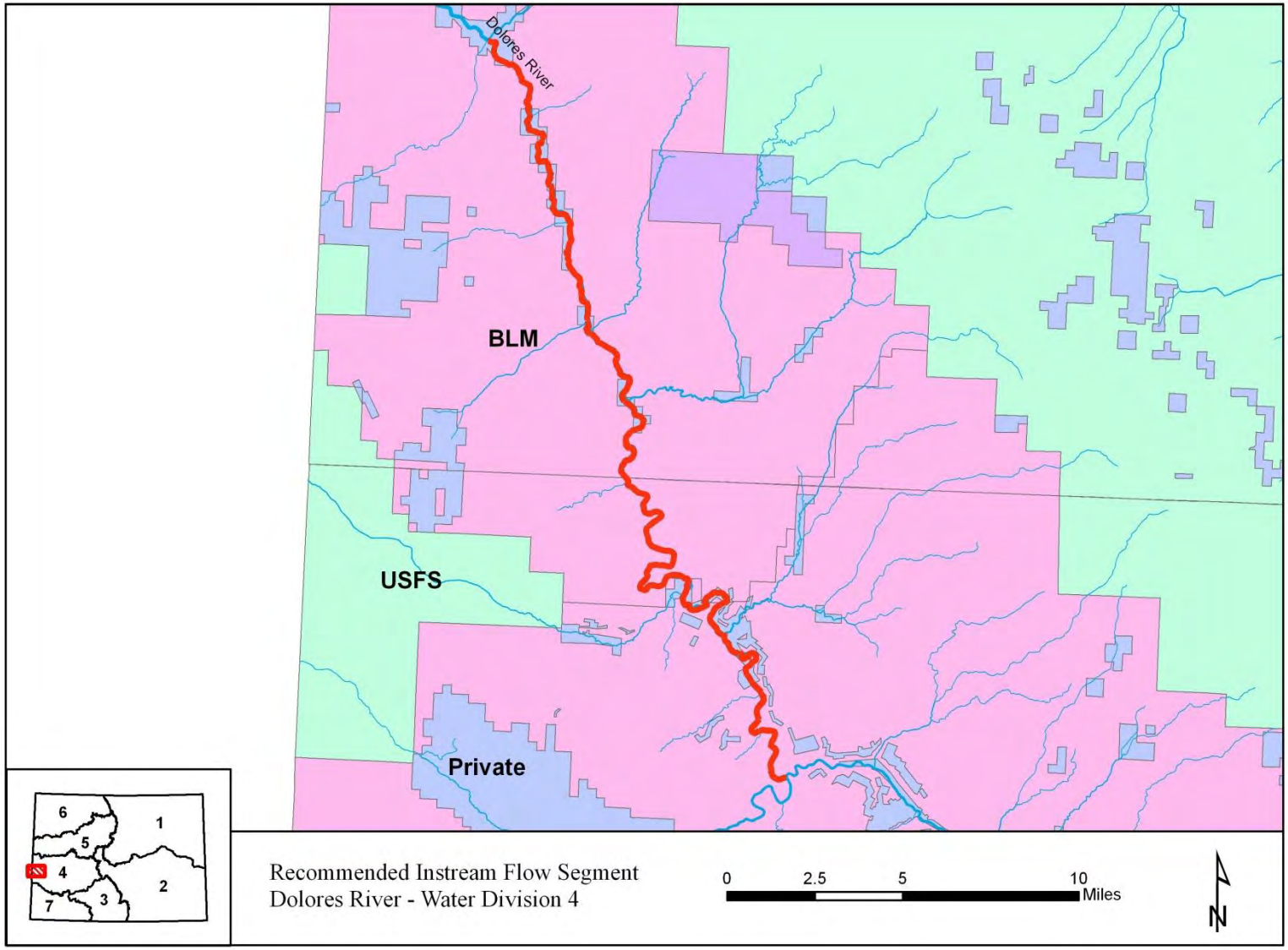

Dolores River
BLM
USFS
Private
6
1
5
4
2
7
3
Recommended Instream Flow Segment
Dolores River - Water Division 4
0
2.5
5
10
Miles
N

Exhibit 4

RULES CONCERNING THE COLORADO INSTREAM FLOW AND NATURAL LAKE LEVEL PROGRAM

Adopted by the
Colorado Water Conservation Board
January 27, 2009

Statement of Basis and Purpose

In 1973, the General Assembly enacted Senate Bill 97, creating the Colorado Instream Flow and Natural Lake Level Program ("ISF Program"), to be administered by the Colorado Water Conservation Board ("Board"). The statutory authority for these Rules is found at sections 37-60-108 and 37-92-102(3), C.R.S. (2008). The purpose of these Rules, initially adopted in 1993, is to codify and establish procedures for the Board to implement the ISF Program.

The Board has amended the Rules several times since 1993 to reflect changes in the statutes related to the ISF Program. Notably, in 1999, the Board repealed the existing Rule 5 in its entirety, and, among other things, adopted a new Rule 5 to establish a public notice and comment process for instream flow water right appropriations. In 2003, the Board amended Rule 6 to implement the provisions of Senate Bill 02-156 by identifying factors that the Board will consider when determining whether to acquire water, water rights, or interests in water, and by establishing procedures for notice, public input, and, if necessary, hearings. In 2004, the Board amended Rule 6 to implement House Bill 03-1320, codified at section 37-83-105, C.R.S. (2003), to allow for emergency loans of water for instream flows. The Board also amended Rule 6 to enable the Board to finalize an acquisition within a two-meeting time frame, if necessary. In 2005, the Board amended Rule 6 to implement House Bill 05-1039, establishing how the Board and its staff will respond to offers of water for temporary instream flow use and expedite use of loaned water for instream flow purposes.

In 2009, the Board amended Rule 6 to adopt criteria specified in House Bill 08-1280 (codified at sections 37-92-102(3), 37-92-103 and 37-92-305, C.R.S.) for evaluating proposed leases or loans of water, and to incorporate H.B. 1280's requirements for: (1) specific conditions that must be met as part of the CWCB's approval of a proposed loan or lease of water; (2) provisions that must be included in all agreements for loans or leases of water under section 37-92-102(3); and (3) actions that the Board must take in connection with loans or leases of water. Rule 6 does not incorporate those provisions of H.B. 1280 that direct the water courts or the Division of Water Resources to take certain actions in regard to water acquisitions by the Board for instream flow use.

Specifically, the 2009 Rules 6a., 6c., 6e, 6j., 6k., 6l., and 6m. clarify the Board's evaluation process, Board funding for water leases and purchases, and public input for proposed acquisitions of water, water rights or interests in water for instream flow use. Rule 6f. identifies additional factors for loans and leases of water, and Rules 6g. and 6h. describe recording requirements and water reuse provisions to be included in contracts or agreements for water acquisitions. Rule 6i. incorporates H.B 1280's requirements regarding water court applications filed by the Board to obtain a decreed right to use acquired water for instream flow purposes. Regarding the historical consumptive use quantification referred to in Rule 6i.(1), the Board will not object to a water rights owner requesting a term and condition from the water court that the historical consumptive use determination shall not apply to the water right at the expiration of the lease or loan.

In 2009, the Board also amended Rules 8e.—h. (De Minimis Rule) to recognize priority administration of the CWCB's instream flow water rights and clarify that the

decision not to file a statement of opposition under this Rule does not constitute: (1) acceptance by the CWCB of injury to any potentially affected instream flow water right; or (2) a waiver of the CWCB's right to place an administrative call for any instream flow water right. Rule 8e.(1) sets forth what type of notice the CWCB will provide to water court applicants and to the Division Engineer when it elects not to file a statement of opposition to a water court application under this Rule.

Finally, in 2009, the Board amended Rule 8i.(3) (Injury Accepted with Mitigation) to provide notice to water users of: (1) the information they must submit to the CWCB when requesting that the CWCB enter into a pretrial resolution under which it will accept injury with mitigation; (2) the factors the CWCB will consider in evaluating an injury with mitigation proposal; and (3) the terms and conditions the CWCB will require in decrees incorporating injury with mitigation.

In general, it is the policy of the CWCB to consider injury with mitigation proposals only when no other reasonable water supply alternatives can be implemented. Exceptions to the policy may be granted when the proponent can demonstrate that the proposed mitigation will result in significant and permanent enhancements to the natural environment of the subject stream or lake existing at the time the proponent proposes the injury with mitigation.

DEPARTMENT OF NATURAL RESOURCES

Colorado Water Conservation Board

RULES CONCERNING THE COLORADO INSTREAM FLOW AND NATURAL LAKE LEVEL PROGRAM

2 CCR 408-2

1. TITLE.

Rules Concerning the Colorado Instream Flow and Natural Lake Level Program, hereafter referred to as the Instream Flow ("ISF") Program as established in §37-92-102 (3) C.R.S., shall be hereinafter referred to as the "ISF Rules."

2. PURPOSE OF RULES.

The purpose of the ISF Rules is to set forth the procedures to be followed by the Board and Staff when implementing and administering the ISF Program. By this reference, the Board incorporates the Basis and Purpose statement prepared and adopted at the time of rulemaking. A copy of this document is on file at the Board office.

3. STATUTORY AUTHORITY.

The statutory authority for the ISF Rules is found at §37-60-108, C.R.S. and §37-92-102 (3), C.R.S. Nothing in these rules shall be construed as authorizing the Board to deprive the people of the state of Colorado of the beneficial use of those waters available by law and interstate compact.

4. DEFINITIONS.

4a. Agenda Mailing List.

The agenda mailing list consists of all Persons who have sent a notice to the Board Office that they wish to be included on such list. These Persons will be mailed a Board meeting agenda prior to each scheduled Board meeting.

4b. Board.

Means the Colorado Water Conservation Board as defined in §§37-60-101, 103 and 104, C.R.S.

4c. Board Office.

The Colorado Water Conservation Board's office is located at 1313 Sherman Street, 7th Floor, Denver, CO 80203. The phone number is (303) 866-3441. The facsimile number is (303) 866-4474. The Board's website is http://www.cwcb.state.co.us.

4d. Contested Hearing Mailing List.

The Contested Hearing Mailing List shall consist of all Persons who have received Party status or Contested Hearing Participant status pursuant to Rules 5l. or 5m. This mailing list is specific to a contested appropriation.

4e. Contested Hearing Participant.

Any Person who desires to participate in the contested ISF process, but not as a Party, may obtain Contested Hearing Participant status pursuant to Rule 5m. A Person with such status will receive all Party documents. Contested Hearing Participants may comment on their own behalf, but may not submit for the record technical evidence, technical witnesses or legal memoranda.

4f. CWCB Hearing Officer.

The Hearing Officer is appointed by the Board and is responsible for managing and coordinating proceedings related to contested ISF appropriations, acquisitions or modifications, such as setting prehearing conferences and adjusting deadlines and schedules to further the Parties' settlement efforts or for other good cause shown. The Hearing Officer does not have the authority to rule on substantive issues.

4g. Final Action.

For purposes of Rule 5, final action means a Board decision to (1) file a water right application, (2) not file a water right application or (3) table action on an ISF appropriation; however, tabling an action shall not be construed as abandonment of its intent to appropriate.

4h. Final Staff ISF Recommendation.

Staff's ISF recommendation to the Board is based on Staff's data and report, and public comments and data contained in the official record.

4i. ISF.

Means any water, or water rights appropriated by the Board for preservation of the natural environment to a reasonable degree, or any water, water rights or interests in water acquired by the Board for preservation or improvement of the natural environment to a reasonable degree. “ISF” includes both instream flows between specific points on a stream and natural surface water levels or volumes for natural lakes.

4j. ISF Subscription Mailing List(s).

The ISF Subscription Mailing List(s) are specific to each water division. The ISF Subscription Mailing List(s) shall consist of all Persons who have subscribed to the list(s) by sending notice(s) to the Board Office that they wish to be included on such list for a particular water division. The Staff shall, at such times as it deems appropriate, mail to all Persons on the water court resume mailing list in each water division an invitation to be included on the ISF Subscription Mailing List for that water division. Persons on the list are responsible for keeping Staff apprised of address changes. Persons on the ISF Subscription Mailing List(s) shall receive agendas and other notices describing activities related to ISF recommendations, appropriations and acquisitions in the particular water division. Persons may be required to pay a fee in order to be on the ISF Subscription Mailing List(s).

4k. Mail.

For the purposes of the ISF Rules, mail refers to regular or special delivery by the U.S. Postal Service or other such services, electronic delivery (e-mail), or delivery by FAX transmission.

4l. Party.

Any Person may obtain Party status pursuant to Rule 5l. Only a Person who has obtained Party status may submit, for the record, technical evidence, technical witnesses or legal memoranda. Each Party is responsible for mailing copies of all documents to all other Parties and Contested Hearing Participants.

4m. Person.

Means any human being, partnership, association, corporation, special district, water conservancy district, water conservation district, municipal entity, county government, state government or agency thereof, and federal government or agency thereof.

4n. Proper Notice.

Means the customary public notice procedure that is provided each year by the Board in the preamble to the Board's January Board meeting agenda. This customary public notice procedure may include posting of the agenda at the Board office, filing legal notices when required, mailing to Persons on the Board mailing lists and posting notices on the Board's website.

4o. Stacking.

As used in Rule 6, the terms “stack” or “stacking” refer to an instance in which the Board holds more than one water right for the same lake or reach of stream and exercises the rights independently according to their decrees.

4p. Staff.

Means the Director of the Colorado Water Conservation Board (“CWCB Director”) and other personnel employed by the Board.

5. ORIGINAL APPROPRIATION PROCEDURE.

5a. Recommendation of Streams and Lakes for Protection.

All Persons interested in recommending certain stream reaches or natural lakes for inclusion in the ISF Program may make recommendations to the Board or Staff at any time. Staff will provide a preliminary response to any Person making such a recommendation within 30 working days after receipt of the recommendation at the Board Office. Staff will collaborate with State and Federal agencies and other interested Persons to plan and coordinate collection of field data necessary for development of ISF recommendations. The Staff shall advise the Board, at least annually, of all new recommendations received and of streams and lakes being studied for inclusion in the ISF Program.

5b. Method of Making Recommendations.

All recommendations transmitted to the Board or Staff for water to be retained in streams or lakes to preserve the natural environment to a reasonable degree must be made with specificity and in writing.

5c. Board Approval Process.

Periodically, after studying streams and lakes for inclusion in the ISF Program, Staff will recommend that the Board appropriate ISF rights. The Board and Staff will use the following annual schedule for initiating, processing and appropriating ISF water rights:

January

- The January Board meeting agenda will list proposed ISF appropriations to be appropriated that year.
- Staff will provide data, engineering and other information supporting each proposed ISF appropriation to the Board prior to or at the January Board meeting.

- Staff will present its information and recommendation for each proposed ISF appropriation at the January Board meeting.

- The Board will take public comment on the proposed ISF appropriations at the January Board meeting.

- The Board may declare its intent to appropriate for each proposed ISF appropriation at the January Board meeting, provided that the particular ISF appropriation has been listed as being under consideration in a notice, mailed at least 60 days prior to the January Board meeting, to the ISF Subscription Mailing List for the relevant water division(s).

- Notice of the Board having declared its intent to appropriate will be distributed through the ISF Subscription Mailing List for the relevant water division(s).

March

- The Board will take public comment on all ISF appropriations at the March Board meeting.

- Notice to Contest an ISF appropriation, pursuant to Rule 5k, must be submitted to the Board Office by March 31st, or the first business day thereafter.

April

- Staff will notify all Persons on the ISF Subscription Mailing List(s) of contested ISF appropriations by April 10th, or the first business day thereafter.

- Notice of Party status or Contested Hearing Participant status, pursuant to Rules 5l. or 5m., must be submitted to the Board Office by April 30th, or the first business day thereafter.

May

- Staff will report to the Board which ISF appropriations are being contested.

- The Board may set hearing dates for contested ISF appropriations.

- At the May Board meeting, the Board may take final action on all uncontested ISF appropriations.

July

- A prehearing conference will be held prior to the July Board meeting for all contested ISF appropriations (Date specific to be determined by the Hearing Officer).

- Five working days before the prehearing conference, all Parties shall file at the Board office, for the record, any and all legal memoranda, engineering data, biological data and reports or other information upon which the Party will rely.

August

- All Parties must submit written rebuttal statements, including testimony and exhibits, by August 15th, or the first business day thereafter. Except for such rebuttal and testimony provided at the hearing pursuant to Rule 5p.(2), the Board will not accept any statements,

related documentation or exhibits submitted by any Party after the prehearing conference, except for good cause shown or as agreed upon by the Parties.

September

- Staff will make its final recommendations to the Board, based upon its original report, all public comments, documents submitted by the Parties and all data contained in the official record, at the September Board meeting.
- Notice of the Final Staff ISF Recommendations will be sent to all Persons on the Contested Hearing Mailing List prior to the September Board meeting.
- Parties may choose to continue or withdraw their Notice to Contest an ISF appropriation at or before the September Board Meeting.
- The Board will hold hearings on all contested ISF appropriations.

November

- The Board shall update the public on the results of any hearings through its agenda and may take final action on contested ISF appropriations.

When necessary, the Board may modify or delay this schedule or any part thereof as it deems appropriate.

5d. Board's Intent to Appropriate.

Notice of the Board's potential action to declare its intent to appropriate shall be given in the January Board meeting agenda and the Board will take public comment regarding its intent to appropriate at the January meeting.

(1) After reviewing Staff's recommendations for proposed ISF appropriations, the Board may declare its intent to appropriate specific ISF water rights. At that time, the Board shall direct the Staff to publicly notice the Board's declaration of its intent to appropriate.

(2) After the Board declares its intent to appropriate, notice shall be published in a mailing to the ISF Subscription Mailing Lists for the relevant water divisions and shall include:

(a) A description of the appropriation (e.g. stream reach, lake location, amounts, etc.);

(b) Availability (time and place) for review of Summary Reports and Investigations Files for each appropriation; and,

(c) Summary identification of any data, exhibits, testimony or other information in addition to the Summary Reports and Investigations Files supporting the appropriation.

(3) Published notice shall also contain the following information:

(a) The Board may change flow amounts of contested ISF appropriations based on information received during the public notice and comment period.

(b) Staff will maintain, pursuant to Rule 5e.(3), an ISF Subscription Mailing List for each water division composed of the names of all Persons who have sent notice to the Board Office that they wish to be included on such list for a particular water division. Any Person

desiring to be on the ISF Subscription Mailing List(s) must send notice to the Board Office.

(c) Any meetings held between Staff and members of the public will be open to the public. Staff may provide Proper Notice prior to any such meetings and may provide notice to Persons on the ISF Subscription Mailing List(s).

(d) Any Notice to Contest must be received at the Board office no later than March 31st, or the first business day thereafter. All Notices of Party status and Contested Hearing Participant status must be received at the Board office no later than April 30th, or the first business day thereafter.

(e) Staff will announce its Final Staff ISF Recommendation concerning contested appropriations at the September Board meeting and will send notice of the Final Staff ISF Recommendations to all Persons on the Contested Hearing Mailing List.

(f) The Board may take final action on any uncontested ISF appropriations at the May Board meeting.

(4) After the Board declares its intent to appropriate, notice of the Board's action shall be mailed within five working days to the County Commissioners of the county(ies) in which the proposed reach or lake is located.

(5) Final action by the Board on ISF appropriations will occur no earlier than the May Board meeting.

5e. Public Comment.

(1) The Board will hear comment on the recommended action to declare its intent to appropriate at the January Board Meeting.

(2) ISF appropriations will be noticed in the Board agenda for each regularly scheduled subsequent meeting until the Board takes final action. Prior to March 31st, at each regularly scheduled Board meeting, time will be allocated for public comment. Subsequent to March 31st, the Board will accept public comment on any contested ISF appropriations or lake levels only at the hearings held on those appropriations pursuant to Rule 5j.

(3) Staff will maintain an ISF Subscription Mailing List for each water division. Any Person desiring to receive information concerning proposed ISF appropriations for that water division must contact the Board Office to request inclusion on that ISF Subscription Mailing List.

5f. Date of Appropriation.

The Board may select an appropriation date that may be no earlier than the date the Board declares its intent to appropriate. The Board may declare its intent to appropriate when it concludes that it has received sufficient information that reasonably supports the findings required in Rule 5i.

5g. Notice.

Agenda and ISF Subscription Mailing List(s) notice shall be given pursuant to Rule 5d. and the public shall be afforded an opportunity to comment pursuant to Rule 5e. Notice of the date of final action on uncontested ISF appropriations shall be mailed to Persons on the ISF Subscription Mailing Lists for the relevant water divisions, maintained pursuant to Rule 5e.(3).

5h. Final Board Action on an ISF Appropriation.

The Board may take final action on any uncontested ISF appropriation(s) at the May Board meeting or any Board meeting thereafter. If a Notice to Contest has been filed, the Board shall proceed under Rules 5j. - 5q.

5i. Required Findings.

Before initiating a water right filing to confirm its appropriation, the Board must make the following determinations:

(1) Natural Environment.

That there is a natural environment that can be preserved to a reasonable degree with the Board's water right if granted.

(2) Water Availability.

That the natural environment will be preserved to a reasonable degree by the water available for the appropriation to be made.

(3) Material Injury.

That such environment can exist without material injury to water rights.

These determinations shall be subject to judicial review in the water court application and decree proceedings initiated by the Board, based on the Board's administrative record and utilizing the criteria of §§24-4-106(6) and (7), C.R.S.

5j. Procedural Rules for Contested ISF Appropriations.

(1) Whenever an ISF appropriation is contested, the Board shall hold a hearing at which any Party may present evidence, witnesses and arguments for or against the appropriation and any Contested Hearing Participant or member of the public may comment. The hearing shall be a notice and comment hearing as authorized in §37-92-102(4)(a), C.R.S., and shall not be a formal agency adjudication under §24-4-105, C.R.S.

(2) These rules are intended to assure that information is received by the Board in a timely manner. Where these rules do not address a procedure or issue, the Board shall determine the procedures to be followed on a case-by-case basis. The Board may waive the requirements of these rules whenever the Board determines that strict adherence to the rules is not in the best interests of fairness, unless such waiver would violate applicable statutes. For any such waiver, the Board shall provide appropriate justification, in writing, to Persons who have Party or Contested Hearing Participant status.

(3) In a hearing on a contested ISF appropriation, a Party may raise only those issues relevant to the statutory determinations required by §37-92-102(3)(c), C.R.S. and the required findings in Rule 5i.

5k. Notice to Contest.

(1) To contest an ISF appropriation, a Person must comply with the provisions of this section. The Board must receive a Notice to Contest the ISF appropriation by March 31st, or the first business day thereafter.

(2) A Notice to Contest an ISF appropriation shall be made in writing and contain the following information:

(a) Identification of the Person(s) requesting the hearing;

(b) Identification of the ISF appropriation(s) at issue; and,

(c) The contested facts and a general description of the data upon which the Person will rely to the extent known at that time.

(3) After a Party has filed a Notice to Contest an ISF appropriation, any other Person may participate as a Party or a Contested Hearing Participant pursuant to Rules 5l. or 5m.

(4) Staff will notify all Persons on the relevant ISF Subscription Mailing List(s) of contested ISF appropriations by April 10th, or the first business day thereafter.

5l. Party Status.

(1) Party status will be granted to any Person who timely files a Notice of Party Status with the Staff. Any Person filing a Notice to Contest shall be granted Party status and need not also file a Notice of Party Status. A Notice of Party status must be received by April 30th, or the first business day thereafter. A Notice of Party status shall set forth a brief and plain statement of the reasons for obtaining Party status, the contested facts, the matters that the Person claims should be decided and a general description of the data to be presented to the Board. The Board will have discretion to grant or deny Party status to any Person who files a Notice of Party Status after April 30th or the first business day thereafter, for good cause shown.

(2) Only a Party may submit for the record technical evidence, technical witnesses or file legal memoranda. Each Party is responsible for mailing copies of all documents submitted for Board consideration to all other Parties and Contested Hearing Participants.

(3) The Staff shall automatically be a Party in all proceedings concerning contested ISF appropriations.

(4) Where a contested ISF appropriation is based fully or in part on another agency's recommendation pursuant to Rule 5a., that agency shall automatically be a Party in any proceeding.

(5) All Parties, whether they achieved such status by filing a Notice to Contest or a Notice of Party Status, shall be afforded the same rights in the contested ISF appropriation proceedings. Specifically, but without limiting the generality of the foregoing sentence, any Person who filed a Notice of Party Status is entitled to raise issues not raised by any Person who filed a Notice to Contest.

5m. Contested Hearing Participant Status.

(1) Any Person who desires to participate in the process, but not as a Party, may obtain Contested Hearing Participant status by filing a notice thereof at the Board Office prior to April 30th. A Person with such status will receive all Party documents specific to the contested appropriation. Contested Hearing Participants may comment on their own behalf, but may not submit for the record technical evidence, technical witnesses or legal memoranda. The Board will have discretion to grant or deny Contested Hearing Participant status to any Person who filed a Notice of Contested Hearing Participant Status after April 30th or the first business day thereafter, for good cause shown.

(2) The request for Contested Hearing Participant status must be received by April 30th, or the first business day thereafter.

(3) Staff shall notify all Parties and Contested Hearing Participants of the list of Contested Hearing Participants prior to May 31st. Thereafter, Parties shall also mail their prehearing statements and any other documents to Contested Hearing Participants.

5n. <u>Prehearing Conference.</u>

(1) The Board will designate a Hearing Officer, who shall schedule and preside over prehearing conferences and assist the Parties with procedural matters, such as setting prehearing conferences and adjusting deadlines and schedules to further the Parties' settlement efforts or for other good cause shown. All prehearing conferences will be scheduled and held prior to the July Board meeting.

(2) On or before five working days before the prehearing conference, each Party shall file 25 copies of its prehearing statement with the Board, and provide an electronic version when possible. The prehearing statement shall identify all exhibits, engineering data, biological data and reports or other information that the Party will rely upon at the hearing and shall contain:

(a) A specific statement of the factual and legal claims asserted (issues to be resolved) and the legal basis upon which the Party will rely;

(b) Copies of all exhibits to be introduced at the hearing;

(c) A list of witnesses to be called and a brief description of their testimony;

(d) Any alternative proposal to the proposed ISF appropriation;

(e) All written testimony to be offered into evidence at the hearing;

and

(f) Any legal memoranda.

Each Party shall deliver a copy of its prehearing statement to all other Parties, Contested Hearing Participants, the Hearing Officer and directly to the Assistant Attorneys General representing Staff and the Board five working days before the prehearing conference. The Board will not consider information, other than rebuttal statements and testimony provided at the hearing pursuant to Rule 5p.(2), submitted by the Parties after this deadline except for good cause shown or as agreed upon by the Parties.

(3) Any Contested Hearing Participant may also submit written comments 5 working days prior to the prehearing conference. Contested Hearing Participants who submit written comments for the Board's consideration shall provide 25 copies to the Board, and a copy to all other Contested Hearing Participants, Parties, the Hearing Officer and the Assistant Attorneys General representing Staff and Board, and provide an electronic version when possible.

(4) The prehearing conference will afford the Parties the opportunity to address such issues as time available for each Party at the hearing, avoiding presentation of duplicative information, consolidation of concerns, etc. The Parties may formulate stipulations respecting the issues to be raised, witnesses and exhibits to be presented, and/or any other matters which may be agreed to or admitted by the Parties. At the prehearing conference, the Parties shall make known any objections to the procedures or evidence that they may raise at the hearing unless such objections could not have been reasonably determined at that time.

(5) August 15th, or the first business day thereafter, is the last day for submission of written rebuttal statements, including testimony, legal memoranda, and exhibits. Twenty-five copies of such

materials must be provided to the Board, and an electronic version also provided, when possible. Except for such rebuttal and testimony provided at the hearing pursuant to Rule 5p.(2), the Board will not accept any statements, related documentation or exhibits submitted by any Party after the deadline set forth in Rules 5n.(2) and 5n.(3), except for good cause shown or as agreed upon by the Parties. The scope of rebuttal is limited to issues and evidence presented in the prehearing statements. Any documentation to be submitted pursuant to this subsection (5) shall be delivered to the Board and mailed to all Parties and Contested Hearing Participants by August 15th, or the first business day thereafter, unless the Parties agree otherwise.

5o. Notice of Hearings on Contested ISF Appropriations.

(1) Staff shall mail notice of prehearing conference(s) on contested ISF appropriations to all Persons on the Contested Hearing Mailing List for the particular ISF appropriation. The notice shall specify the time and place of the prehearing conference and any procedural requirements that the Board deems appropriate.

(2) The Board may postpone a hearing to another date by issuing written notice of the postponement no later than 7 calendar days prior to the original hearing date.

5p. Conduct of Hearings.

(1) In conducting any hearing, the Board shall have authority to: administer oaths and affirmations; regulate the course of the hearing; set the time and place for continued hearing; limit the number of technical witnesses; issue appropriate orders controlling the subsequent course of the proceedings; and take any other action authorized by these Rules.

(2) At the hearing, the Board shall hear arguments, concerns or rebuttals from Parties, Contested Hearing Participants and interested members of the public. The Board may limit testimony at the hearing. Without good cause, the Board will not permit Parties or Contested Hearing Participants to introduce written material at the hearing not previously submitted pursuant to these Rules. The Board, in making its determinations, need not consider any written material not timely presented.

(3) Only the Board may question witnesses at the hearing except where the Board determines that, for good cause shown, allowing the parties to question witnesses may materially aid the Board in reaching its decision, or where such questioning by the Parties relates to the statutory findings required by §37-92-102(3)(c), C.R.S. The Board may terminate questioning where the Board determines that such questioning is irrelevant or redundant or may terminate such questioning for other good cause.

(4) The hearing shall be recorded by a reporter or by an electronic recording device. Any Party requesting a transcription of the hearing shall be responsible for the cost of the transcription.

5q. Final Board Action.

The Board may take final action at the hearing or at a later date.

5r. Statement of Opposition.

In the event that any Person files a Statement of Opposition to an ISF water right application in Water Court, the Staff may agree to terms and conditions that would prevent injury. Where the resolution of the Statement of Opposition does not involve a change regarding the Board's determinations under Rule 5i. (including but not limited to the amount, reach, and season), the Board is not required to review and ratify the resolution. Staff may authorize its counsel to sign any court documents necessary to finalize this type of pretrial resolution without Board ratification.

5s. Withdrawal of Filing.

If the Board elects to withdraw a Water Court filing, notice shall be given in the agenda of the Board meeting at which the action is expected to occur.

6. ACQUISITION OF WATER, WATER RIGHTS OR INTERESTS IN WATER FOR INSTREAM FLOW PURPOSES.

The Board may acquire water, water rights, or interests in water for ISF purposes by the following procedures:

6a. Means of Acquisition.

The Board may acquire, by grant, purchase, donation, bequest, devise, lease, exchange, or other contractual agreement, from or with any Person, including any governmental entity, such water, water rights, or interests in water that are not on the Division Engineer's abandonment list in such amounts as the Board determines are appropriate for stream flows or for natural surface water levels or volumes for natural lakes to preserve or improve the natural environment to a reasonable degree.

6b. 120 Day Rule.

At the request of any Person, including any governmental entity, the Board shall determine in a timely manner, not to exceed one hundred twenty days, unless further time is granted by the requesting Person, what terms and conditions the Board will accept in a contract or agreement for the acquisition. The 120-day period begins on the day the Board first considers the proposed contract or agreement at a regularly scheduled or special Board meeting.

6c. Stacking Evaluation.

The Board shall evaluate whether to combine or stack the acquired water right with any other ISF appropriation or acquisition, based upon the extent to which the acquired water will provide flows or lake levels to preserve or improve the natural environment to a reasonable degree.

If the Board elects to combine or stack the acquired water right, the details of how the water rights are to be combined or stacked with other existing ISF appropriations or acquisitions must be set forth in the application for a decree to use the acquired right for instream flow purposes.

6d. Enforcement of Acquisition Agreement.

Pursuant to section 37-92-102(3), C.R.S., any contract or agreement executed between the Board and any Person which provides water, water rights, or interests in water to the Board shall be enforceable by either party thereto as a water matter in the water court having jurisdiction over the water right according to the terms of the contract or agreement.

6e. Appropriateness of an Acquisition.

The Board shall evaluate the appropriateness of any acquisition of water, water rights, or interests in water to preserve or improve the natural environment. Such evaluation shall include, but need not be limited to consideration of the following factors:

(1) The reach of stream or lake level for which the use of the acquired water is proposed, which may be based upon any one or a combination of the following: the historical location of return flow; the length of the existing instream flow reach, where applicable; whether an existing instream flow water right relies on return flows from the water right proposed for acquisition; the environment to

be preserved or improved by the proposed acquisition; or such other factors the Board may identify;

(2) The natural flow regime;

(3) Any potential material injury to existing decreed water rights;

(4) The historical consumptive use and historical return flows of the water right proposed for acquisition that may be available for instream flow use;

(5) The natural environment that may be preserved or improved by the proposed acquisition, and whether the natural environment will be preserved or improved to a reasonable degree by the water available from the proposed acquisition;

(6) The location of other water rights on the subject stream(s);

(7) The effect of the proposed acquisition on any relevant interstate compact issue, including whether the acquisition would assist in meeting or result in the delivery of more water than required under compact obligations;

(8) The effect of the proposed acquisition on the maximum utilization of the waters of the state;

(9) Whether the water acquired will be available for subsequent use or reuse downstream;

(10) The cost to complete the transaction or any other associated costs; and

(11) The administrability of the acquired water right when used for instream flow purposes.

The Board shall determine how to best utilize the acquired water, water rights or interest in water to preserve or improve the natural environment.

6f. <u>Factors Related to Loans and Leases.</u>

In addition to considering the factors listed above, for loans and leases of water, water rights and interests in water for ISF purposes under section 37-92-102(3),

(1) The Board shall consider the extent to which the leased or loaned water will preserve or improve the natural environment to a reasonable degree, including but not limited to:

  (a) Whether the amount of water available for acquisition is needed to provide flows to meet a decreed ISF amount in below average years; and

  (b) Whether the amount of water available for acquisition could be used to and would improve the natural environment to a reasonable degree, either alone or in combination with existing decreed ISF water rights.

(2) In considering the extent to which the leased or loaned water will preserve or improve the natural environment to a reasonable degree, the Board will request and review a biological analysis from the Colorado Division of Wildlife, and will review any other biological or scientific evidence presented to the Board.

(3) If other sources of water are available for acquisition on the subject stream reach(es) by purchase or donation, the Board shall fully consider each proposed acquisition and give preference first to the donation and then to a reasonable acquisition by purchase.

(4) The Board shall obtain confirmation from the Division Engineer that the proposed lease or loan is administrable and is capable of meeting all applicable statutory requirements.

(5) The Board shall determine, through negotiation and discussion with the lessor, the amount of compensation to be paid to the lessor of the water based, in part, upon the anticipated use of the water during and after the term of the lease.

(6) The Board shall consider evidence of water availability based upon the historical record(s) of diversion, the beneficial use of the subject water right, the location and timing of where return flows have historically returned to the stream, and the reason(s) the water is available for lease or loan.

6g. Recording Requirements.

(1) All contracts or agreements for leases or loans of water, water rights or interests in water under section 37-92-102(3) shall require the Board to:

(a) Maintain records of how much water the Board uses under the contract or agreement each year it is in effect; and

(b) Install any measuring device(s) deemed necessary by the Division Engineer (1) to administer the lease or loan of water, (2) to measure and record how much water flows out of the reach after use by the Board under the lease or loan; and (3) to meet any other applicable statutory requirements.

(2) All contracts or agreements for leases or loans of water shall provide for the recording of the actual amount of water legally available and capable of being diverted under the leased or loaned water right during the term of the lease or loan, with such records provided to the Division of Water Resources for review and publication.

6h. Water Reuse.

All contracts or agreements for the acquisition of water, water rights or interests in water under section 37-92-102(3) shall provide that the Board or the seller, lessor, lender or donor of the water may bring about beneficial use of the historical consumptive use of the acquired water right downstream of the ISF reach as fully consumable reusable water, pursuant to the water court decree authorizing the Board to use the acquired water.

(1) The bringing about of beneficial use of the historical consumptive use of the water may be achieved by direct use, sale, lease, loan or other contractual arrangement by the Board or the seller, lessor, lender or donor.

(2) The contract or agreement also shall provide that the Division Engineer must be notified of any agreement for such beneficial use downstream of the ISF reach prior to the use.

(3) Prior to any beneficial use by the Board of the historical consumptive use of the acquired water right downstream of the ISF reach, the Board shall find that such use:

(a) Will be consistent with the Board's statutory authority and with duly adopted Board policies and objectives; and

(b) Will not injure vested water rights or decreed conditional water rights.

6i. Applications for a Decreed Right to Use Water for ISF Purposes.

The Board shall file a change of water right application or other applications as needed or required with the water court to obtain a decreed right to use water for ISF purposes under all contracts or agreements for acquisitions of water, water rights or interests in water under section 37-92-102(3), including leases and loans of water. The Board shall file a joint application with the Person from whom the Board has acquired the water or a Person who has facilitated the acquisition, if requested by such Person. The Water Court shall determine matters that are within the scope of section 37-92-305, C.R.S. In a change of water right proceeding, the Board shall request the Water Court to:

(1) Verify the quantification of the historical consumptive use of the acquired water right;

(2) Verify the identification, quantification and location of return flows to ensure that no injury will result to vested water rights and decreed conditional water rights;

(3) Include terms and conditions providing that:

(a) The Board or the seller, lessor, lender, or donor of the water may bring about the beneficial use of the historical consumptive use of the changed water right downstream of the ISF reach as fully consumable reusable water, subject to such terms and conditions as the water court deems necessary to prevent injury to vested water rights and decreed conditional water rights; and

(b) When the Board has not identified such downstream beneficial use at the time of the change of water right, the Board may amend the subject change decree, if required by the Division Engineer, to add such beneficial use(s) of the historical consumptive use downstream of the ISF reach at the time the Board is able to bring about such use or reuse, without requiring requantification of the original historical consumptive use calculation;

and

(4) Decree the method by which the historical consumptive use should be quantified and credited during the term of the agreement for the lease or loan of the water right pursuant to section 37-92-102(3), C.R.S.

6j. Limitation on Acquisitions.

The Board may not accept a donation of water rights that were acquired by condemnation, or that would require the removal of existing infrastructure without approval of the current owner of such infrastructure.

6k. Temporary Loans of Water to the Board.

The Board may accept temporary loans of water for instream flow use for a period not to exceed 120 days in any one year, in accordance with the procedures and subject to the limitations set forth in section 37-83-105, C.R.S.

(1) Within 5 working days after receiving an offer of a temporary loan of water to the Board for temporary instream flow use, the Director will provide a response to the proponent and, unless the proposed loan has no potential value for instream flow use, staff will coordinate with the proponent on preparing and submitting the necessary documentation to the State and Division Engineers required by sections 37-83-105(2)(a)(I) and (2)(b)(I), C.R.S., and providing the public notice required by section 37-83-105(2)(b)(II), C.R.S.

(2) Provided that the State Engineer has made a determination of no injury pursuant to section 37-83-105(2)(a)(III), C.R.S., the Board hereby delegates authority to the CWCB Director to accept temporary loans of water for instream flow use in accordance with the procedures and subject to

the limitations set forth in section 37-83-105 and to take any administrative action necessary to put the loaned water to instream flow use.

(3) Provided that the State Engineer's determination of non-injury is still in effect, the Director shall notify the proponent and the State Engineer whether the temporary loan is to be exercised in subsequent years. Such notification shall be provided within 5 working days of the Director being notified by the proponent that the water is available for use under the temporary loan. The CWCB's use of loaned water for instream flows shall not exceed the CWCB's decreed instream flow amount or extend beyond the CWCB's decreed instream flow reach at any time during the loan term, and shall comply with any terms and conditions imposed by the State Engineer to prevent injury. The purpose of this delegation is to expedite use of temporarily loaned water for instream flows by the Board.

(4) At the first regular or special Board meeting after the Director accepts or rejects an offer of a loan of water to the Board for temporary instream flow use under (1) or (2) above, the Board shall vote either to ratify or overturn the Director's decision.

(5) The Board, Director and staff will expedite all actions necessary to implement Rule 6k.

6l. Funds for Water Right Acquisitions.

The Board may use any funds available to it for costs of the acquisition of water rights and their conversion to ISF use. The Board shall spend available funds for such costs in accordance with section 37-60-123.7, C.R.S. and any other applicable statutory authority, and with applicable Board policies and procedures.

6m. Public Input on Proposed Acquisitions.

The Board shall follow the public review process in Rules 11a. - 11c. when acquiring water, water rights or interests in water, except for temporary loans or leases as provided in Rule 6k. above and except as provided below.

(1) Prior to Board consideration of any proposed acquisition, Staff shall mail notice of the proposed acquisition to all Persons on the ISF Subscription Mailing List and the State Engineer's Substitute Supply Plan Notification List for the relevant water division, and shall provide Proper Notice. Such notice shall include:

(a) The case number adjudicating the water right proposed to be acquired, and the appropriation date, adjudication date, priority, decreed use(s), and flow amount of the water right proposed to be acquired, and approximately how much of the water right the Board will consider acquiring;

(b) The location of the stream reach or lake that is the subject of the proposal, including, when available, the specific length of stream reach to benefit from the proposed acquisition;

(c) Any available information on the purpose of the acquisition, including the degree of preservation or improvement of the natural environment to be achieved;

(d) Any available scientific data specifically supporting the position that the acquisition will achieve the goal of preserving or improving the natural environment to a reasonable degree; and

(e) In addition to (a) - (d) above, for leases and loans of water, water rights or interests in water under section 37-92-102(3), such notice shall include the proposed term of the lease or loan and the proposed season of use of the water under the lease or loan.

(2) At every regularly scheduled Board meeting subsequent to the mailing of notice, and prior to final Board action, Staff will report on the status of the proposed acquisition and time will be reserved for public comment.

(3) Any Person may address the Board regarding the proposed acquisition prior to final Board action. Staff shall provide any written comments it receives regarding the proposed acquisition directly to the Board.

(4) Any Person may request the Board to hold a hearing on a proposed acquisition. Such a request must be submitted to the Board in writing within twenty days after the first Board meeting at which the Board considers the proposed acquisition, and must include a brief statement, with as much specificity as possible, of why a hearing is being requested.

(5) At its next regularly scheduled meeting after receipt of the request for a hearing, or at a special meeting, the Board will consider the request and may, in its sole discretion, grant or deny such a request. All hearings scheduled by the Board shall be governed by the following procedures:

(a) A hearing on a proposed acquisition must be held within the 120 day period allowed for Board consideration of an acquisition pursuant to Rule 6b., unless the Person requesting the Board to consider the proposed acquisition agrees to an extension of time.

(b) The Board shall appoint a Hearing Officer to establish the procedures by which evidence will be offered.

(c) At least thirty days prior to the hearing date(s), the Board shall provide written notice of the hearing(s) to the Person proposing the acquisition, all interested parties known to the Board, and all Persons on the ISF Subscription Mailing List and the State Engineer's Substitute Supply Plan Notification List for the relevant water division. The Board also shall provide Proper Notice, as defined in ISF Rule 4n.

(d) Any Person who desires party status shall become a Party upon submission of a written Notice of Party Status to the Board Office. The Notice shall include the name and mailing address of the Person and a brief statement of the reasons the Person desires party status. The Board Office must receive Notice of Party Status within seven days after notice of the hearing is issued.

(e) The Hearing Officer shall set timelines and deadlines for all written submissions. Prehearing statements will be required, and shall include, but not be limited to, the following: 1) a list of all disputed factual and legal issues; 2) the position of the Party regarding the factual and legal issues; 3) a list identifying all of the witnesses that will testify for the Party, and a summary of the testimony that those witnesses will provide; and 4) copies of all exhibits that the Party will introduce at the hearing(s).

(f) Any Party may present testimony or offer evidence identified in its prehearing statement regarding the proposed acquisition.

(g) The Hearing Officer shall determine the order of testimony for the hearing(s), and shall decide other procedural matters related to the hearing(s). The Hearing Officer does not have authority to rule on substantive issues, which authority rests solely with the Board.

(h) The Board will not apply the Colorado Rules of Evidence at hearings on proposed acquisitions.

(i) The Board may permit general comments from any Person who is not a Party; however, the Board may limit these public comments to five minutes per Person.

(j) The Board may take final action at the hearing(s) or continue the hearing and/or deliberations to a date certain.

(k) Board hearings may be recorded by a reporter or by an electronic recording device. Any Party requesting a transcription of the hearing(s) shall be responsible for the cost of the transcription.

(l) When necessary, the Board may modify this hearing procedure schedule or any part thereof as it deems appropriate.

6n. Board Action to Acquire Water, Water Rights or Interests in Water.

The Board shall consider the acquisition during any regular or special meeting of the Board. At the Board meeting, the Board shall consider all presentations or comments of Staff or any other Person. After such consideration, the Board may acquire, acquire with limitations, or reject the proposed acquisition.

7. INUNDATION OF ISF RIGHTS.

Inundation of all or a portion of an ISF stream reach or lake may be an interference with the Board's usufructuary rights that have been acquired by Board action. “Inundation” as used in this section is the artificial impoundment of water within an ISF or natural lake; “inundation” does not refer to the use of a natural stream as a conveyance channel as long as such use does not raise the waters of the stream above the ordinary high watermark as defined in §37-87-102 (1)(e), C.R.S.

7a. Small Inundations.

Staff may file a Statement of Opposition to inundations described in this section if it determines that the ISF right or natural environment will be adversely affected by the inundation. The Staff shall not be required to file a Statement of Opposition to applications proposing small inundations. Small inundations are those in which the impoundment is 100 acre-feet or less, or the surface acreage of the impoundment is 20 acres or less, or the dam height of the structure is 10 feet or less. The dam height shall be measured vertically from the elevation of the lowest point of the natural surface of the ground, where that point occurs along the longitudinal centerline of the dam up to the flowline crest of the spillway of the dam.

(1) All structures proposed by any applicant on a stream reach shall be accumulated for the purpose of determining whether the inundations proposed by the applicant are small inundations. In the event the cumulative surface acreage, volume impounded, or dam height of all impoundments exceed the definition of a small inundation, Staff may file a Statement of Opposition to that application.

(2) In the event that no Statement of Opposition is filed pursuant to the terms of this section, the Board shall be deemed to have approved the inundation proposed without a request by the applicant.

7b. Application of Rule 7.

The provisions of this rule will not be applied to the following water rights:

(1) any absolute or conditional water right that is senior to an ISF right;

(2) any senior conditional water right that seeks a finding of reasonable diligence;

(3) any junior absolute or conditional water right which was decreed prior to July 10, 1990, or had an application for decree pending prior to July 10, 1990, unless the Board had filed a Statement of Opposition to the absolute or conditional water right application prior to July 10, 1990; or

(4) any inundation of an ISF reach by water that does not have an absolute or conditional water right if the inundation occurred prior to July 10, 1990.

7c. Request to Inundate.

Any Person seeking permission to inundate shall timely submit a written request for permission to inundate to the Board Office. No requests for inundation will be considered or approved until the Person seeking permission to inundate files a water court application outlining their storage plans or files plans and specifications with the State Engineer for a jurisdictional dam pursuant to §37-87-105, C.R.S. The Board will consider the request to inundate in a timely manner.

7d. Staff Investigation.

After receiving the request to inundate, the Staff may seek the recommendations from the Division of Wildlife, Division of Parks and Outdoor Recreation, Division of Water Resources, United States Department of Agriculture and United States Department of Interior.

7e. Required Information.

In any written request to inundate, the requesting Person shall at a minimum include information on the following factors: the location of the inundation, the size of the inundation, impact of the inundation on the natural environment, any unique or rare characteristics of the ISF water right to be inundated, any regulatory requirements or conditions imposed upon the applicant by federal, state and/or local governments, all terms and conditions included in applicant's water court decree, and any compensation or mitigation offered by the Person proposing the inundation.

7f. Determination of Interference.

In response to the request to inundate, the Board shall determine whether the proposed inundation interferes with an ISF right. When making this determination, the Board shall consider, without limitation, the extent of inundation proposed and the impact of the proposed inundation on the natural environment existing prior to the inundation.

7g. Consideration of Request to Inundate.

If the Board determines that a proposed inundation interferes with an ISF right, the Board may then approve, approve with conditions, defer, or deny the request to inundate. In making this decision, the Board shall consider all relevant factors, including, but not limited to (1) the extent of inundation proposed; (2) the impact of the proposed inundation on the natural environment existing prior to the inundation; (3) the degree to which the beds and banks adjacent to the ISF right subject to the inundation are publicly or privately owned; (4) the economic benefits arising from the inundation; (5) the benefits to recreation and downstream ISF segments arising from the inundation; (6) the degree to which the proposed inundation will allow development of Colorado's allotment of interstate waters as determined by compact or adjudication; and, (7) any mitigation or compensation offered to offset adverse impacts on the ISF right. After considering all relevant factors, the Board shall take one of the actions set forth in Rules 7h. - 7k. below.

7h. Approval.

If the Board approves the request to inundate, any Statement of Opposition filed by the Board shall be withdrawn.

7i. Conditional Approval.

The Board may require certain conditions to be performed prior to approval. Failure to perform any condition will be a reason for denial.

7j. Deferral.

When it appears that other governmental agencies may impose terms and conditions upon the issuance of a permit to construct a facility which will cause an inundation, the Board may defer consideration of the request to inundate until all other governmental bodies have finalized the permit or approval conditions.

7k. Denial of Request to Inundate.

Requests for permission to inundate may be denied if in the discretion of the Board the request is inconsistent with the goals of the ISF Program. The Board may decide to deny a request for permission to inundate if it finds:

(1) No compensation or mitigation would be adequate for the injury caused by the inundation; or

(2) No compensation or mitigation acceptable to the Board has been proposed by applicant; or

(3) The proposed inundation is inconsistent with the goals of the ISF Program.

7l. Remedies.

The Board may seek any administrative, legal or equitable remedy through state courts (including water courts), federal courts, city, county, state or federal administrative proceedings to resolve actual or proposed inundation of its ISF rights.

7m. Board Has Sole Right to Protect ISF Rights from Interference.

Only the Board may seek to prevent interference with an ISF right by inundation and only the Board may seek compensation or mitigation for such interference.

7n. Public Review Process.

The Board shall follow the public review process in Rules 11a. - 11c. prior to any Board decision on a request to inundate an ISF right.

8. PROTECTION OF ISF APPROPRIATIONS.

The Board delegates the day-to-day management and administration of the ISF Program to Staff. Staff shall seek ratification of its decisions as set forth in Rules 8c., 8e.(2), 8i., and 8j.

8a. Resume Review.

Staff shall review the monthly resumes of all water divisions. The Staff shall evaluate each resume entry for the possibility of injury or interference to an ISF right.

8b. Statement of Opposition.

In the event Staff identifies a water right application in the resume that may injure an ISF right, Staff shall file a Statement of Opposition to that application. In the event Staff identifies a water right application in the resume that may interfere with an ISF right as contemplated in Rule 7, Staff may file a Statement of Opposition to that application.

8c. Ratification of Statements of Opposition.

At a Board meeting following the filing of the Statement of Opposition, Staff shall apprise the Board of the filing of a Statement of Opposition and the factual basis for the Staff action. At that time, the Board shall ratify the filing, disapprove the filing, or table the decision to a future meeting if more information is needed prior to making a decision.

8d. Notice.

Prior to ratification of a Statement of Opposition, the Staff shall mail the applicant a copy of the Board memorandum concerning the ratification and a copy of the agenda of the meeting in which the ratification will be considered. Following a Board action considering a Statement of Opposition, the Staff shall notify the applicant and/or its attorney in writing of the Board's action.

8e. De Minimis Rule.

In the event that Staff determines a water court application would result in a 1 percent depletive effect or less on the stream reach or lake subject of the ISF right, and the stream reach or lake has not been excluded from this rule pursuant to Rules 8f. or 8h., Staff shall determine whether to file a Statement of Opposition. Staff's decision not to file a Statement of Opposition does not constitute: (1) acceptance by the Board of injury to any potentially affected ISF water right; or (2) a waiver of the Board's right to place an administrative call for any ISF water right.

(1) If Staff does not file a Statement of Opposition, Staff shall notify the Division Engineer for the relevant water division that it has not filed a Statement of Opposition, but that it may place an administrative call for the potentially affected ISF water right(s). Such a call could be enforced against the water right(s) subject of the application by the Division Engineer in his or her enforcement discretion. Staff also shall mail a letter to the applicant at the address provided on the application notifying the applicant: (a) of Staff's decision not to file a Statement of Opposition pursuant to this Rule; (b) that the CWCB may place a call for its ISF water rights to be administered within the prior appropriation system; and (c) that the Division Engineer's enforcement of the call could result in curtailment or other administration of the subject water right(s).

(2) If Staff files a Statement of Opposition, Staff shall seek Board ratification by identifying and summarizing the Statement of Opposition on the Board meeting consent agenda pursuant to Rule 8c.

8f. Cumulative Impact.

In determining existence of a de minimis impact, Staff shall consider the existence of all previous de minimis impacts on the same stream reach or lake. If the combined total of all such impacts exceeds 1 percent, then Staff will file a Statement of Opposition regardless of the individual depletive effect of an application.

8g. Notification of Staff Action.

At a Board meeting following a Staff determination to apply the De Minimis rule, the Staff shall notify the Board about the factual basis leading to its application of the De Minimis rule.

8h. Exclusion from De Minimis Rule.

The Board may at any time exclude any stream reach or lake, or any portion thereof, from application of the De Minimis rule.

8i. Pretrial Resolution.

Staff may negotiate a pretrial resolution of any injury or interference issue that is the subject of a Statement of Opposition. The Board shall review the pretrial resolution pursuant to the following procedures:

(1) No Injury.

In the event the pretrial resolution includes terms and conditions preventing injury or interference and does not involve a modification, or acceptance of injury or interference with mitigation, the Board is not required to review and ratify the pretrial resolution. Staff may authorize its counsel to sign any court documents necessary to finalize this type of pretrial resolution without Board ratification.

(2) No Injury/Modification.

In the event the pretrial resolution addresses injury or interference through modification of the existing ISF decree, the process set forth in Rule 9 shall be followed prior to any Board decision to ratify the pretrial resolution.

(3) Injury Accepted with Mitigation.

In the event a proposed pretrial resolution will allow injury to or interference with an ISF or natural lake level (NLL) water right, but mitigation offered by the applicant could enable the Board to accept the injury or interference while continuing to preserve or improve the natural environment to a reasonable degree, and if the proposed pretrial resolution does not include a modification under ISF Rule 9, the Board shall:

(a) Conduct a preliminary review of the proposed pretrial resolution during any regular or special meeting to determine whether the natural environment could be preserved or improved to a reasonable degree with the proposed injury or interference if applicant provided mitigation; and

(b) At a later regular or special meeting, take final action to ratify, refuse to ratify or ratify with additional conditions.

(c) No proposed pretrial resolution considered pursuant to this Rule 8i.(3) may receive preliminary review and final ratification at the same Board meeting.

(d) The Board shall not enter into any stipulation or agree to any decretal terms and conditions under this Rule that would result in the Division of Water Resources being unable to administer the affected ISF or NLL water right(s) in accordance with the priority system or with Colorado water law.

(e) To initiate CWCB staff review of an Injury with Mitigation proposal, the proponent must provide the following information in writing:

i. Location of injury to ISF or NLL water right(s) (stream(s) or lake(s) affected, and length of affected reach(es));

ii. Quantification of injury (amount, timing and frequency);

iii. Type of water use that would cause the injury;

iv. Analysis showing why full ISF or NLL protection is not possible;

v. Detailed description of the proposed mitigation, including all measures taken to reduce or minimize the injury;

vi. Detailed description of how the proposed mitigation will enable the Board to continue to preserve or improve the natural environment of the affected stream of lake to a reasonable degree despite the injury;

vii. Identification and feasibility analysis of: (1) all water supply alternatives considered by the proponent in the context of this proposal; (2) all alternatives evaluated by the proponent to fully protect the potentially affected ISF or NLL water right, but rejected as infeasible; and (3) all alternatives evaluated by the proponent and designed to mitigate the injury to or interference with the affected ISF or NLL water right. This information shall address the environmental and economic benefits and consequences of each alternative; and

viii. A discussion of the reasonableness of each alternative considered.

(f) After receipt and review of the required information, staff will consult with the DOW and with the entity that originally recommended the affected ISF or NLL water rights(s) (if other than DOW) to determine whether additional field work is necessary and to identify any scheduling concerns. Staff will request a recommendation from the DOW as to whether the proposed mitigation will enable the Board to continue to preserve or improve the natural environment of the affected stream or lake to a reasonable degree despite the injury, including a discussion of the reasonableness of the alternatives considered. CWCB staff will use best efforts to consult with affected land owners and managers regarding the proposal.

(g) Prior to bringing the proposal to the Board for preliminary consideration, staff will consult with the Division of Water Resources on whether the proposal would result in the Division of Water Resources being unable to administer the affected ISF or NLL water right(s) in accordance with the priority system or with Colorado water law.

(h) At the first meeting of the two-meeting process required by this Rule, staff will bring the proposal to the Board for preliminary consideration after completing its review of the proposal and its consultation with DOW. Staff will work with the proponent and interested parties to address any preliminary concerns prior to bringing a proposal to the Board. Preliminary consideration by the Board may result in requests for more information or for changes to the proposal. Staff will work with the proponent and interested parties to finalize the proposal and bring it back to the Board for final action at a subsequent Board meeting.

(i) The Board will consider the following factors when evaluating Injury with Mitigation proposals. Because Injury with Mitigation proposals may involve unique factual situations, the Board may consider additional factors in specific cases. Further, evaluation of each Injury with Mitigation proposal will require the exercise of professional judgment regarding the specific facts of the proposal.

i. Extent of the proposed injury:

1. Location of injury – affected stream(s) or lake and length of affected reach(es);

2. Amount, timing and frequency of shortage(s) or impacts to the affected ISF of NLL water right(s); and

3. Potential impact to the natural environment of the affected stream reach(es) or lake from the proposed injury.

ii. Benefits of the mitigation to the natural environment:

1. The nature and extent of the benefits the mitigation will provide to the existing natural environment of the affected stream or lake;

2. The scientific justification for accepting the mitigation; and

3. Whether the mitigation will enable the Board to continue to preserve or improve the natural environment of the subject stream or lake to a reasonable degree.

(j) Evaluation of proposed alternatives. The Board shall evaluate: (1) all water supply alternatives considered by the proponent in the context of this proposal; (2) all alternatives evaluated by the proponent to fully protect the potentially affected ISF or NLL water right, but rejected as infeasible; and (3) all alternatives evaluated by the proponent and designed to mitigate the injury to or interference with the affected ISF or NLL water right. In its evaluation, the Board shall consider the following factors:

i. Availability of on-site mitigation alternatives;

ii. Technical feasibility of each alternative;

iii. Environmental benefits and consequences of each alternative;

iv. Economic benefits and consequences of each alternative;

v. Reasonableness of alternatives;

vi. Administrability of proposed alternatives by the Board and the Division Engineer; and

vi. For mitigation alternatives, whether the mitigation was or will be put in place to satisfy a requirement or need unrelated to the Injury with Mitigation proposal.

(k) The Board will consider mitigation on a different reach of stream or another stream ("off-site mitigation") as a last resort and will only consider mitigation in an area other than the affected stream reach if no reasonable alternative exists for mitigation on the affected stream reach. The Board only will consider off-site mitigation on stream(s) located in the same drainage as the affected stream. Factors that the Board may consider in looking at such a proposal include, but are not limited to, the degree and frequency of impact to the affected stream; the environmental benefits provided to the off-site stream by the mitigation; whether the proposal could, in effect, constitute a modification of the ISF water right on the affected stream; or whether the proposal could result in the Division of Water Resources being unable to administer the affected ISF water right(s) in accordance with the priority system or with Colorado water law.

(l) Stipulations and water court decrees that incorporate Injury with Mitigation shall include, but not be limited to inclusion of, the following terms and conditions:

i. A provision that the proponent will not divert water or take any other action that would reduce flows in the affected stream or levels in the affected lake below the decreed ISF or NLL amount until the agreed-upon mitigation measures are in place and fully operational;

ii. A requirement that the structural components of the mitigation be maintained permanently;

iii. A provision allowing CWCB or DOW staff access to the property on which structural components of the mitigation are located to inspect the structures at certain time intervals, and, if necessary, to perform biological stream or lake monitoring. This provision shall clearly define the reasonable nature, extent and timing of such access (i.e, advance notice, dates, times or season of access, coordination with proponent, and location and routes of access);

iv. A term providing that if the proponent ceases to provide the agreed upon mitigation (such as removing structural components or failing to maintain them to a specified level, or ceasing to implement non-structural components), that the proponent will not divert water or take any other action that would reduce flows in the affected stream or levels in the affected lake below the decreed ISF or NLL amount because the Board will no longer accept the injury based upon the mitigation no longer being in effect -- in such case, if the Board places a call for the affected ISF or NLL water right, the Board will notify the Division Engineer that this provision of the decree now is in effect and that the Board is not accepting the injury;

v. A requirement that the proponent install and pay operation and maintenance costs of (or commit to pay operation and maintenance costs if the CWCB installs) any measuring devices deemed necessary by the Division Engineer to administer the terms of the stipulation and decree implementing the Injury with Mitigation pretrial resolution; and

vi. A term providing that the water court will retain jurisdiction to enforce the terms and conditions set forth above in subsections (i) - (vi), and any other terms and conditions specific to the Injury with Mitigation pretrial resolution, as a water matter.

8j. Authorization to Proceed to Trial.

In the event that a Statement of Opposition filed by the Board is not settled prior to the last regularly scheduled Board meeting prior to the trial date, Staff shall seek Board authorization to proceed to trial. In the event that Staff is authorized to proceed to trial, the Board may adjourn to executive session to discuss settlement parameters with its counsel. Staff is authorized to settle any litigation without Board ratification if the settlement terms are consistent with instructions given by the Board to its counsel.

8k. Public Review Process.

The Board shall follow the public review process in Rules 11a. - 11c. prior to consideration of a request to ratify a pretrial resolution pursuant to Rule 8i.(3).

8l. Notice.

At any time Staff verifies that an ISF water right is not being fulfilled as a result of water use against which the ISF water right is entitled to protection, the Staff shall provide Proper Notice, including a description of what the Board is doing in response to the situation.

9. MODIFICATION OF ISF RIGHTS.

The Board may modify any existing decreed ISF right according to the procedures set forth in this Rule. "Modification" of an ISF right within the meaning of this Rule includes a decrease in the rate of flow described in the existing ISF decree, segmenting an existing ISF reach into shorter reaches with the result of decreasing the rate of flow in any portion of an ISF reach, or subtracting water from an ISF right during any particular time period or season.

9a. Need for Modification.

Modification may be requested by the Staff or by any Person who has filed a water right application on an ISF reach or who has applied for any governmental permit for facilities located in or near an ISF reach and who complies with Rules 9b. and 9c. Any request for modification, except by staff, shall be made in writing, submitted to Staff and such writing shall contain the following information:

(1) name, address and telephone number of the Person seeking modification;

(2) stream or lake subject of request;

(3) modification requested;

(4) reason for modification; and

(5) the scientific data supporting the request.

9b. Need for Water.

Any Person who requests a modification of an ISF right must, as a precondition to the Board's consideration of the request, establish a need for the water made available by the modification. Staff does not have to comply with this rule and any governmental entity seeking to implement the terms of an agreement specified in Rule 9f. does not have to comply with this section.

9c. Grounds for Modification.

No request for modification may be considered until the applicant establishes that one of the following reasons for modification exists:

(1) Mistake.

An ISF right may be considered for modification if the requesting Person establishes that an error was made in the calculations upon which the original or supplemental appropriation or enlargement to an original appropriation was made.

(2) Excessive Flow.

An ISF right may be considered for modification if the requesting Person establishes that the ISF flow rate is in excess of the amount of water necessary to accomplish the purpose of the original, supplemental or enlarged ISF right when that right was appropriated.

9d. Recovery Implementation or Other Intergovernmental Agreement.

An ISF right may be modified if such modification was agreed upon by the Board as part of the Recovery Implementation Program for the Endangered Fishes of the Colorado River Basin or any other agreement between the Board and another governmental entity. Modifications made as a part of the Recovery Implementation Program for the Endangered Fishes of the Colorado River Basin need not be subject to the public review process in Rule 9e. Criteria for modifications made in the ISF rights decreed as part of the Recovery Implementation Program for the Endangered Fishes of the Colorado River Basin will be established in the decrees governing such appropriations.

9e. Public Review Process of Requests for Modification.

The Board shall adhere to the following public review process when considering requests for modification:

(1) Notice.

Notice of the proposed modification and the date of the public meeting at which it will first be considered shall be printed in the resume in the Water Court having jurisdiction over the decree that is the subject of the modification. The first public meeting of the Board at which the modification is to be considered shall occur at least sixty days after the month in which the resume is published. Notice shall also be published in a newspaper of statewide distribution within thirty to forty-five days prior to such first public meeting.

(2) Public Meeting.

If the Board decides at such first public meeting to give further consideration to the proposed modification, the Board shall announce publicly the date of a subsequent public meeting for such purpose. If the Board decides that it will not give further consideration to the proposed modification, it shall state, in writing, the basis for its decision.

(3) Request for Delay.

On the written request of any Person made within thirty days after the date of the first public meeting, the Board shall delay the subsequent public meeting for up to one year to allow such Person the opportunity for the collection of scientific data material to the proposed modification. The Board need not grant the request if it determines that the request is made solely to delay the proceedings.

(4) Procedures.

On the written request of any Person made within thirty days after the date of the first public meeting, the Board shall, within sixty days after such request, establish fair and formal procedures for the subsequent public meeting, including the opportunity for reasonable disclosure, discovery, subpoenas, direct examination, and cross examination. Subject to these rights and requirements, where a meeting will be expedited and the interests of the participants will not be substantially prejudiced thereby, the Board may choose to receive all or part of the evidence in written form.

(5) Final Determination.

The Board shall issue a final written determination regarding the modification that shall state its effective date, be mailed promptly to the Persons who appeared by written or oral comment at the Board's proceeding, and be filed promptly with the water court.

10. ENFORCEMENT AGREEMENTS.

The Board may attach conditions to an appropriation, decreased appropriation, or acquisition, and may enter into any enforcement agreements that it determines will preserve or improve the natural environment to a reasonable degree. The Board may enter into enforcement agreements that limit the

Board's discretion in the protection, approval of inundation, modification or disposal of ISF right, and/or may delegate limited authority to act on the Board's behalf.

10a. Ratification of Enforcement Agreements.

No enforcement agreement shall be effective to limit the discretion of the Board until that agreement and all of its terms are reviewed and ratified by the Board. Upon ratification, the Director may execute the agreement and the agreement shall be binding upon the Board for the term set forth in the enforcement agreement.

10b. Public Review Process.

The Board shall follow the public review process set forth in Rules 11a. - 11c. prior to any Board decision to ratify an Enforcement Agreement.

11. PUBLIC REVIEW PROCESS.

Except as otherwise provided in the ISF Rules, the Board shall follow the public review process set forth below prior to any Board decision requiring public review.

11a. Public Notice.

Public notice of all Board actions under these Rules shall be provided through the agenda of each regular or special Board meeting.

11b. Public Comment.

Except as otherwise provided in Rules 5k. and 6m., at a regular or special meeting, the Board shall consider public comment on the recommended ISF action prior to the Board action on the recommendation in any or all of the following manners:

(1) Oral and/or written comments may be directed to Staff. When such comments are made, Staff may summarize these comments to the Board.

(2) Oral and/or written comments, subject to reasonable limitations established by the Board, may be made directly to the Board during the public meeting.

11c. Public Agency Recommendations.

Prior to taking an ISF action pursuant to Rules 5 or 6, the Board shall request recommendations from the Division of Wildlife and the Division of Parks and Outdoor Recreation. The Board shall also request recommendations from the United States Department of Agriculture and the United States Department of Interior. The Board may also request comments from other interested Persons or agencies as it deems appropriate.

Prior to taking an ISF action pursuant to Rules 7, 8, 9, or 10, the Board may request recommendations from the Division of Wildlife, the Division of Parks and Outdoor Recreation, the Division of Water Resources, the United States Department of Agriculture, the United States Department of Interior or other Persons as it deems appropriate.

11d. Board Procedures.

At a regular or special Board meeting, the Board may, as necessary, adopt or amend procedures to supplement these rules.

12. SEVERABILITY.

In the event that any section or subsection of these Rules are judged to be invalid by a court of law or are allowed to expire by the General Assembly, the remaining Rules shall remain in full force and effect.

Exhibit 5

Development of Instream Flow Recommendations In Colorado Using

R2CROSS



Colorado Water Conservation Board
Department of Natural Resources
1313 Sherman Street, Room 721
Denver, Colorado 80203

Water Rights Investigations Section

January 1996

Development of Instream Flow Recommendations In Colorado Using

R2CROSS

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January 1996

Abstract

In 1973, the Colorado State Legislature vested the Colorado Water Conservation Board with the authority to appropriate instream flow water rights in the State of Colorado. Today, the Board holds 1,326 instream flow water rights covering approximately 7,982 miles of Colorado streams. Standardized field and office procedures help to ensure that instream flow recommendations reflect the amount of water required to "preserve the natural environment to a reasonable degree", as prescribed by state statute. R2CROSS is one of the standard techniques employed by state and federal agencies to model instream hydraulic parameters. R2CROSS was chosen because it is time and labor efficient and produces comparable results to more costly techniques, i.e., the Instream Flow Incremental Methodology. This manuscript provides an overview of Colorado's Instream Flow Program and documentation for the Board's R2CROSS Lotus macro. The R2CROSS macro runs efficiently on an IBM-compatible 80486 personal computer equipped with a hard disk drive, and DOS 6.0, Windows 3.1, and Lotus 1-2-3 Release 4 for Windows software.

Acknowledgments

The Colorado Water Conservation Board would like to thank everyone involved in the development of the Board's R2CROSS Lotus macro. In addition, the author wishes to acknowledge the persons involved in the review and testing of the R2CROSS macro including R. Barry Nehring and Jay Skinner of the Colorado Division of Wildlife, Dr. Eric P. Bergersen, Dr. Kurt Fausch, and Charles Gowan of Colorado State University, Dennis Murphy of the Bureau of Land Management, Dave Gerhardt of the United States Forest Service, Dan Merriman, Anne Janicki, and Margaret Langdon of the Colorado Water Conservation Board, and Steven O. Sims of the State Attorney General's Office. The Board is very grateful to all of those who participated in the development of the R2CROSS macro and this document.

Disclaimer

The R2CROSS macro is in the public domain, and the recipient may not assert any proprietary rights thereto nor represent it to anyone as other than a Colorado State Government-produced program. R2CROSS is provided "as-is" without warranty of any kind, including, but not limited to, the implied warranties of merchantability and fitness for a particular purpose. The user assumes all responsibility for the accuracy and suitability of this program for a specific application. In no event will the Colorado Water Conservation Board or the Colorado Division of Wildlife be liable for any damages, including lost profits, lost savings, or other incidental or consequential damages arising from the use of or the inability to use this program.

The CWCB staff verified the calculations preformed in its R2CROSS program with hand-held calculators and by comparison with other Manning's equation-based hydraulic streamflow models. Based upon this verification process, the staff believes that the instream hydraulic parameters summarized in the R2CROSS staging table are accurate calculations of Manning's equation. However, the CWCB does not suggest that the predicted hydraulic parameters will necessarily be realized at any particular stream discharge.

On November 10, 1993, the Colorado Water Conservation Board adopted Rules and Regulations that codified the procedures the Board follows in appropriating instream flow water rights. This document is intended to conform to the procedures presented in the Rules and Regulations.

Table of Contents

Abstract ..... -ii-

Acknowledgments ..... -iii-

Disclaimer ..... -iii-

Table of Contents ..... -iv-

List of Tables and Figures ..... -v-

Introduction ..... -1-

Colorado's Instream Flow Program ..... -1-
- Instream Flow Legislation ..... -1-
- Field Procedures ..... -2-
  - Field Data Site Selection ..... -2-
  - Hydraulic Data Collection ..... -3-
  - Biologic Data Collection ..... -5-
  - The Field Form ..... -5-
- Office Procedures ..... -10-
  - Background on the R2CROSS Methodology 10-
  - Biologic Instream Flow Recommendations ..... -18-
  - Water Availability Requirements ..... -19-
- Appropriating and Protecting an Instream Flow Water Right ..... -20-
- Summary ..... -20-

R2CROSS Program Documentation ..... -21-
- Setup and Installation ..... -21-
  - Copying R2CROSS to a Hard Disk Drive ..... -21-
  - Loading Lotus 1-2-3 and Retrieving the R2CROSS Macro ..... -22-
- Iron Creek Example ..... -23-
- The R2CROSS Menu ..... -24-
  - Input ..... -24-
  - Verify ..... -25-
  - Save ..... -25-
  - Calculate ..... -26-
  - Graph ..... -26-
  - Retrieve ..... -26-
  - Printers ..... -27-
  - Quit ..... -27-
- Terminating and Reactivating the R2CROSS Macro ..... -27-

Literature Cited ..... -28-

Appendix A - Program Calculations ..... -30-

List of Tables and Figures

Tables

Table 1. Field equipment list for making streamflow measurements ..... -4-
Table 2. Criteria used to determine minimum flow requirements using the R2CROSS single transect method (Nehring 1979) ..... -19-
Table 3. Data entry and data editing using the <ENTER> key and arrow keys ..... -22-
Table 4. Hydraulic Formulas used in R2CROSS staging table ..... -34-

Figures

Figure A. Typical stream cross section ..... -5-
Figure B. Field data input sheet (Front Page) ..... -8-
Figure C. Field data input sheet (Back Page) ..... -9-
Figure D. The R2CROSS Menu ..... -11-
Figure E. R2CROSS proof sheet ..... -12-
Figure F. Final output from R2CROSS (Page 1) ..... -13-
Figure G. Final output from R2CROSS (Page 2) ..... -14-
Figure H. Final output from R2CROSS (Page 3) ..... -15-
Figure I. Final output from R2CROSS (Page 4) ..... -16-
Figure J. Final output from R2CROSS (Page 5) ..... -17-
Figure K. Cross section plot from R2CROSS ..... -18-
Figure L. Sequence of operations performed by R2CROSS macro ..... -32-
Figure M. Lotus 1-2-3 worksheet layout for R2CROSS macro ..... -33-

Introduction

Colorado's Instream Flow Program originated in 1973 with the passage of Senate Bill 97 (SB 97). Under SB 97, the Colorado Water Conservation Board (CWCB) was vested with the authority to appropriate instream flow water rights in the State of Colorado (§ 37-92-102(3), C.R.S. (1990)). Instream flow water rights are held by the CWCB on behalf of the people of the State of Colorado to "preserve the natural environment to a reasonable degree." Today, the CWCB holds 1,326 instream flow water rights covering approximately 7,982 miles of Colorado streams.

Determining the quantity of water required to preserve the natural environment to a reasonable degree can be a difficult task. The CWCB, in cooperation with the Colorado Division of Wildlife (DOW), has developed standard field and office procedures to ensure that each instream flow appropriation is necessary and reasonable and that the amount of water recommended is available for appropriation.

The R2CROSS methodology described in this document is a valuable tool in developing these instream flow recommendations. The CWCB uses R2CROSS because it is time and labor efficient and produces results which are comparable to more data intensive techniques (Nehring 1979).

This manuscript is divided into two sections. The first section describes Colorado's Instream Flow Program, including some of the statutory guidelines that have shaped the program. It also describes the standard field techniques and office procedures that are used by the CWCB staff in the development of R2CROSS-based instream flow recommendations. This section is intended to provide an understanding of the procedural and technical aspects of Colorado's Instream Flow Program.

The second section of the manuscript is a users' manual for the CWCB's R2CROSS macro. The CWCB has received many requests for its R2CROSS macro from both the public and private sectors but has been hesitant to release the program without proper documentation. The second section of the manuscript is intended to provide that documentation.

Colorado's Instream Flow Program

Instream Flow Legislation

The CWCB was created in 1937 to serve as the State's chief water planning agency (§ 37-60-101 through 123, C.R.S. (1990)). Today, the CWCB is responsible for the administration of the State's Instream Flow Program, protection of endangered aquatic species, identification of flood plains, funding of new water development and water conservation projects, and negotiation of inter- and intra-state water planning issues.

The CWCB is a fourteen-member board. The board consists of one Governor-appointee from each of the eight major river drainages in the State and one from the City and County of Denver. Each Governor-appointee must also be confirmed by the Colorado State Senate. Ex-officio members of the board include the

Executive Director of the Department of Natural Resources, the Directors of the CWCB and DOW, the State Attorney General, and the State Engineer. The diverse backgrounds of its board members provides the CWCB with an excellent representation of Colorado's various water interests.

Colorado's Instream Flow Program was created in 1973 when the Colorado State Legislature recognized "the need to correlate the activities of mankind with some reasonable preservation of the natural environment" through the passage of SB 97. Within SB 97, the definition of beneficial use was changed to include minimum stream flows and the CWCB was vested with the authority to appropriate "waters of natural streams and lakes ... as may be required ... to preserve the natural environment to a reasonable degree." SB 97 was amended by Senate Bill 414 in 1981, Senate Bill 91 in 1986, Senate Bill 212 in 1987, and Senate Bill 54 in 1994. These changes and amendments are consolidated within § 37-92-102(3), C.R.S. (1990), the Instream Flow statute.

The Instream Flow statute sets forth the guidelines for the administration of Colorado's Instream Flow Program. The statute vests the CWCB with the exclusive authority to appropriate and acquire instream flow and natural lake level water rights. In order to encourage other entities to participate in Colorado's Instream Flow Program, the statute directs the CWCB to request instream flow recommendations from other state and federal agencies prior to initiating an instream flow appropriation. The CWCB routinely requests instream flow recommendations from the DOW, Colorado Division of Parks and Outdoor Recreation, United States Department of Agriculture, and United States Department of Interior (the "cooperating agencies").

Prior to appropriating an instream flow water right, the statute requires the CWCB to: (1) "determine that the natural environment will be preserved to a reasonable degree by the water available for the appropriation to be made; (2) determine that there is a natural environment that can be preserved to a reasonable degree with the CWCB's water right, if granted; and (3) determine that such environment can exist without material injury to water rights" (§ 37-92-102(3c), C.R.S. (1990)). The CWCB makes these determinations based upon a review of the supporting technical data and a final instream flow recommendation prepared by the CWCB staff.

Standardized field and office procedures have been developed to help ensure that final instream flow recommendations meet statutory guidelines and are consistent. The standard field procedures that were established concern selection of transect sites and collection of hydraulic and biologic data. Standard office procedures have been established for determining biological instream flow recommendations using output from R2CROSS and for analyzing water availability.

Field Procedures

Instream flow recommendations are typically based on hydraulic and biologic data collected during a single field visit. Hydraulic data collection consists of setting up a transect, surveying stream channel geometry, and measuring stream discharge. Biologic data is gathered to document the existence of a natural environment. The biologic data usually consists of a fish sample, collected by electrofishing, and an aquatic invertebrate sample.

Field Data Site Selection

The R2CROSS method requires that stream discharge and channel profile data be collected in a riffle stream habitat-type. A riffle is a stream segment that is controlled by channel geometry rather than a downstream

flow control. Riffles are most easily visualized as the stream reaches which would dry up most quickly should streamflow cease.

Biologically, riffles are essential to the production of benthic invertebrates and the passage, spawning, egg incubation, feeding, and protective cover of fish. Riffles are also the stream habitat-type most sensitive to changes in hydraulic parameters with variation in discharge (Nehring 1979). Riffles are critical to a healthy aquatic environment because small reductions in streamflow may result in large reductions in water depth and the amount of wetted perimeter available for aquatic habitat. Maintaining adequate streamflow in riffles also preserves the natural environment in other important stream habitat-types such as pools and runs (Nehring 1979).

Hydraulic engineers have developed several mathematical models and equations to predict instream hydraulic parameters (Chow 1959). Manning's equation is one such model that is well-suited to the riffle stream habitat-type (Grant et al. 1992). In order to maximize the reliability of Manning's equation, transects are placed within a riffle so that streamflow is uniform across the transect (Grant et al. 1992). The transect represents the average stream width, depth, and cross-sectional area within the riffle being characterized. Transects should be located in areas that exhibit natural banks or grasslines and concentrated water flow, free from braiding. They should not be located on eroded or undercut streambanks.

Hydraulic Data Collection

Stream discharge is measured using standardized procedures established by the United States Geological Survey (USGS) (Buchanan and Somers 1969). On streams less than 50 feet in width, channel geometry is typically measured using sag-tape methodology (Silvey 1976; Ray and Megahan 1979). Larger streams typically require the use of a land survey level and stadia rod (Benson and Dalrymple 1967). A list of required field equipment for making streamflow measurements is provided in Table 1.

The sag-tape methodology consists of suspending a steel tape from bank to bank across the stream channel, perpendicular to the streamflow (Figure A). Metal cross section stakes are driven into the ground above the grassline. The steel tape is suspended by attaching the zero-end of the tape to one of the metal stakes, stretching the tape across the stream, and then attaching the other end to a tape clamp and spring scale fastened to the metal stake on the opposite streambank. A minimum of 15 pounds of tension is applied to the tape, as the tape is drawn up and clamped. A survey level and stadia rod are used to adjust the ends of the tape up or down until they are level, thereby producing a consistent datum from which vertical distance measurements can be read.

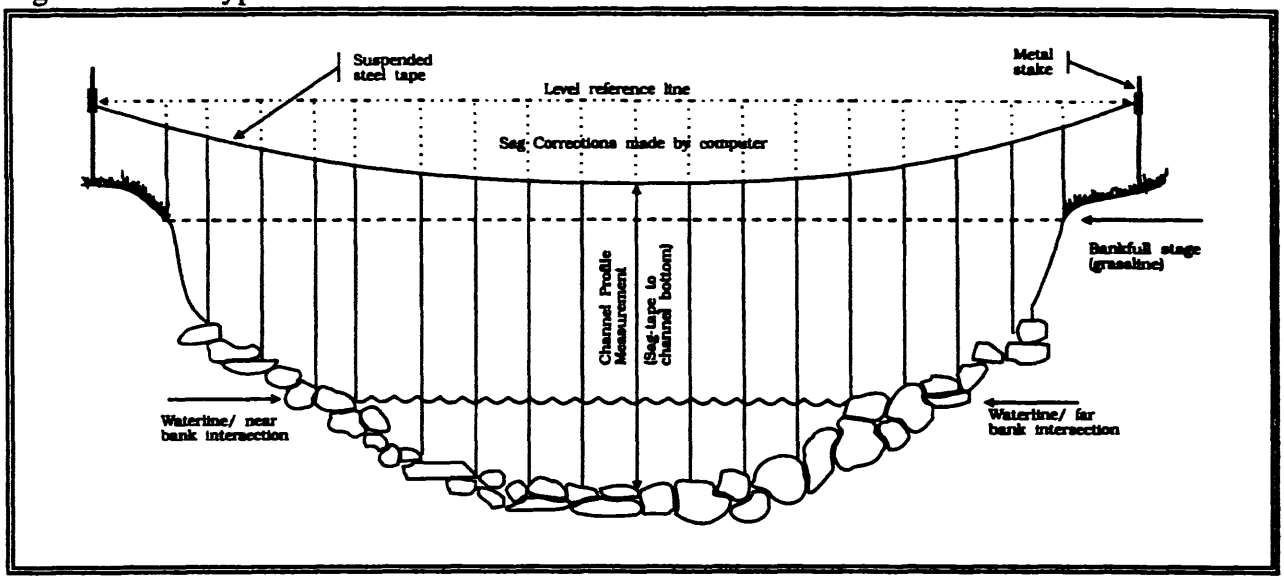
The R2CROSS program uses the standard weight of a one-foot section of the steel tape, tape tension, and the length of tape in suspension to correct horizontal distance and vertical depth measurements made from the sagging tape. The program adjusts the coordinates at each cross section vertical so that the corrected measurements correspond to a level datum from stake to stake and not the curved datum created by the sagging tape (Figure A).

On larger streams, vertical measurements between the suspended tape and the stream channel may be replaced with readings using a survey level and stadia rod. The suspended tape is then used to measure only the horizontal location of each cell vertical. There is no need to precisely level the ends of the suspended tape or to record the tape tension as no sag corrections are required.

Table 1. Field equipment list for making streamflow measurements

Equipment	Description
100' Steel Survey tape	Stretched between cross section stakes. (Obtain standard weight of a 1.0 foot section of tape from manufacturer)
Spring Tension Scale	Used to measure pounds of tension on steel tape when stretched between stakes.
Tape Clamp Handle	Holds tape in tension.
Cross Section Stakes	Two 24"-36" metal stakes used to maintain tape tension and to level steel tape. Must be strong enough to be driven into rocky stream bank.
Discharge Wading Rod (or Stadia Rod)	Used to measure vertical depths from suspended tape to stream channel.
Level, Tripod, and Stadia Rod	Used to level ends of suspended tape and to measure slope.
Current Meter	Pygmy, Price AA, Marsh-McBirney or similar devise used to measure stream velocity.
Hand Sledge Hammer	Used to drive cross section stakes into streambank.
Staging Pin	Used to detect changes in discharge during the streamflow measurement.
100' Fiberglass Tape	Used to measure horizontal distance from suspended tape to water-slope stadia rod readings.
Field Forms and Clipboard	Standardized form to ensure complete set of field data.
Miscellaneous Items	Camera, film, maps, waders, stopwatch and calculator.

Figure A. Typical stream cross section



Biologic Data Collection

Biologic sampling is conducted to document the existence of a natural environment. Coldwater fish species, particularly salmonids, have been used to indicate the existence of such a natural environment in the majority of the CWCB's instream flow appropriations to date. Warmwater fish species and other aquatic life forms may be used to document the existence of a natural environment in more downstream, low-elevation stream segments. In addition to salmonids, the CWCB has used amphibians, such as frogs and salamanders, and warmwater fish species, including the endangered fishes of the Colorado River basin, as the biologic basis for instream flow appropriations.

Biologic data typically consists of a fish sample, collected by electrofishing, and an aquatic invertebrate sample. Captured fish are identified and measured and a length-frequency distribution is constructed for each species. The sample is not tied directly to the R2CROSS hydraulic modeling but it may be used to refine the biologic instream flow recommendation to meet the specific habitat requirements of unique populations.

The Field Form

The CWCB and DOW use a standardized field form to record all field data. The use of this form helps to ensure that all instream flow recommendations are based upon a uniform set of field data. The front page of the form provides space for cross section "Location Information", "Supplemental Data", "Channel Profile Data", an "Aquatic Sampling Summary", and "Comments" (Figure B). The back page is dedicated to "Discharge/Cross Section Notes" (Figure C).

The "Location Information" section of the field form is used to describe the location of the cross section as well as the date and names of the members of the field crew. Geographic information can be obtained from either USGS or United States Forest Service (USFS) maps. Water divisions and DOW water codes can be obtained from the State Engineers' Office, the CWCB, or the DOW.

The "Supplemental Data" section is used to provide supporting documentation of the field data collection effort. Most importantly, this section is used to record the tape manufacturer's standard weight (lbs/ft) and tape tension (lbs). The R2CROSS program uses this information, together with the length of tape in suspension, to adjust vertical distances measured from the sagging tape to a level reference datum.

The "Channel Profile Data" section of the form is used to establish the relationship between the sag-tape cross section and the stream. Stadia rod readings are taken at each end of the suspended tape and at the water surface on the right and left streambanks. These readings are recorded within the "Rod Reading (ft)" column. They are used to assure that the ends of the tape are level and to quantify the vertical distance between the suspended tape and the water surface. Water surface readings and horizontal distances are also recorded upstream and downstream of the suspended tape. These observations are used to establish the water surface slope for input into Manning's equation.

The right side of the "Channel Profile Data" section is used to graphically depict the relative locations of the suspended tape and survey level, the direction of streamflow, and any photographic documentation of the field data collection effort. Photographs of the suspended tape are taken looking up, down, and across the stream.

Biologic sampling is summarized in the "Aquatic Sampling Summary" portion of the field form. Biologic data typically consists of a fish sample, collected by electrofishing, and an aquatic invertebrate sample. Captured fish are identified by species and measured to the nearest inch. A species-specific length-frequency distribution is created by placing a hashmark in the appropriate cell of the table as each fish is measured. Aquatic invertebrate sampling is summarized within the space provided at the bottom of this section.

All other pertinent field data is recorded in the "Comments" section of the field form. This section is often used to record weather conditions, water turbidity, or species-specific biomass estimates. This additional information helps characterize the field data when it is being analyzed in the office.

The "Discharge/Cross Section Notes" portion of the field form is used to record all of the hydraulic measurements associated with the discharge measurement (Figure C). A heading is provided to record the stream name, cross section number, date, edge of water looking downstream, the staging pin reading, and time at the beginning of the stream discharge measurement. The table below the heading is used to record "Features", "Distance From Initial Point", "Width", "Total Vertical Depth From Tape/Inst(rument)", and "Water Depth" channel geometry parameters at each cell vertical. Stream velocity measurements are recorded under the columns labeled "Depth of Observation", "Revolutions", "Time", and "Velocity" for each wet cell. All discharge measurement procedures are as outlined by Buchanan and Somers (1969).

The first and last channel geometry measurements are always taken at the cross section stakes. Channel geometry measurements should also be taken at the grassline-streambank and streambank-waterline intersections and at all distinguishable slope breaks between these two intersection points. The horizontal locations of the grassline-streambank and streambank-waterline intersections are also documented by placing a "G" and a "W" in the appropriate row of the "Features" column of the field form. Grassline is identified at the normal high water line, not flood stage, and is generally located below sedges and other plants that may survive submerged under high flows. The "Features"

column is also used to document the horizontal locations of the two cross section stakes ("S") and any rocks ("R") or other features that may have an impact on the discharge measurement.

In streams with uniform bottom profiles (i.e., sand, cobble, etc.), channel geometry and discharge measurements are taken at fixed intervals within the wetted portion of the channel. The interval is varied in streams with boulder substrates to more accurately reflect changes in the velocity distribution with changes in channel bottom profile. The stream discharge measurement is divided into a minimum of 20 to 30 discharge cells, depending upon wetted stream width, with a minimum cell width of 0.3 feet. Sufficient measurements are taken to ensure that no more than 10% of the total streamflow occurs within a single discharge cell. Horizontal and vertical distances are taken from the suspended tape and recorded to the nearest tenth of a foot. Stream velocity (ft/sec) within each cell is averaged and recorded.

The bottom of the "Discharge/Cross Section Notes" section is used to summarize the discharge measurement. Space is also provided to record the names of the persons responsible for the field data calculations, the staging pin reading, and time at the end of the stream discharge measurement.

Figure B. Field data input sheet (Front Page)

COLORADO WATER CONSERVATION BOARD

FIELD DATA FOR INSTREAM FLOW DETERMINATIONS

LOCATION INFORMATION

STREAM NAME:					CROSS-SECTION NO.:
CROSS-SECTION LOCATION					
DATE	OBSERVERS:				
LEGAL DESCRIPTION	¼ SECTION:	SECTION	TOWNSHIP N/S	RANGE: E/W	PM:
COUNTY:	WATERSHED	WATER DIVISION:	DOW WATER CODE		
MAP(S)	USGS:				
	USFS:				

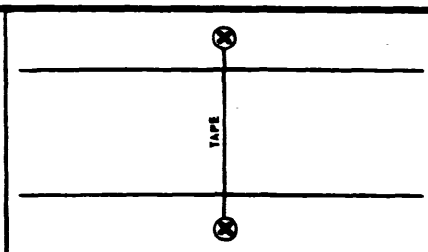
SUPPLEMENTAL DATA

SAG TAPE SECTION SAME AS DISCHARGE SECTION: YES / NO	METER TYPE			
METER NUMBER	DATE RATED	CALIB/SPIN ____ sec	TAPE WEIGHT ____ lbs/foot	TAPE TENSION ____ lbs
CHANNEL BED MATERIAL SIZE RANGE		PHOTOGRAPHS TAKEN YES/NO	NUMBER OF PHOTOGRAPHS	

CHANNEL PROFILE DATA

STATION	DISTANCE FROM TAPE (ft)	ROD READING (ft)
⊗ Tape @ Stake LB	0.0	
⊗ Tape @ Stake RB	0.0	
① WS @ Tape LB/RB	0.0	
② WS Upstream		
③ WS Downstream		
SLOPE		

SKETCH



LEGEND:

Stake ⊗

Station ①

Photo ◇

Direction of Flow

AQUATIC SAMPLING SUMMARY

STREAM ELECTROFISHED YES/NO	DISTANCE ELECTROFISHED ____ft	FISH CAUGHT YES/NO	WATER CHEMISTRY SAMPLED YES/NO

LENGTH - FREQUENCY DISTRIBUTION BY ONE-INCH SIZE GROUPS (1.0-1.9, 2.0-2.9, ETC.)

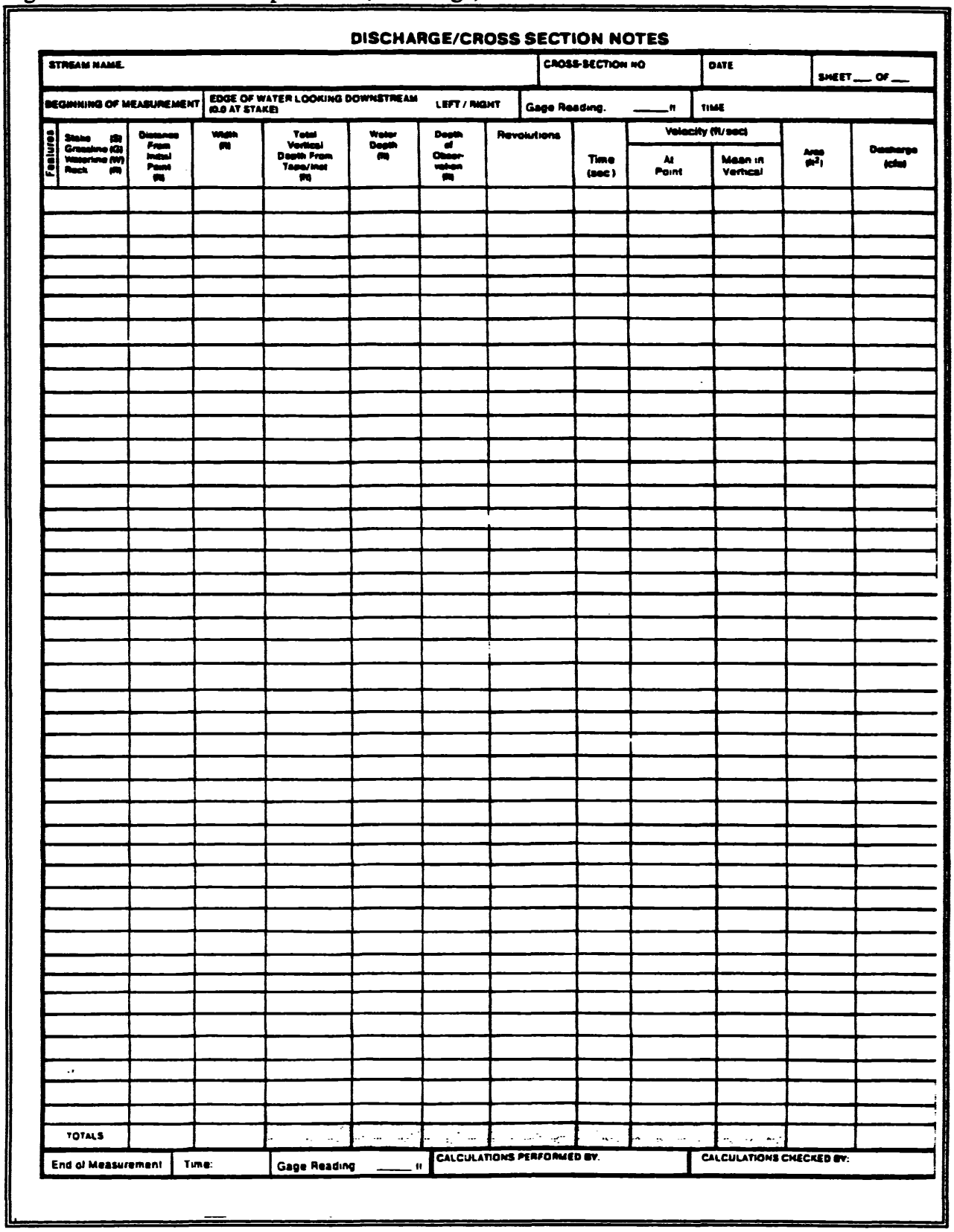
SPECIES (FILL IN)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	>15	TOTAL

AQUATIC INSECTS IN STREAM SECTION BY COMMON OR SCIENTIFIC ORDER NAME

COMMENTS

FORM #ISF FD 1-85

Figure C. Field data input sheet (Back Page)



DISCHARGE/CROSS SECTION NOTES

STREAM NAME		CROSS-SECTION NO	DATE	SHEET ___ OF ___
BEGINNING OF MEASUREMENT	EDGE OF WATER LOOKING DOWNSTREAM (0.0 AT STAKE) LEFT / RIGHT	Gage Reading. _____ ft	TIME	

Features: Stake (S) Grassline (G) Waterline (W) Rock (R)	Distance From Initial Point (ft)	Width (ft)	Total Vertical Depth From Tape/rod (ft)	Water Depth (ft)	Depth of Observation (ft)	Revolutions	Time (sec)	Velocity (ft/sec) At Point	Velocity (ft/sec) Mean in Vertical	Area (ft^2)	Discharge (cfs)

Office Procedures

The CWCB uses a Lotus 1-2-3 macro, called R2CROSS, to process the field data and model instream hydraulic parameters at streamflows above and below the field-measured discharge. The CWCB relies upon the biologic expertise of the cooperating agencies to interpret the output from R2CROSS and develop an initial, biologic instream flow recommendation. This initial recommendation is designed to address the unique biologic requirements of each stream without regard to water availability. After receiving the cooperating agencies' biologic recommendation, the CWCB staff evaluates stream hydrology to determine whether water is physically available for an instream flow appropriation.

Background on the R2CROSS Methodology

Three instream hydraulic parameters, average depth ($\bar{x}_d$), average velocity ($\bar{x}_v$), and percent wetted perimeter (*%WP*), are used to develop biologic instream flow recommendations in Colorado. The DOW has determined that by maintaining these three hydraulic parameters at adequate levels across riffle habitat-types, aquatic habitat in pools and runs will also be maintained for most life stages of fish and aquatic invertebrates (Nehring 1979).

The R2CROSS methodology uses Manning's equation to predict $\bar{x}_d$, $\bar{x}_v$, *%WP*, and other instream hydraulic parameters, at discharges both above and below the field-measured stream discharge. The methodology is both time and labor efficient, requires data from only a single stream transect, and has been found to produce similar results to more data intensive techniques (Nehring 1979) such as the Instream Flow Incremental Methodology (IFIM) developed by the U.S. Fish and Wildlife Service (Bovee 1982).

In 1973, the CWCB staff performed all Manning's equation calculations with a hand-held calculator. In 1981, the USFS released "*Program Documentation for R2-CROSS-81*" (Weatherred et al. 1981). This Fortran-based, mainframe computer program automated the repetitive task of manipulating and recalculating Manning's equation by hand. The CWCB used the USFS version of R2CROSS on the Colorado State University mainframe computer until 1985.

In 1986, the CWCB staff began development of a personal computer version of R2CROSS using the macro capabilities of Lotus 1-2-3. The CWCB found the R2CROSS macro to be advantageous because it ran on a personal computer and it could be customized to the specific needs of the CWCB. The most recent version of R2CROSS is menu-driven (Figure D) and requires very little experience with Lotus 1-2-3. The macro formats the R2CROSS worksheet, initiates data entry, and performs all calculations and printing automatically.

Figures E through K provide an example of R2CROSS output from a typical Colorado stream. Figure E is a "Proof Sheet" that is printed and inspected for data entry errors prior to performing final R2CROSS calculations. Final output consists of a five page printout (Figures F through J). Page one summarizes most of the stream location information, supplemental data, and channel profile data from the field form (Figure F). Page two summarizes the channel geometry/discharge field data set and values computed from the raw field data, including an estimate of Manning's "n" (Figure G). Page three consists of a water line comparison table which the program uses to interpolate the single water surface elevation that results in a calculated cross-sectional area equal to the field-measured cross-sectional area (Figure H). Page four is the staging table that is used by the cooperating agency to develop an initial, biologic instream flow recommendation

(Figure I). The staging table provides estimates of modeled instream hydraulic parameters at stages above and below the measured discharge. Page five summarizes measured and calculated flows, waterlines, and depths (Figure J). It also presents estimates of mean velocity, Manning's "n", water slope, and upper and lower streamflow limits within which the instream flow recommendation should fall. In general, hydraulic models based upon Manning's equation are most accurate when predicted flows fall within a range of 0.4 to 2.5 times measured flow (Bovee and Milhous 1978; Bovee 1982). Space is also provided for a narrative describing the basis for the initial instream flow recommendation and for the signatures of the personnel involved in making the recommendation. The macro can also be used to generate a plot of the stream cross section (Figure K).

Figure D. The R2CROSS Menu

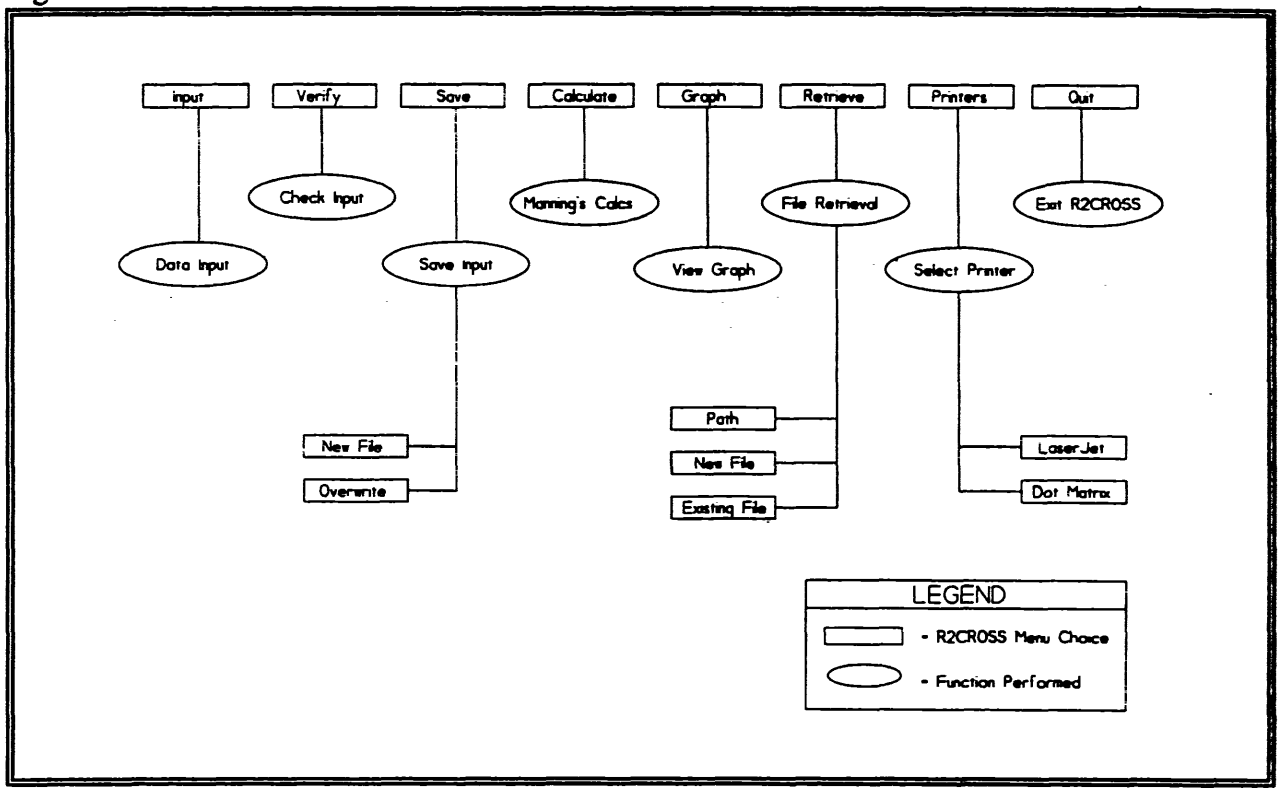


Figure E. R2CROSS proof sheet

PROOF SHEET

LOCATION INFORMATION

STREAM NAME:	IRON CREEK
XS LOCATION:	100 YDS U/S DWB DIVERSION
XS NUMBER:	1
DATE:	10/17/86
OBSERVERS:	SEAHOLM, PUTTMAN
1/4 SEC:	
SECTION:	20
TWP:	2S
RANGE:	76W
PM:	6TH
COUNTY:	GRAND
WATERSHED:	FRASER
DIVISION:	5
DOW CODE:	25482
USGS MAP:	BYERS PEAK
USFS MAP:	ARAPAHOE

SUPPLEMENTAL DATA

TAPE WT:	0.0106
TENSION:	28

CHANNEL PROFILE DATA

SLOPE:	0.0055

INPUT DATA # DATA POINTS= 34

FEATURE	DIST	VERT DEPTH	WATER DEPTH	VEL	A	Q	TAPE TO WATER
S	0.00	1.10	0.00	0.00	0.00	0.00	0.00
	0.50	1.30	0.00	0.00	0.00	0.00	0.00
1 G	1.00	1.40	0.00	0.00	0.00	0.00	0.00
	2.00	1.80	0.00	0.00	0.00	0.00	0.00
	2.50	1.95	0.00	0.00	0.00	0.00	0.00
	3.00	2.00	0.00	0.00	0.00	0.00	0.00
R	3.50	1.90	0.00	0.00	0.00	0.00	0.00
	4.00	2.45	0.00	0.00	0.00	0.00	0.00
	4.50	2.45	0.00	0.00	0.00	0.00	0.00
W	5.00	2.60	0.00	0.00	0.00	0.00	0.00
	5.70	3.00	0.40	0.80	0.20	0.16	2.61
	6.00	3.10	0.45	0.45	0.13	0.06	2.66
	6.30	3.00	0.40	1.10	0.12	0.13	2.61
	6.60	3.00	0.40	0.95	0.12	0.11	2.61
	6.90	2.95	0.35	0.95	0.11	0.10	2.61
	7.20	2.85	0.25	0.70	0.07	0.05	2.61
	7.50	3.10	0.50	0.75	0.15	0.11	2.61
	7.80	3.10	0.50	0.65	0.15	0.10	2.61
	8.10	3.10	0.50	0.85	0.15	0.13	2.61
	8.40	3.20	0.60	0.95	0.18	0.17	2.61
	8.70	3.20	0.60	1.10	0.18	0.20	2.61
	9.00	3.20	0.60	1.35	0.18	0.24	2.61
	9.30	3.15	0.55	1.40	0.16	0.23	2.61
	9.60	3.25	0.65	1.50	0.19	0.29	2.61
	9.90	3.30	0.70	1.55	0.21	0.33	2.61
	10.20	3.30	0.70	1.60	0.21	0.34	2.61
	10.50	3.30	0.70	1.25	0.12	0.15	2.61
W	10.55	2.60	0.00	0.00	0.00	0.00	0.00
1 G	11.00	1.30	0.00	0.00	0.00	0.00	0.00
	11.50	0.85	0.00	0.00	0.00	0.00	0.00
	12.00	0.60	0.00	0.00	0.00	0.00	0.00
	12.50	0.55	0.00	0.00	0.00	0.00	0.00
	13.00	0.55	0.00	0.00	0.00	0.00	0.00
S	13.50	0.50	0.00	0.00	0.00	0.00	0.00
				TOTALS	2.65	2.91	

Figure F. Final output from R2CROSS (Page 1)

```
                    **************************************************
                    *         COLORADO WATER CONSERVATION BOARD      *
                    *     INSTREAM FLOW / NATURAL LAKE LEVEL PROGRAM *
                    *      STREAM CROSS-SECTION AND FLOW ANALYSIS    *
                    **************************************************

LOCATION INFORMATION
====================

STREAM NAME:    IRON CREEK
XS LOCATION:    100 YDS U/S DWB DIVERSION
XS NUMBER:      1

DATE:           10/17/86
OBSERVERS:      SEAHOLM, PUTTMAN

1/4 SEC:
SECTION:        20
TWP:            2S
RANGE:          76W
PM:             6TH

COUNTY:         GRAND
WATERSHED:      FRASER
DIVISION:       5
DOW CODE:       25482

USGS MAP:       BYERS PEAK
USFS MAP:       ARAPAHOE

SUPPLEMENTAL DATA           *** NOTE ***
=================       Leave TAPE WT and TENSION
                      at defaults for data collected
TAPE WT:        0.0106  with a survey level and rod
TENSION:            28

CHANNEL PROFILE DATA
====================
SLOPE:          0.0055



INPUT DATA CHECKED BY: .....................................DATE.....................

ASSIGNED TO: ...............................................DATE.....................
```

Figure G. Final output from R2CROSS (Page 2)

STREAM NAME: IRON CREEK
XS LOCATION: 100 YDS U/S DWB DIVERSION
XS NUMBER: 1

	INPUT DATA	# DATA POINTS= 34			VALUES COMPUTED FROM RAW FIELD DATA				
	FEATURE	DIST	VERT DEPTH	WATER DEPTH	VEL	WETTED PERIM.	WATER DEPTH	AREA (Am)	Q (Qm)	% Q CELL
	S	0.00	1.10	0.00	0.00	0.00	0.00	0.00	0.00	0.0%
		0.50	1.30	0.00	0.00	0.00	0.00	0.00	0.00	0.0%
1	G	1.00	1.40	0.00	0.00	0.00	0.00	0.00	0.00	0.0%
		2.00	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.0%
		2.50	1.95	0.00	0.00	0.00	0.00	0.00	0.00	0.0%
		3.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0%
	R	3.50	1.90	0.00	0.00	0.00	0.00	0.00	0.00	0.0%
		4.00	2.45	0.00	0.00	0.00	0.00	0.00	0.00	0.0%
		4.50	2.45	0.00	0.00	0.00	0.00	0.00	0.00	0.0%
	W	5.00	2.60	0.00	0.00	0.00	0.00	0.00	0.00	0.0%
		5.70	3.00	0.40	0.80	0.81	0.40	0.20	0.16	5.5%
		6.00	3.10	0.45	0.45	0.32	0.45	0.13	0.06	2.1%
		6.30	3.00	0.40	1.10	0.32	0.40	0.12	0.13	4.5%
		6.60	3.00	0.40	0.95	0.30	0.40	0.12	0.11	3.9%
		6.90	2.95	0.35	0.95	0.30	0.35	0.11	0.10	3.4%
		7.20	2.85	0.25	0.70	0.32	0.25	0.07	0.05	1.8%
		7.50	3.10	0.50	0.75	0.39	0.50	0.15	0.11	3.9%
		7.80	3.10	0.50	0.65	0.30	0.50	0.15	0.10	3.4%
		8.10	3.10	0.50	0.85	0.30	0.50	0.15	0.13	4.4%
		8.40	3.20	0.60	0.95	0.32	0.60	0.18	0.17	5.9%
		8.70	3.20	0.60	1.10	0.30	0.60	0.18	0.20	6.8%
		9.00	3.20	0.60	1.35	0.30	0.60	0.18	0.24	8.4%
		9.30	3.15	0.55	1.40	0.30	0.55	0.16	0.23	7.9%
		9.60	3.25	0.65	1.50	0.32	0.65	0.19	0.29	10.1%
		9.90	3.30	0.70	1.55	0.30	0.70	0.21	0.33	11.2%
		10.20	3.30	0.70	1.60	0.30	0.70	0.21	0.34	11.6%
		10.50	3.30	0.70	1.25	0.30	0.70	0.12	0.15	5.3%
	W	10.55	2.60	0.00	0.00	0.70	0.00	0.00	0.00	0.0%
1	G	11.00	1.30	0.00	0.00	0.00	0.00	0.00	0.00	0.0%
		11.50	0.85	0.00	0.00	0.00	0.00	0.00	0.00	0.0%
		12.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.0%
		12.50	0.55	0.00	0.00	0.00	0.00	0.00	0.00	0.0%
		13.00	0.55	0.00	0.00	0.00	0.00	0.00	0.00	0.0%
	S	13.50	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.0%
	TOTALS					6.49	0.7 (Max.)	2.65	2.91	100.0%

Manning's n = 0.0552

Figure H. Final output from R2CROSS (Page 3)

STREAM NAME: IRON CREEK
XS LOCATION: 100 YDS U/S DWB DIVERSION
XS NUMBER: 1

WATER LINE COMPARISON TABLE

WATER LINE	MEAS AREA	COMP AREA	AREA ERROR
2.36	2.65	4.21	59.0%
2.38	2.65	4.07	53.9%
2.40	2.65	3.94	48.8%
2.42	2.65	3.81	43.8%
2.44	2.65	3.67	38.8%
2.46	2.65	3.54	33.8%
2.48	2.65	3.42	29.2%
2.50	2.65	3.30	24.7%
2.52	2.65	3.18	20.2%
2.54	2.65	3.07	15.8%
2.56	2.65	2.95	11.4%
2.57	2.65	2.89	9.3%
2.58	2.65	2.84	7.1%
2.59	2.65	2.78	5.0%
2.60	2.65	2.72	2.9%
2.61	2.65	2.67	0.8%
2.62	2.65	2.61	-1.3%
2.63	2.65	2.56	-3.4%
2.64	2.65	2.50	-5.5%
2.65	2.65	2.45	-7.6%
2.66	2.65	2.39	-9.6%
2.68	2.65	2.28	-13.7%
2.70	2.65	2.18	-17.8%
2.72	2.65	2.07	-21.9%
2.74	2.65	1.96	-25.9%
2.76	2.65	1.86	-29.9%
2.78	2.65	1.75	-33.9%
2.80	2.65	1.65	-37.8%
2.82	2.65	1.54	-41.8%
2.84	2.65	1.44	-45.6%
2.86	2.65	1.34	-49.5%

WATERLINE AT ZERO
AREA ERROR = 2.611

Figure I. Final output from R2CROSS (Page 4)

STREAM NAME: IRON CREEK
XS LOCATION: 100 YDS U/S DWB DIVERSION
XS NUMBER: 1

GL = lowest Grassline elevation corrected for sag
STAGING TABLE *WL* = Waterline corrected for variations in field measured water surface elevations and sag

	DIST TO WATER (FT)	TOP WIDTH (FT)	AVG. DEPTH (FT)	MAX. DEPTH (FT)	AREA (SQ FT)	WETTED PERIM. (FT)	PERCENT WET PER (%)	HYDR RADIUS (FT)	FLOW (CFS)	AVG. VELOCITY (FT/SEC)
GL	1.40	**9.97**	1.21	1.90	12.09	12.14	100.0%	1.00	24.07	1.99
	1.61	9.38	1.07	1.70	10.08	11.37	93.6%	0.89	18.57	1.84
	1.66	9.23	1.04	1.65	9.61	11.18	92.0%	0.86	17.36	1.81
	1.71	9.09	1.01	1.60	9.15	10.99	90.5%	0.83	16.18	1.77
	1.76	8.95	0.97	1.55	8.70	10.80	89.0%	0.81	15.04	1.73
	1.81	8.80	0.94	1.50	8.26	10.61	87.4%	0.78	13.95	1.69
	1.86	8.62	0.91	1.45	7.82	10.39	85.5%	0.75	12.93	1.65
	1.91	8.41	0.88	1.40	7.40	10.13	83.5%	0.73	11.97	1.62
	1.96	7.90	0.88	1.35	6.99	9.55	78.6%	0.73	11.33	1.62
	2.01	7.16	0.92	1.30	6.61	8.75	72.0%	0.76	10.96	1.66
	2.06	7.10	0.88	1.25	6.26	8.63	71.0%	0.73	10.08	1.61
	2.11	7.04	0.84	1.20	5.90	8.51	70.0%	0.69	9.24	1.57
	2.16	6.97	0.80	1.15	5.55	8.39	69.1%	0.66	8.42	1.52
	2.21	6.91	0.75	1.10	5.21	8.27	68.1%	0.63	7.64	1.47
	2.26	6.85	0.71	1.05	4.86	8.15	67.1%	0.60	6.88	1.42
	2.31	6.79	0.67	1.00	4.52	8.02	66.1%	0.56	6.16	1.36
	2.36	6.72	0.62	0.95	4.18	7.90	65.1%	0.53	5.47	1.31
	2.41	6.66	0.58	0.90	3.85	7.78	64.1%	0.49	4.81	1.25
	2.46	6.09	0.58	0.85	3.52	7.16	58.9%	0.49	4.38	1.24
	2.51	5.91	0.55	0.80	3.22	6.93	57.1%	0.46	3.86	1.20
	2.56	5.72	0.51	0.75	2.93	6.70	55.2%	0.44	3.37	1.15
WL	2.61	5.55	0.48	0.70	2.65	6.48	53.4%	0.41	2.91	1.10
	2.66	5.45	0.43	0.65	2.37	6.33	52.1%	0.37	**2.46**	**1.04**
	2.71	5.36	0.39	0.60	2.10	6.18	**50.9%**	0.34	**2.04**	**0.97**
	2.76	5.27	0.35	0.55	1.84	6.03	**49.7%**	0.30	**1.66**	0.90
	2.81	5.18	0.30	0.50	1.57	5.88	48.4%	0.27	1.31	0.83
	2.86	5.08	0.26	0.45	1.32	5.72	47.1%	0.23	0.99	0.75
	2.91	4.78	**0.22**	0.40	1.07	5.33	43.9%	0.20	**0.73**	0.68
	2.96	4.47	**0.19**	0.35	0.84	4.94	40.7%	0.17	**0.51**	0.61
	3.01	3.73	0.17	0.30	0.63	4.11	33.8%	0.15	0.36	0.57
	3.06	3.36	0.13	0.25	0.45	3.66	30.2%	0.12	0.22	0.49
	3.11	2.41	0.12	0.20	0.29	2.63	21.6%	0.11	0.14	0.46
	3.16	2.22	0.08	0.15	0.18	2.39	19.7%	0.07	0.06	0.35
	3.21	1.05	0.08	0.10	0.08	1.15	9.4%	0.07	0.03	0.34
	3.26	0.88	0.04	0.05	0.03	0.93	7.6%	0.04	0.01	0.22

** NOTE**: Bold and underlined text within the Iron Creek staging table was added to facilitate explanation of the procedure for developing biologic instream flow recommendations (see Pages 18-19). Standard R2CROSS staging table printouts will not contain these enhancements.

Figure J. Final output from R2CROSS (Page 5)

STREAM NAME: IRON CREEK
XS LOCATION: 100 YDS U/S DWB DIVERSION
XS NUMBER: 1

SUMMARY SHEET

MEASURED FLOW (Qm)=	2.91 cfs	RECOMMENDED INSTREAM FLOW:
CALCULATED FLOW (Qc)=	2.91 cfs	==========
(Qm-Qc)/Qm * 100 =	-0.1 %	
		FLOW (CFS) PERIOD
MEASURED WATERLINE (WLm)=	2.61 ft	========== ======
CALCULATED WATERLINE (WLc)=	2.61 ft	
(WLm-WLc)/WLm * 100 =	-0.1 %	_____ _____
MAX MEASURED DEPTH (Dm)=	0.70 ft	_____ _____
MAX CALCULATED DEPTH (Dc)=	0.70 ft	
(Dm-Dc)/Dm * 100	0.6 %	_____ _____
MEAN VELOCITY=	1.10 ft/sec	_____ _____
MANNING'S n=	0.055	
SLOPE=	0.0055 ft/ft	
.4 * Qm =	1.2 cfs	
2.5 * Qm=	7.3 cfs	

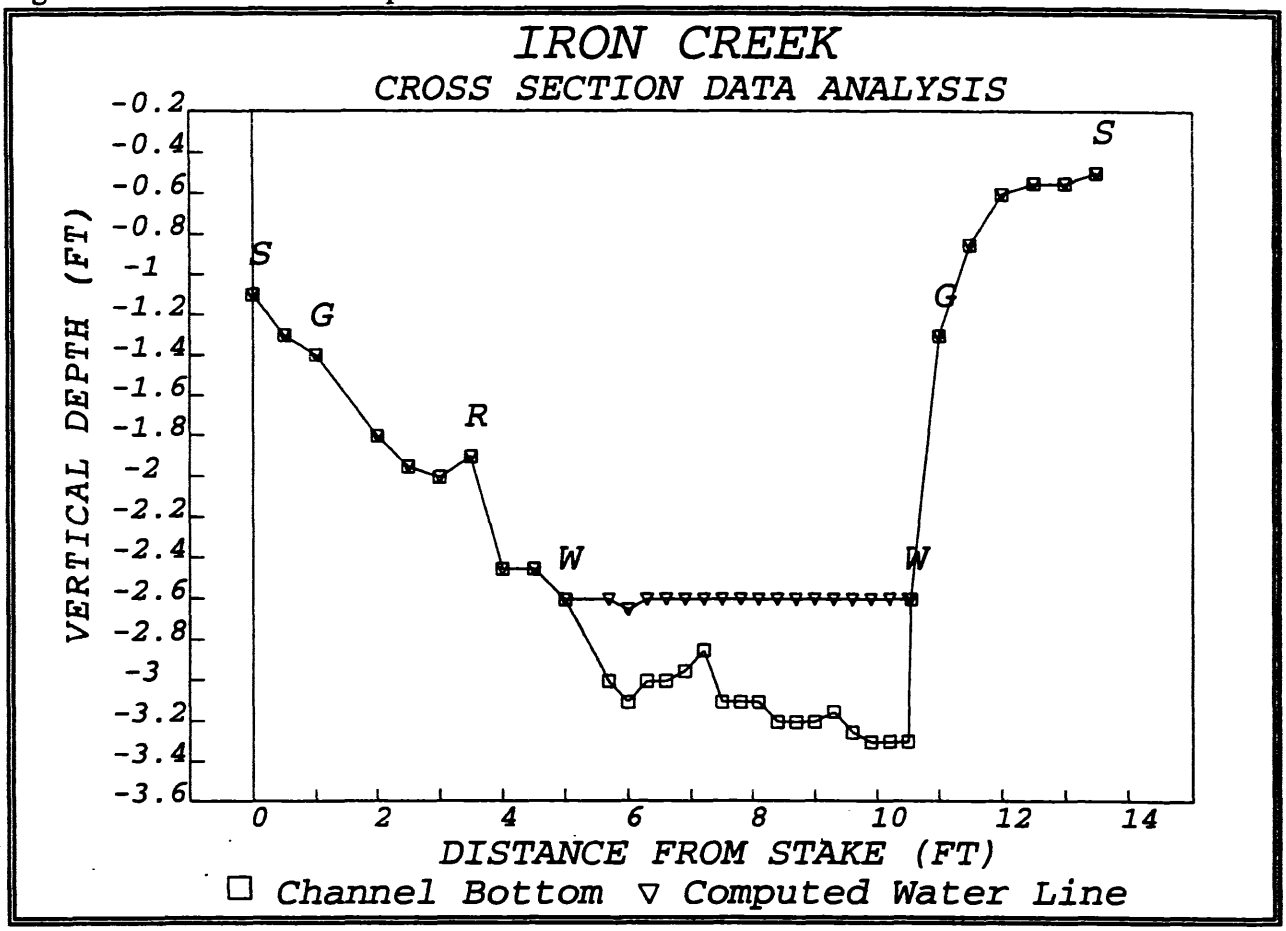
RATIONALE FOR RECOMMENDATION:
==========

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RECOMMENDATION BY: .....AGENCY..... DATE:.....

CWCB REVIEW BY: ..... DATE:.....

Figure K. Cross section plot from R2CROSS



Biologic Instream Flow Recommendations

When using R2CROSS, biologic instream flow recommendations are based on maintaining three principal hydraulic criteria, $\bar{x}_d$, $\bar{x}_v$, and *%WP*, at adequate levels across the stream transect (Table 2). The $\bar{x}_d$ and *%WP* criteria are functions of stream top width and grassline-to-grassline wetted perimeter, respectively. A constant $\bar{x}_v$ of 1 ft/sec is recommended for all streams. The DOW has determined that these three parameters are good indices of flow-related stream habitat quality and that maintenance of these parameters at adequate levels across riffle habitat-types will also result in maintenance of adequate aquatic habitat in pools and runs for most life stages of fish and aquatic invertebrates (Nehring 1979).

The three critical hydraulic parameters are estimated within the R2CROSS staging table at various levels of discharge (Figure I). Biologic instream flow recommendations are developed by locating the modeled streamflow(s) in the R2CROSS staging table that satisfy the three hydraulic criteria summarized in Table 2. The streamflow that meets two of the three criteria is considered as an initial winter flow recommendation. Initial summer flow recommendations are based upon satisfying all three criteria (Skinner, pers. comm). Aquatic biologists may modify summer and winter flow recommendations

Table 2. Criteria used to determine minimum flow requirements using the R2CROSS single transect method (Nehring 1979)

Stream Top Width (ft)[1]	Average Depth (ft)	Percent Wetted Perimeter (%)[1]	Average Velocity (ft/sec)
1-20	0.2	50	1.0
21-40	0.2-0.4	50	1.0
41-60	0.4-0.6	50-60	1.0
61-100	0.6-1.0	≥ 70	1.0

[1] At bankfull discharge.

based upon biologic considerations such as stream conditions, species composition, and aquatic habitat quality.

These hydraulic criteria can be applied to the R2CROSS staging table from the Iron Creek example (Figure I) to develop an initial biologic instream flow recommendation. In this example, the grassline top width of Iron Creek is 9.97 ft. Therefore, the DOW criteria for an $\bar{x}_d$ of 0.2 feet would be satisfied at a flow of approximately 0.6 cfs. The *%WP* criterion of 50% would be met at a flow of around 1.75 cfs and an $\bar{x}_v$ of 1 ft/sec at a flow of 2.25 cfs. Based upon this analysis, a winter flow recommendation of 1.75 cfs would meet the $\bar{x}_d$ and *%WP* criteria and a summer flow recommendation of 2.25 cfs would satisfy all three criteria. These initial recommendations may be adjusted up or down based upon biologic judgment and expertise.

Water Availability Requirements

Once an initial biologic instream flow recommendation has been developed, the CWCB staff must determine whether water is physically available to satisfy the biologic recommendation. The staff uses stream gaging records to analyze physical water availability whenever possible. In the absence of a gage record, the staff may use standardized hydrologic techniques, such as areal apportionment or synthetic streamflow modeling (Kircher et al. 1985), to estimate physical water availability. The staff may also conduct a review of the State Engineer's water rights tabulation and consult with Division Engineers and District Water Commissioners to determine the effect of senior diversions on a stream reach.

The water availability analyses may lead the CWCB staff to conclude that sufficient water is not available to meet the biologic recommendation. In that situation, the CWCB staff may request that the cooperating agency reconsider its biologic recommendation and determine whether the natural environment can be preserved with the amount of water available. If the natural environment can be preserved with the available water, the instream flow recommendation may be revised to reflect the lower available flow amounts. If the statutory water availability requirement cannot be satisfied, the CWCB must reject the instream flow recommendation.

Appropriating and Protecting an Instream Flow Water Right

On November 10, 1993, the CWCB adopted the "Statement of Basis and Purpose and Rules and Regulations Concerning the Colorado Instream Flow and Natural Lake Level Program." These Rules and Regulations codified existing CWCB procedures for implementing the Instream Flow Program and established procedures for handling acquisition of water, water rights, and interests in water including conditional rights, modification of instream flows, and inundation of instream flow water rights. The CWCB's procedural requirements for appropriating and protecting instream flow water rights are also described in great detail within these Rules and Regulations.

The procedural aspects of appropriating and protecting an instream flow water right are beyond the intended scope of this manuscript. Individuals who are interested in learning more about these procedures are encouraged to obtain a copy of the above-referenced Rules and Regulations from the CWCB.

Summary

In 1973, the Colorado State Legislature vested the CWCB with the authority to appropriate instream flow water rights to preserve the natural environment to a reasonable degree. Since that time, the CWCB has completed instream flow appropriations on approximately 7,982 miles of Colorado streams, and the Instream Flow Program is expanding.

The CWCB has adopted standardized field and office procedures for developing instream flow recommendations. This standardization helps to ensure that each instream flow recommendation is "necessary" and "reasonable", as required by state statute.

R2CROSS is one of the standard methodologies employed by the CWCB to model instream hydraulic parameters. The CWCB has chosen to use the R2CROSS methodology because it is both time and labor efficient, requiring data from only a single stream transect. It has also been found to produce similar results to more data intensive techniques like the IFIM. The R2CROSS macro is also easy to use and requires very little in the way of computer hardware or software.

Biologic instream flow recommendations based upon output from R2CROSS are designed to maintain $\bar{x}_v$, $\bar{x}_d$, and *%WP* at critical levels across riffle habitat-types. It is assumed that by maintaining these critical hydraulic parameters across riffles, aquatic habitat in pools and runs is also preserved. In addition to biologic considerations, water must be physically available for the CWCB to file for an instream flow water right.

An instream flow water right requires a coordinated effort between various state and federal agencies, the public, and the CWCB. The culmination of these efforts is a decreed instream flow water right that is held by the CWCB on behalf of the people of Colorado to "preserve the natural environment to a reasonable degree."

The Colorado State Legislature enacted SB 97 in 1973. By "recognizing the need to correlate the activities of mankind with some reasonable preservation of the natural environment" (§ 37-92-102(3), C.R.S. (1990)), the Legislature sought to balance traditional water development with some reasonable protection of Colorado's natural environment. This is not a simple task in the semi-arid Western United States where water is a scarce, and extremely valuable resource. The ongoing success of Colorado's Instream Flow Program assures that coordination between water development and protection of the natural environment will continue -- both now and into the future.

R2CROSS Program Documentation

Program documentation for the R2CROSS macro is divided into four sections. The "Setup and Installation" section describes the hardware and software requirements of the R2CROSS macro and installation of the R2CROSS program on a hard disk drive. The "Iron Creek Example" provides an opportunity for the new user to learn the most common procedures for entering and analyzing typical R2CROSS data sets and to verify that a newly installed version of R2CROSS is operating properly. "The R2CROSS Menu" provides detailed program documentation for each of the menu choices within R2CROSS (Figure D). Instructions for "Terminating and reactivating the R2CROSS macro" are described in the final section.

Appendix A provides a brief description of the "Program Calculations" that are performed within the R2CROSS macro. Rather than emphasizing the technical aspects of these calculations, this appendix is intended to provide a fundamental understanding of the operations being performed within the macro.

Output from the R2CROSS macro was verified against several simple hand-calculated examples. More complex cross sections were verified by comparison with output from the MANSQ option of IFIM (Bovee 1982). Based on this verification process, it is our belief that the instream hydraulic parameters summarized in the R2CROSS staging table are accurate estimations based upon Manning's equation.

To date, the majority of the CWCB's instream flow water rights have been based upon recommendations from an R2CROSS analysis. The CWCB chose the R2CROSS methodology because it is both time and labor efficient. It has also been shown to produce similar results to more costly techniques for modeling streamflows (Nehring 1979).

The CWCB hopes that the release of the R2CROSS macro will foster a greater understanding of this technical aspect of Colorado's Instream Flow Program. It is intended to be user-friendly. If you have any problems running the macro or questions regarding its operation, please feel free to contact the CWCB staff.

Setup and Installation

The R2CROSS macro runs efficiently on an IBM-compatible 80486 personal computer equipped with a hard disk drive, and DOS 6.0, Windows 3.1, and Lotus 1-2-3 Release 4 for Windows software.

Copying R2CROSS to a Hard Disk Drive

To begin installation of the R2CROSS program, create an R2CROSS subdirectory on your computer's hard drive using the DOS command:

md c:\R2CROSS

and press <ENTER>.

Copy the files from the enclosed diskette into this subdirectory using the DOS command:

copy a:*.* c:\R2CROSS.

Press <ENTER> to execute the command.

Loading Lotus 1-2-3 and Retrieving the R2CROSS Macro

To run the R2CROSS macro, load your copy of Lotus 1-2-3 Version 4 for Windows and open the R2CROSS.WK4 file using the Lotus menu commands "File" and "Open". The R2CROSS macro begins with an introductory message screen. Press <ENTER> to continue.

The data entry and data editing routines of the R2CROSS macro were intended to be very user-friendly. In R2CROSS, the <ENTER> key is used to complete the entry of all data within the "Location Information", "Supplemental Data", and "Channel Profile Data" sections of the data input screen (see Figure E). After entering the stream "Slope", the macro moves into the "Input Data" table. The arrow keys are used to complete the entry of all data within the "Input Data" table. After using the arrow keys to complete the entry of all data within the "Input Data" table, simultaneously press "<Ctrl> G" to exit the data entry routine.

After initial data entry, the arrow keys are used to correct and edit all data entry errors, including corrections to the "Location Information", "Supplemental Data", and "Channel Profile Data" (which were initially entered using the <ENTER> key). Table 3 is intended to help clarify the proper use of the <ENTER> key and the arrow keys within the R2CROSS data entry and data editing routines.

Table 3. Data entry and data editing using the <ENTER> key and arrow keys

	Initial data entry	Data correction/ editing
Location Information Supplemental Data Channel Profile Data	<ENTER> key	Arrow keys
Input Data Table	Arrow keys	Arrow keys

The "Iron Creek Example" which follows is a useful exercise. It is intended to familiarize new users with the data entry nuances of the R2CROSS macro and to verify that the newly installed copy of the R2CROSS macro is operating properly. We recommend that new users take a couple of minutes to work through the "Iron Creek Example" in order to gain hands-on experience with the R2CROSS macro prior to entering individual data sets.

Iron Creek Example

Figure E depicts an actual set of R2CROSS field data collected on Iron Creek, a tributary to the Fraser River in Grand County, Colorado. Assuming that the R2CROSS macro has been installed and initiated as described above, highlight the "Printers" menu choice and select either the LaserJet or Dot Matrix menu choice. Other printer-types may require a customized setup (consult your Lotus 1-2-3 reference manual).

In order to ensure that all subsequent data files are stored in the R2CROSS subdirectory, select the "Retrieve" menu choice, choose the "Path" suboption, key-in:

c:\ R2CROSS

and press <ENTER>.

To initiate data entry, select the "Input" menu option. R2CROSS then prompts you to enter the number of data points collected in the stream cross section. Count the number of data points (Iron Creek has 34), key-in this number at the prompt, and press <ENTER>.

Enter the remainder of the data within the "Location Information", "Supplemental Data", and "Channel Profile Data" sections of the R2CROSS macro. Use the <ENTER> key to complete each data entry and move the cursor through each of the data input cells in sequential order. The final use of the <ENTER> key occurs after keying-in the stream "Slope".

After entering the stream "Slope", use the arrow keys to enter all of the "Feature", "Dist", "Vert Depth", "Water Depth", and "Vel" data from the Input Data table of Figure E. The grasslines on each streambank represent a very important piece of information in the R2CROSS analysis. In the Iron Creek example, these grasslines occur at distances of 1.00 and 11.00 feet. It is imperative that these grasslines be identified within R2CROSS by placing the number "1" in the appropriate cell of Column A in the R2CROSS worksheet. This designation is so important that the R2CROSS macro will not proceed until the two grasslines have been specified. After entering all of the data within the Input Data table, including the two grasslines, simultaneously press "<Ctrl> G" to terminate the data entry routine and return to the main R2CROSS menu.

Select the "Verify" option to print a "Proof Sheet" for comparison with Figure E. If data entry errors are found, return to the "Input" menu option and correct them. When editing data, use the arrow keys to move around the worksheet and correct mistakes. When all data entry errors have been corrected, exit the editing routine by pressing "<Ctrl> G". The data editing routine can be repeated until all data entry errors have been corrected.

Once all data entry errors have been corrected, use the "Save" menu choice to store the input data file to the R2CROSS directory on the hard disk drive. Select the "New File" menu option, type an appropriate eight letter file name for the data set, and press <ENTER>. The file will automatically be saved with a .WK4 file extension. **Caution: do not name the file "R2CROSS".**

Select the "Calculate" option and press <ENTER> to initiate staging table calculations and print the final output from R2CROSS. Verify that the printed output is identical to Figures F through J.

Select the "Graph" option to view the cross section plot. Press <ENTER> to exit the view and print the cross section plot.

Exit the R2CROSS macro by selecting the "Quit" option. Answer "No" to the Lotus prompt to exit R2CROSS and remain in Lotus 1-2-3.

This general procedure can be followed to enter, edit, and analyze almost all R2CROSS datasets. To begin data entry on your own R2CROSS data set, select "Retrieve" a "New file" from the R2CROSS menu.

The R2CROSS Menu

The R2CROSS menu consists of eight main menu choices arranged from left to right across the top of the computer screen (Figure D). Use the arrow keys to move between menu choices and the <ENTER> key to select a highlighted menu choice.

Input

The "Input" menu choice is used to enter data in a new R2CROSS.WK4 worksheet or to correct/edit data in an existing worksheet. As depicted in Table 3, the <ENTER> key is used for the initial entry of the information contained within the "Location Information", "Supplemental Data", and "Channel Profile Data" sections of the field form. The arrow keys are used for the initial entry of the "Discharge/Cross Section Notes" within the "Input Data" table. The arrow keys are also used for all subsequent editing of data. This procedure ensures that the cursor is always located within the appropriate cell of the worksheet during the initial entry of the "Location Information", "Supplemental data" and "Channel Profile Data" (not always a one cell movement) and also allows the greatest flexibility in the initial entry of the discharge notes and subsequent editing of data.

Entering data in a new file

To enter data in a new file:

1. *Select the "Input" menu choice.*
2. *Count the number of data points (cell verticals) collected across the stream channel. Key-in that number and press <ENTER>. R2CROSS automatically sizes the worksheet to the proper number of discharge cells.*
3. *Once the worksheet has been sized, the macro prompts for the entry of a "Stream Name". Key-in the "Stream Name" and press the <ENTER> key to complete the data entry. Follow this same procedure for all of the information contained within the "Location Information", "Supplemental Data", and "Channel Profile Data" data entry cells. The final use of the <ENTER> key occurs after the entry of a stream "Slope". The cursor then moves to the upper left corner of the "Input Data" table (cell C50).*
4. *Use the arrow keys to enter all channel geometry and stream velocity data within the "Input Data" table. Key-in the horizontal distance from the zero stake to the cell vertical in the "Dist" column, vertical distance from the suspended tape to the channel bottom in the "Vert Depth" column, water depth in the "Water Depth" column, and water velocity in the "Vel" column for each cell in the cross section. Use the "Feature" column (Column B) to indicate the horizontal locations of the cross section stakes (S), grasslines (G), waterlines (W), and other features such as rocks (R), etc. Finally, enter a "1" in the appropriate cell of Column A to indicate the location of the grassline/streambank intersection on each streambank. R2CROSS uses the grassline locations to determine bankfull wetted perimeter and top width. These grassline locations are integral to the development of biologic instream flow recommendations in Colorado. The R2CROSS macro will not proceed until the grassline/streambank intersection on each streambank has been depicted with a "1" in Column A of the worksheet.*

5. *When all of the field data has been entered in the "Input Data" table, simultaneously press "<Ctrl> G" to exit from the "Input" routine and return to the main R2CROSS menu.*

Editing data in the current worksheet

To correct data entry errors in the current worksheet:

1. *Select the "Input" option.*
2. *Use the arrow keys to edit data. Data editing begins at the top of the "Input Data" table in cell C50. Move the cursor up from cell C50 to edit "Location Information", Supplemental Data", or "Channel Profile Data". Move down to edit data within the "Input Data" table.*
3. *After correcting all data entry errors, simultaneously press "<Ctrl> G" to terminate the "Input" routine and return to the main R2CROSS menu.*

Editing data in an "Existing file"

Previously-saved files can be retrieved, edited and re-run. Use the R2CROSS menu to "Retrieve" an "Existing file" and then following the instructions under "Editing data in the current worksheet" to edit previously-saved data files.

Verify

The "Verify" option is used to initiate R2CROSS discharge calculations and print a proof sheet (Figure E). Prior to running "Verify", be sure that the proper printer has been initialized (see "Printer" menu option).

Printed output consists of the cross section input data, calculated cross-sectional area, and calculated discharge. The proof sheet should be reviewed to verify accurate entry of all field measurements before continuing to the "Save" option. If data entry errors are discovered, return to the instructions for "Editing data in the current worksheet" and correct the errors. Proceed to "Save" only after all field data has been entered correctly.

Save

Use "Save" to store data input files. Data input files should always be saved prior to running the "Calculate" option because they are generally smaller in size and they can be retrieved, edited, and rerun if necessary. The "Calculate" option can not be run twice on the same file!

Prior to saving data input files, be sure to run the "Retrieve" and "Path" menu options to specify the location of data storage.

There are two suboptions under the "Save" menu choice, "New file" and "Overwrite". Choose your option carefully and do not overwrite the original R2CROSS.WK4 file!

New file

The first suboption, "New file", is used to save a newly created R2CROSS data set. This is accomplished by the following procedure:

1. *Select "Save" and then "New file" from the R2CROSS menu. R2CROSS prompts for the name of a new file.*
2. *Enter a name of up to eight characters and press <ENTER>.*

If a filename is selected that already exists in the default directory, the computer will beep and the file will not be saved. Should this happen, either repeat the above procedure and save under a different file name or go to the "Overwrite" suboption.

Overwrite

The "Overwrite" suboption is designed to overwrite an existing data file. Use the following procedure to perform this task:

1. *Select "Save" and then "Overwrite" from the R2CROSS menu. R2CROSS will list the files in the current directory that you may chose to overwrite.*
2. *Select a file from the list using the arrow keys and overwrite it by pressing <ENTER>. The existing file will be replaced with the current file. Do not select the original R2CROSS.WK4 file!*

Calculate

"Calculate" initiates all staging table calculations and prints a five page data summary (Figures F through Figure J). Be sure that you have saved your input data set and that the proper printer type has been specified prior to running "Calculate". This operation may take several minutes depending upon the speed of your computer. A detailed explanation of the four major calculations performed within R2CROSS can be found in "Appendix A - Program Calculations".

Graph

The "Graph" option allows the user to view and print a cross-section plot of the stream transect (Figure K). The cross section plot is useful for revealing potential problems with the input data set or potential errors in data collection or data entry. Errors, such as misread rod readings on waterlines or ground profiles, are often easily detected on a cross section plot.

Retrieve

The "Retrieve" menu option has three suboptions, "Path", "New file", and "Existing file". These suboptions are used to change the current file storage path and to retrieve data files.

Path

The "Path" suboption changes the current data storage location. A valid storage path may be any drive and/or directory which is in existence on the computer's hard drive. To select a new path, follow these steps:

1. *Select "Retrieve" and then "Path" from the R2CROSS menu.*
2. *Type in the name of an existing directory on your hard drive and press <Enter>.*

Subsequent files will be stored and retrieved within this directory. In the event that a non-existent path is entered, the computer will beep and return to the main menu. The default directory will remain in effect until a valid path has been entered.

The "Path" suboption choice is not frequently used. It may be appropriate if you wish to organize R2CROSS data from different streams into separate subdirectories. However, file organization can also be accomplished by simply using descriptive file names. If you do decide to create separate directories for your R2CROSS output files, you should copy the files from the R2CROSS diskette into each of these subdirectories so that they can be retrieved when you want to create a new data set.

New file

The "New file" suboption is used to initiate data entry on a new cross section. It erases the current worksheet from the screen and replaces it with a blank R2CROSS.WK4 worksheet. Read the introductory message and press <ENTER> to initiate data entry.

Existing file

The final suboption, "Existing file", retrieves a previously-saved R2CROSS data set from storage. Simply select the file to be retrieved. Select the "Input" command on the R2CROSS menu to edit the dataset. Staging table calculations are initiated by selecting the "Calculate" option. Remember, the "Calculate" option cannot be run twice on the same file.

Printers

LaserJet

Dot Matrix

The "Printers" menu option is used to format R2CROSS output for either a LaserJet or Dot Matrix type printer. The proper printer-type should be selected prior to running the "Verify" or "Calculate" menu options. Use the arrow keys to highlight the proper printer and press the <ENTER> key. Experienced Lotus 1-2-3 users can setup additional printers prior to retrieving the R2CROSS.WK4 worksheet if necessary. Consult a Lotus manual for specific instructions on setting up other types of printers.

Quit

Select the "Quit" menu option and answer "No" to the Lotus prompt to de-activate the R2CROSS macro and return to normal Lotus 1-2-3 operations. De-activating the R2CROSS macro allows for the use of standard Lotus 1-2-3 commands on all unprotected cells within the current data file. The R2CROSS menu can be reactivated by simultaneously pressing "<Ctrl> M". Alternatively, a new R2CROSS worksheet can be brought up from within Lotus 1-2-3 by retrieving the original R2CROSS.WK4 file from the computer's hard disk drive (see "Installation" section).

Terminating and Reactivating the R2CROSS Macro

Situations may arise where the macro must be terminated during data entry or calculation routines. To terminate the R2CROSS macro and return to the standard Lotus 1-2-3 menu, press <Ctrl><Break>. Then press the <Esc> key several times to clear the Lotus error message screen.

If the R2CROSS macro was terminated due to a data entry error or a problem with the execution of the macro, the integrity of the worksheet may have been compromised. If so, the current worksheet should be erased and a fresh copy of the R2CROSS.WK4 file retrieved from the computer's hard disk drive. The data should definitely be re-entered if the macro failed during the "Calculate" option of R2CROSS. Trying to rerun a compromised dataset may result in additional problems and unreliable output. It is always safer, albeit more time consuming, to start over.

If you do not believe the data in the current worksheet has been compromised, the R2CROSS macro can be re-activated by simultaneously pressing "<Ctrl> M". Macro operation will begin with the standard R2CROSS menu and data entry or calculations may then resume within the existing file.

Literature Cited

Bovee, K.D. 1982. A guide to stream habitat analysis using the Instream Flow Incremental Methodology. Instream Flow Information Paper No. 12. Washington, DC: U.S. Fish and Wildlife Service (FWS/OBS-82/26). 248pp.

Bovee, K.D. and R. Milhous. 1978. Hydraulic simulation in instream flow studies: Theory and techniques. Instream Flow Information Paper No. 5. Washington, DC: U.S. Fish and Wildlife Service (FWS/OBS -78/33). 143pp.

Buchanan, T.J. and W.P. Somers. 1969. Discharge measurements at gaging stations. Techniques of Water-Resources Investigations of the United States Geological Survey, Book 3, Chapter A8. United States Government Printing Office, Washington, D.C. 20402.

Benson, M.A., and T. Dalrymple. 1967. General field and office procedures for indirect discharge measurements. Techniques of Water-Resources Investigations of the United States Geological Survey, Book 3, Chapter A1. United States Government Printing Office, Washington, D.C. 20402.

Chow, V.T. 1959. Open-channel hydraulics. McGraw-Hill Book Company, New York. 680p.

Colorado Water Conservation Board. 1993. Statement of Basis and Purpose and Rules and Regulations Concerning the Colorado Instream Flow and Natural Lake Level Program. Department of Natural Resources. Denver, CO. 80203.

Grant, G.E., J.E. Duval, G.J. Koerper and J.L. Fogg. 1992. XSPRO: A channel cross-section analyzer. Technical Note 387. Bureau of Land Management. Denver, CO. 80225-0047.

Kircher, J.E., A.F. Choquette and B.D. Richter. 1985. Estimation of natural streamflow characteristics in western Colorado. Water-Resources Investigations Report 85-4086. United States Geological Survey. Box 25425, Denver Federal Center. Lakewood, CO 80225.

Laursen, H.I. 1978. Structural analysis. Second edition. New York. McGraw-Hill Book Company.

Nehring, R.B. 1979. Evaluation of instream flow methods and determination of water quantity needs for streams in the State of Colorado. Colorado Division of Wildlife. Fort Collins, CO.

Ray, G.A. and W.F. Megahan. 1979. Measuring cross sections using a sag tape: a generalized procedure. USDA Forest Service General Technical Report INT-47. Intermountain Forest and Range Experiment Station. U.S. Department of Agriculture. Ogden, UT. 84401.

Silvey, L. 1976. R-2 Cross Program: A sag-tape method of channel cross section measurement for use with instream flow determinations. United States Department of Agriculture, Forest Service Region 2. 11177 W. 8th Avenue. Lakewood, CO 80225.

Skinner, J. Instream Flow Coordinator. Colorado Division of Wildlife. Personal communication.

Weatherred, J.D., H.L. Silvey and D.J. Pfankuch. 1981. Program documentation for R2-CROSS-81. Watershed Systems Development Group. United States Department of Agriculture, Forest Service. 3825 East Mulberry Street. Fort Collins, CO 80524.

Appendix A - Program Calculations

Some R2CROSS users may be interested in the operation and layout of the Lotus 1-2-3 macro. Figure L depicts the sequence of operations performed within each R2CROSS menu option. Figure M provides the layout of the R2CROSS macro within the Lotus 1-2-3 worksheet. The four major computations performed within the R2CROSS macro are sag-tape corrections, estimation of Manning's "n", calculation of a water line comparison table, and calculation of a staging table.

Sag-Tape Calculations.

Channel geometry measurements that are taken using the sag-tape methodology must be corrected to a level reference. R2CROSS uses catenary curve formulas to compute these corrections from a sagging tape that has been leveled at each end. The use of the catenary curve solution is based on the assumption that the suspended steel tape is analogous to a suspended cable placed under a unidirectionally distributed load (Laursen 1978).

The derivation of the catenary curve solution is beyond the scope of this manuscript. Basically, R2CROSS uses the length of tape in suspension, the tension applied to the tape, and the standard weight of one foot of tape to apply the necessary vertical distance corrections to each cell vertical within the cross section.

When using a level and stadia rod to survey channel geometry, the tape weight and tension defaults, supplied in the original R2CROSS.WK4 worksheet, will simulate an extremely light tape stretched at very high tension. This results in a sag correction of approximately zero at each cell vertical.

Use of Manning's Equation.

Manning's equation is defined as:

$$Q = \frac{1.486 * A * R^{2/3} * S^{1/2}}{n}$$

where;
Q = discharge (cfs);
A = cross-sectional area (ft^2);
R = hydraulic radius (ft);
S = slope (ft/ft); and
n = Manning's "n", a dimensionless coefficient of roughness.

Manning's equation is used in two separate R2CROSS calculations. It is first used within the "Verify" option to provide an initial estimate of Manning's "n" using the rearranged equation:

$$n = \frac{1.486 * A * R^{2/3} * S^{1/2}}{Q}$$

The parameters Q, A, R, and S are calculated from the raw field data and used to solve directly for "n" (Figures G and J). Once estimated, Manning's "n" remains constant throughout the remainder of the streamflow modeling.

Manning's equation is also used within the "Calculate" option to solve for Q at each simulated water surface elevation within the staging table (Table 4).

Calculation of the Water Line Comparison Table.

R2CROSS uses two techniques for estimating cross-sectional area. One estimate is obtained by summing the product of "measured" water depth and cell width for all cells in the cross section (A_m). This technique allows independent water surface elevations within each cell and provides the most accurate estimate of cross-sectional area at the time the field measurement was made. However, this technique cannot be used to simulate a single, flat water surface elevation at computer-modeled stream discharges.

The second technique used to estimate cross-sectional area involves projecting a single water surface elevation across the stream channel. Channel bottom elevations are subtracted from this projected water surface elevation to obtain a "computed" water depth at each cell vertical. Cross-sectional area is obtained by summing the product of the "computed" water depth and cell width at each cell vertical (A_c). This technique constrains the water surface to a flat plane and is useful for simulating discharges above and below the field-measured discharge.

The water line comparison table (Figure H) iteratively calculates 31 separate estimates of A_c, using projected waterlines ranging from 0.25 feet above to 0.25 feet below the mean waterline measured in the field. The single water surface elevation that results in A_c equal to A_m is interpolated from the water line comparison table and is used in the staging table as the best estimate of the waterline at the field-measured discharge.

Calculation of the Staging Table.

The final product of the R2CROSS macro is the staging table (Figure I). In addition to the three critical biologic criteria ($\bar{x}_d$, *%WP*, and $\bar{x}_v$), R2CROSS also calculates incremental estimates of top width (TW), maximum depth (D_{max}), cross-sectional area (A), wetted perimeter (WP), hydraulic radius (R), and flow (Q) at a number of waterline elevations. The upper limit of the model occurs at bankfull discharge which is defined as the lower of the two grassline elevations measured in the field. The lower limit is either 1.75 feet below the waterline calculated in the water line comparison table or stage of zero flow (the lowest field-measured channel profile), whichever is higher in elevation. The formulae for each of the parameters estimated in the staging table are summarized in Table 4.

Figure L. Sequence of operations performed by R2CROSS macro

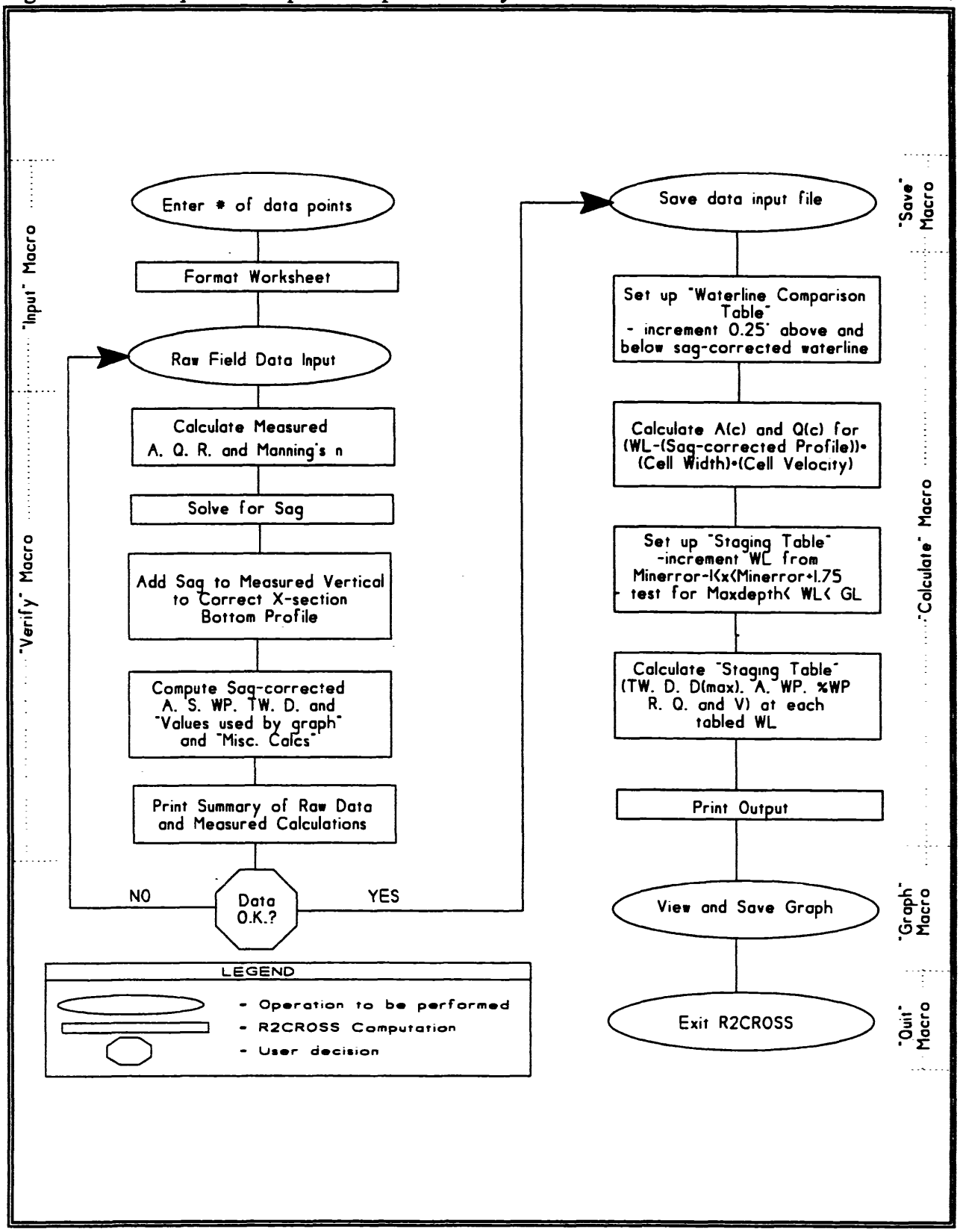


Figure M. Lotus 1-2-3 worksheet layout for R2CROSS macro

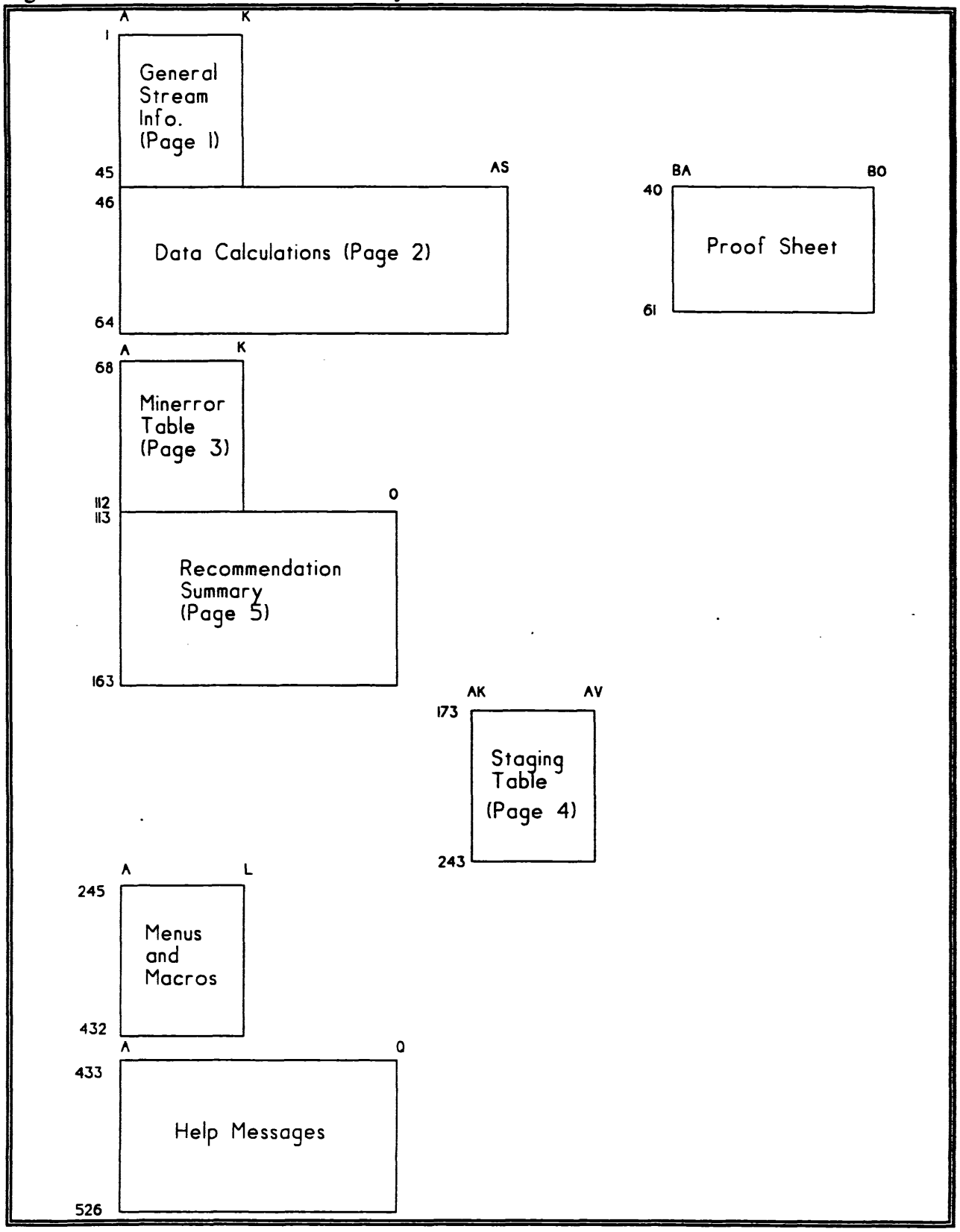


Table 4. Hydraulic Formulas used in R2CROSS staging table

Parameter	Formula
Top Width (TW)	$\sum_{i=1}^{n} TW_i$
Average Depth ($\bar{x}_d$)	$\frac{A}{TW}$
Maximum Depth (D_{max})	$\underset{i=1}{\overset{n}{MAX}}(D_i)$
Area (A)	$\sum_{i=1}^{n} A_i$
Wetted Perimeter (WP)	$\sum_{i=1}^{n} WP_i$
Percent Wetted Perimeter (%WP)	$\frac{WP}{Bankfull\ WP} * 100$
Hydraulic Radius (R)	$\frac{A}{WP}$
Flow (Q)	$\frac{1.486 * A * R^{\frac{2}{3}} * S^{\frac{1}{2}}}{n}$
Average Velocity ($\bar{x}_v$)	$\frac{Q}{A}$

Exhibit 6

Development of Instream Flow Recommendations In Colorado Using

R2CROSS for Microsoft Excel

For additional copies
Write or call:

:

Colorado Water Conservation Board
Department of Natural Resources
1313 Sherman Street, Room 721
Denver, CO 80203
(303) 866-3441

Stream and Lake Protection Section

June 2006

Abstract

In 1973, the Colorado State Legislature vested the Colorado Water Conservation Board with the authority to appropriate instream flow water rights in the State of Colorado. Today, the Board holds over 1,500 instream flow water rights covering approximately 8,500 miles of Colorado streams. Standardized field and office procedures help to ensure that instream flow recommendations reflect the amount of water required to" preserve the natural environment to a reasonable degree", as prescribed by state statute. R2CROSS is one of several instream flow assessment techniques employed by state and federal agencies to model instream hydraulic parameters. R2CROSS was chosen by the State of Colorado because it is time and labor efficient and produces comparable results to more costly instream flow assessment techniques, i.e., the Instream Flow Incremental Methodology. This manuscript provides an overview of Colorado's Instream Flow Program and documentation for the Board's R2CROSS computer macro. The R2CROSS macro requires Microsoft Excel for Windows software to operate.

Acknowledgments

The Colorado Water Conservation Board (CWCB) would like to thank everyone involved in the development of the Board's R2CROSS Excel for Windows macro. The macro was written by Mike Kleypas of MaKro Consulting (www.XLhelp.com/).

In addition, CWCB staff wishes to acknowledge the persons involved in the review and testing of the R2CROSS macro including Mark Uppendahl and Jay Skinner of the Colorado Division of Wildlife and Roy Smith of the Bureau of Land Management.

The Board is very grateful to all of those who participated in the development of the R2CROSS macro and this document.

Disclaimer

The R2CROSS macro is in the public domain, and the recipient may not assert any proprietary rights thereto nor represent it to anyone as other than a Colorado State Government-produced program. R2CROSS is provided "as-is" without warranty of any kind, including, but not limited to, the implied warranties of merchantability and fitness for a particular purpose. The user assumes all responsibility for the accuracy and suitability of this program for a specific application. In no event will the Colorado Water Conservation Board (CWCB) or the Colorado Division of Wildlife be liable for any damages, including lost profits, lost savings, or other incidental or consequential damages arising from the use of or the inability to use this program.

The CWCB staff verified the calculations preformed in its R2CROSS program with hand-held calculators and by comparison with other Manning's equation-based hydraulic streamflow models. Based upon this verification process, the staff believes that the instream hydraulic parameters summarized in the R2CROSS staging table are accurate calculations of Manning's equation. However, the CWCB does not suggest that the predicted hydraulic parameters will necessarily be realized at any particular stream discharge.

On November 10, 1993, the CWCB first adopted Rules that codified the procedures the Board follows in appropriating instream flow water rights. The most recent version of the rules can be found on the CWCB website at:
http://cwcb.state.co.us/Streamandlake/Documents/ADOPTEDRULES11-15-2005.pdf

This document is intended to conform to the procedures presented in the Rules.

Table of Contents

Abstract ii

Acknowledgments ii

Disclaimer iii

Table of Contents 1

List of Tables and Figures 2

Introduction 3

Colorado's Instream Flow Program 3

Instream Flow Legislation 3

Field Procedures 3

Field Data Site Selection 3
Hydraulic Data Collection 3
Biologic Data Collection 5
Digital Camera and GPS Unit 6
The Field Form 6

Office Procedures 11

Background on the R2CROSS Methodology 11
Biologic Instream Flow Recommendations 21
Water Availability Requirements 22

Appropriating and Protecting an Instream Flow Water Right 23

Summary 24

R2CROSS Program Documentation 25

Setup and Installation 25

The R2CROSS Menu 26

Data Input 27
Constant Manning's n Staging Table 29
Cross Section and Wetted Perimeter/Q Plots 29
Starting a new R2CROSS analysis and exiting when finished 29

Literature Cited 31

Appendix A - Program Calculations 33

List of Tables and Figures

Tables

Table 1. Recommended Field Equipment List 4
Table 2. Criteria used to determine minimum flow requirements (Nehring 1979) 21
Table 3. Hydraulic Formulae used in R2CROSS Staging Table 35

Figures

Figure A. Typical stream cross section 5
Figure B. Field data input sheet (Front Page) 8
Figure C. Field data input sheet (Back Page) 9
Figure D. R2CROSS menu in Microsoft Excel for Windows 12
Figure E. R2CROSS Proof Sheet – Iron Creek Example 13
Figure F. Final R2CROSS Output (Page 1) – Iron Creek Example 14
Figure G. Final R2CROSS Output (Page 2) – Iron Creek Example 15
Figure H. Final R2CROSS Output (Page 3) – Iron Creek Example 16
Figure I. Final R2CROSS Output (Page 4) – Iron Creek Example 17
Figure J. Final R2CROSS Output (Page 5) – Iron Creek Example 18
Figure K. Cross Section Plot from R2CROSS – Iron Creek Example 19
Figure L. Wetted Perimeter Plot from R2CROSS – Iron Creek Example 20
Figure M. R2CROSS Menu 26
Figure N. R2CROSS Data Input and Proofing Screen 27
Figure O. Iron Creek Data Entry and Proofing Screen 28

Introduction

Colorado's Instream Flow Program originated in 1973 with the passage of Senate Bill 97 (SB 97). Under SB 97, the Colorado Water Conservation Board (CWCB) was vested with the authority to appropriate instream flow water rights in the State of Colorado (§37-92-102(3), C.R.S. (2002)). Instream flow water rights are held by the CWCB on behalf of the people of the State of Colorado to "preserve the natural environment to a reasonable degree." Today, the CWCB holds over 1,500 instream flow water rights covering approximately 8,500 miles of Colorado streams.

Determining the quantity of water required to preserve the natural environment to a reasonable degree can be a difficult task. The CWCB, in cooperation with the Colorado Division of Wildlife (DOW), has developed standard field and office procedures to ensure that each instream flow appropriation is necessary and reasonable and that the amount of water recommended is available for appropriation.

The R2CROSS methodology described in this document is a valuable tool in developing these instream flow recommendations. The CWCB uses R2CROSS because it is time and labor efficient and produces results which are comparable to more data intensive techniques (Nehring 1979).

This manuscript is divided into two sections. The first section describes Colorado's Instream Flow Program, including some of the statutory guidelines that have shaped the program. It also describes the standard field techniques and office procedures that are used by the CWCB staff in the development of R2CROSS-based instream flow recommendations. This section is intended to provide an understanding of the procedural and technical aspects of Colorado's Instream Flow Program.

The second section of the manuscript is a users' manual for the CWCB's R2CROSS macro. The CWCB has received many requests for its R2CROSS macro from both the public and private sectors but has been hesitant to release the program without proper documentation. The second section of the manuscript is intended to provide that documentation.

Colorado's Instream Flow Program

Instream Flow Legislation

The CWCB was created in 1937 to serve as the State's chief water planning agency (§37-60-101 through 130, C.R.S. (2002)). Today, the CWCB is responsible for the administration of the State's Instream Flow Program, identification of flood plains, funding of new water development and water conservation projects, and negotiation of inter- and intra-state water planning issues.

The CWCB is a fourteen-member board. The board consists of one Governor-appointee from each of the eight major river drainages in the State and one from the City and County of Denver. Each Governor-appointee must also be confirmed by the Colorado State Senate. Ex-officio members of

the board include the Executive Director of the Department of Natural Resources, the Directors of the CWCB and DOW, the State Attorney General, and the State Engineer. The diverse backgrounds of its board members provide the CWCB with an excellent representation of Colorado's various water interests.

Colorado's Instream Flow Program was created in 1973 when the Colorado State Legislature recognized "the need to correlate the activities of mankind with some reasonable preservation of the natural environment" through the passage of SB 97. Within SB 97, the definition of beneficial use was changed to include minimum stream flows and the CWCB was vested with the exclusive authority to appropriate "waters of natural streams and lakes ... as may be required ... to preserve the natural environment to a reasonable degree."

The Instream Flow statute sets forth the guidelines for the administration of Colorado's Instream Flow Program. In order to encourage other entities to participate in Colorado's Instream Flow Program, the statute directs the CWCB to request instream flow recommendations from other state and federal agencies prior to initiating an instream flow appropriation. The CWCB routinely requests instream flow recommendations from the DOW, Colorado Division of Parks and Outdoor Recreation, United States Department of Agriculture, and United States Department of Interior (the "cooperating agencies").

Prior to appropriating an instream flow water right, the statute requires the CWCB to: (1) "determine that the natural environment will be preserved to a reasonable degree by the water available for the appropriation to be made; (2) determine that there is a natural environment that can be preserved to a reasonable degree with the CWCB's water right, if granted; and (3) determine that such environment can exist without material injury to water rights" (§37-92-102(3c), C.R.S. (2002)). The CWCB makes these determinations based upon a review of the supporting technical data and a final instream flow recommendation prepared by the CWCB staff.

Standardized field and office procedures have been developed to help ensure that final instream flow recommendations meet statutory guidelines and are consistent. The standard field procedures that were established concern selection of transect sites and collection of hydraulic and biologic data. Standard office procedures have been established for determining biological instream flow recommendations using output from the R2CROSS program and for analyzing water availability.

Merriman and Janicki (2005) provide additional information on the state of Colorado’s Instream Flow Program.

Field Procedures

The R2CROSS Method is a "Standard Setting" hydraulic based instream flow assessment technique. R2CROSS instream flow recommendations are typically based on hydraulic and biologic data collected during single or multiple field visits. Hydraulic data collection consists of setting up atransect, surveying stream channel geometry, water surface elevations, and measuring stream discharge. Biologic data is gathered to document the existence of a natural environment.

Field Data Site Selection

The R2CROSS method requires that stream discharge and channel profile data be collected in a riffle stream habitat-type. A riffle is a stream segment that is controlled by channel geometry rather than a downstream flow control. Riffles are most easily visualized as the stream reaches which would dry up most quickly should streamflow cease.

Biologically, riffles are essential to the production of benthic invertebrates and the passage, spawning, egg incubation, feeding, and protective cover of fish. Riffles are also the stream habitat-type most sensitive to changes in hydraulic parameters with variation in discharge (Nehring 1979). Riffles are critical to a healthy aquatic environment because small reductions in streamflow may result in large reductions in water depth and the amount of wetted perimeter available for aquatic habitat. Maintaining adequate streamflow in riffles also preserves the natural environment in other important stream habitat-types such as pools and runs (Nehring 1979).

Hydraulic engineers have developed several mathematical models and equations to predict instream hydraulic parameters (Chow 1959). Manning's equation is one such model that is well-suited to the riffle stream habitat-type (Grant et al. 1992). In order to maximize the reliability of Manning's equation, transects are placed within a riffle so that streamflow is uniform across the transect (Grant et al. 1992). Each transect should represent the average stream width, depth, and cross-sectional area within the riffle being characterized. Transects should be located in areas that exhibit natural banks or grasslines and concentrated water flow, free from braiding. They should not be located on eroded or undercut streambanks.

Hydraulic Data Collection

Stream discharge is measured using standardized procedures established by the United States Geological Survey (USGS) (Buchanan and Somers 1969). Channel geometry can be measured using sag-tape methodology (Silvey 1976; Ray and Megahan 1979) or by the use of a land survey level and stadia rod (Benson and Dalrymple 1967). A list of recommended field equipment for completing the required streamflow measurement and channel geometry measurements is provided in Table 1.

The sag-tape methodology consists of suspending a steel tape from bank to bank across the stream channel, perpendicular to the streamflow (Figure A). Metal cross section stakes are driven into the ground above the grassline. The steel tape is suspended by attaching the zero-end of the tape to one of the metal stakes, stretching the tape across the stream, and then attaching the other end to a tape

Table 1. Recommended Field Equipment List

Equipment	Description
100' Steel Survey tape	Stretched between cross section stakes. (Obtain standard weight of a 1.0 foot section of tape from manufacturer)
Spring Tension Scale	Used to measure pounds of tension on steel tape when stretched between stakes.
Tape Clamp Handle	Holds tape in tension.
Cross Section Stakes	Two 24"-36" metal stakes used to maintain tape tension and to level steel tape. Must be strong enough to be driven into rocky stream bank.
Discharge Wading Rod (or Stadia Rod)	Used to measure vertical depths from suspended tape to stream channel.
Level, Tripod, and Stadia Rod	Used to level ends of suspended tape and to measure slope.
Current Meter	Pygmy, Price AA, Marsh-McBirney or similar devise used to measure stream velocity.
Hand Sledge Hammer	Used to drive cross section stakes into streambank.
Staging Pin	Used to detect changes in discharge during the streamflow measurement.
100' Fiberglass Tape	Used to measure horizontal distance from suspended tape to water-slope stadia rod readings.
Field Forms and Clipboard	Standardized form to ensure complete set of field data.
Miscellaneous Items	Digital camera, GPS Unit, maps, waders, stopwatch and calculator.

clamp and spring scale fastened to the metal stake on the opposite streambank. A minimum of 15 pounds of tension is applied to the tape, as the tape is drawn up and clamped. A survey level and stadia rod are used to adjust the ends of the tape up or down until they are level, thereby producing a consistent datum from which vertical distance measurements can be read.

The R2CROSS program uses the standard weight of a one-foot section of the steel tape, tape tension, and the length of tape in suspension to correct horizontal distance and vertical depth measurements made from the sagging tape. The program adjusts the coordinates at each cross section vertical so that the corrected measurements correspond to a level datum from stake to stake and not the curved datum created by the sagging tape (Figure A).

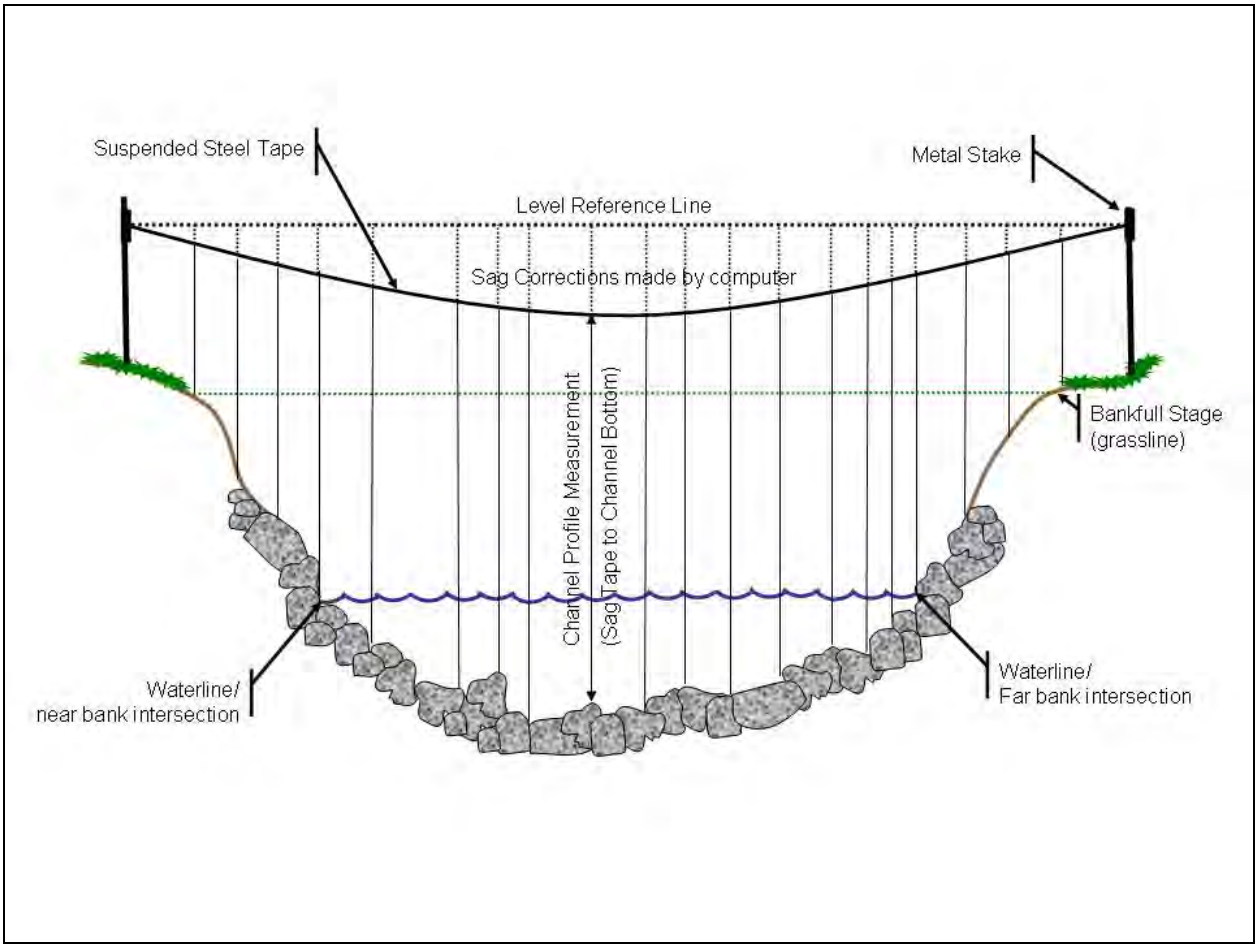


Figure A. Typical stream cross section

Vertical measurements between the suspended tape and the stream channel may be replaced with readings using a survey level and stadia rod. The suspended tape is then used to measure only the horizontal location of each cell vertical. There is no need to precisely level the ends of the suspended tape or to record the tape tension as no sag corrections are required.

Biologic Data Collection

Biologic sampling is conducted to document the existence of a natural environment. Coldwater fish species, particularly salmonids, have been used to indicate the existence of such a natural environment in the majority of the CWCB's instream flow appropriations to date. Warmwater fish species and other aquatic life forms may be used to document the existence of a natural environment in more downstream, low-elevation stream segments. In addition to salmonids, the CWCB has used amphibians, such as frogs and salamanders, and warmwater fish species, including the endangered fishes of the Colorado River basin, as the biologic basis for instream flow appropriations.

Biologic data typically consists of a fish sample, collected by electrofishing, and an aquatic invertebrate sample. Captured fish are identified and measured and a length-frequency distribution is

constructed for each species. The fish sample is not tied directly to the R2CROSS hydraulic modeling but it may be used to refine the biologic instream flow recommendation to meet the specific habitat requirements of unique populations.

Digital Camera and GPS Unit

Digital cameras should be used to record the field data collection effort. A photographic record of the hydraulic data collection process may include pictures of the transect location (upstream, downstream and across stream views) and the stream flow measurement process. These photos can serve as valuable visual evidence that cross sections were properly located in riffles and that standard data collection protocols were met. In addition, photographs may help relocate a transect in the future should additional data be required.

Photos of the biologic data collection effort may also assist the CWCB in making its natural environment findings. Photographs of the biologic sampling process and captured organisms (fish, aquatic insects, etc.) may be used in combination with a statistical summary of the results of biologic sampling to document the existence of a natural environment.

Handheld GPS Units should be used to record field data collection site locations. Geographic coordinate information helps relocate transect locations in the future should additional data be required.

Digital cameras and handheld GPS Units are small in size and light in weight. Digital photos can easily be transferred into written reports and they provide valuable visual evidence. A digital camera and a handheld GPS Unit should be considered standard equipment on any field data collection effort.

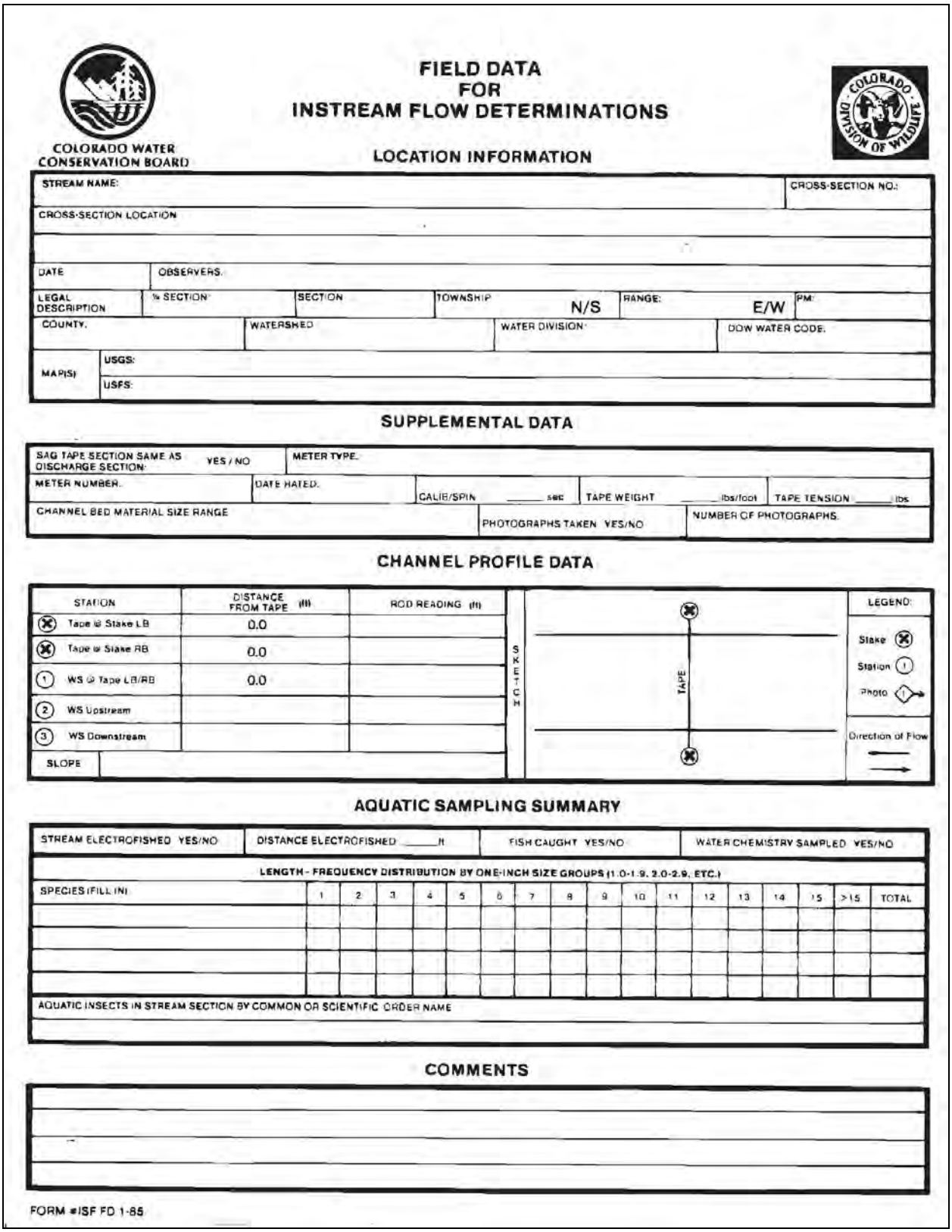
The Field Form

The CWCB and DOW use a standardized field form to record all field data. The use of this form helps to ensure that all instream flow recommendations are based upon a uniform set of field data. The front page of the form provides space for cross section "Location Information", "Supplemental Data", "Channel Profile Data", an "Aquatic Sampling Summary", and "Comments" (Figure B). The back page is dedicated to "Discharge/Cross Section Notes" (Figure C).

The "Location Information" section of the field form is used to describe the location of the cross section as well as the date and names of the members of the field crew. Geographic information can be obtained from USGS maps, United States Forest Service (USFS) maps, or handheld GPS Units. Water divisions and DOW water codes can be obtained from the State Engineers' Office, the CWCB, or the DOW.

The "Supplemental Data" section is used to provide supporting documentation of the field data collection effort. Most importantly, this section is used to record the tape manufacturer's standard weight (lbs/ft) and tape tension (lbs). The R2CROSS program uses this information, together with the length of tape in suspension, to adjust vertical distances measured from the sagging tape to a level reference datum.

The "Channel Profile Data" section of the form is used to establish the relationship between the sag-tape cross section and the stream. Stadia rod readings are taken at each end of the suspended tape and at the water surface on the right and left streambanks. These readings are recorded within the "Rod Reading (ft)" column. They are used to assure that the ends of the tape are level and to quantify the vertical distance between the suspended tape and the water surface. Water surface readings and horizontal distances are also recorded upstream and downstream of the suspended tape. These observations are used to establish the water surface slope for input into Manning's equation.



COLORADO WATER CONSERVATION BOARD

FIELD DATA FOR INSTREAM FLOW DETERMINATIONS

COLORADO DIVISION OF WILDLIFE

LOCATION INFORMATION

STREAM NAME:					CROSS-SECTION NO.:
CROSS-SECTION LOCATION					
DATE	OBSERVERS:				
LEGAL DESCRIPTION	¼ SECTION:	SECTION	TOWNSHIP N/S	RANGE: E/W	PM:
COUNTY:	WATERSHED	WATER DIVISION:	DOW WATER CODE:		
MAP(S)	USGS:				
	USFS:				

SUPPLEMENTAL DATA

SAG TAPE SECTION SAME AS DISCHARGE SECTION: YES / NO	METER TYPE:			
METER NUMBER:	DATE RATED:	CALIB/SPIN ____ sec	TAPE WEIGHT ____ lbs/foot	TAPE TENSION ____ lbs
CHANNEL BED MATERIAL SIZE RANGE	PHOTOGRAPHS TAKEN YES/NO	NUMBER OF PHOTOGRAPHS:		

CHANNEL PROFILE DATA

STATION	DISTANCE FROM TAPE (ft)	ROD READING (ft)
⊗ Tape @ Stake LB	0.0	
⊗ Tape @ Stake RB	0.0	
① WS @ Tape LB/RB	0.0	
② WS Upstream		
③ WS Downstream		
SLOPE		

SKETCH

LEGEND:

Stake ⊗

Station ①

Photo ①

Direction of Flow

AQUATIC SAMPLING SUMMARY

STREAM ELECTROFISHED YES/NO	DISTANCE ELECTROFISHED ____ ft	FISH CAUGHT YES/NO	WATER CHEMISTRY SAMPLED YES/NO

LENGTH - FREQUENCY DISTRIBUTION BY ONE-INCH SIZE GROUPS (1.0-1.9, 2.0-2.9, ETC.)

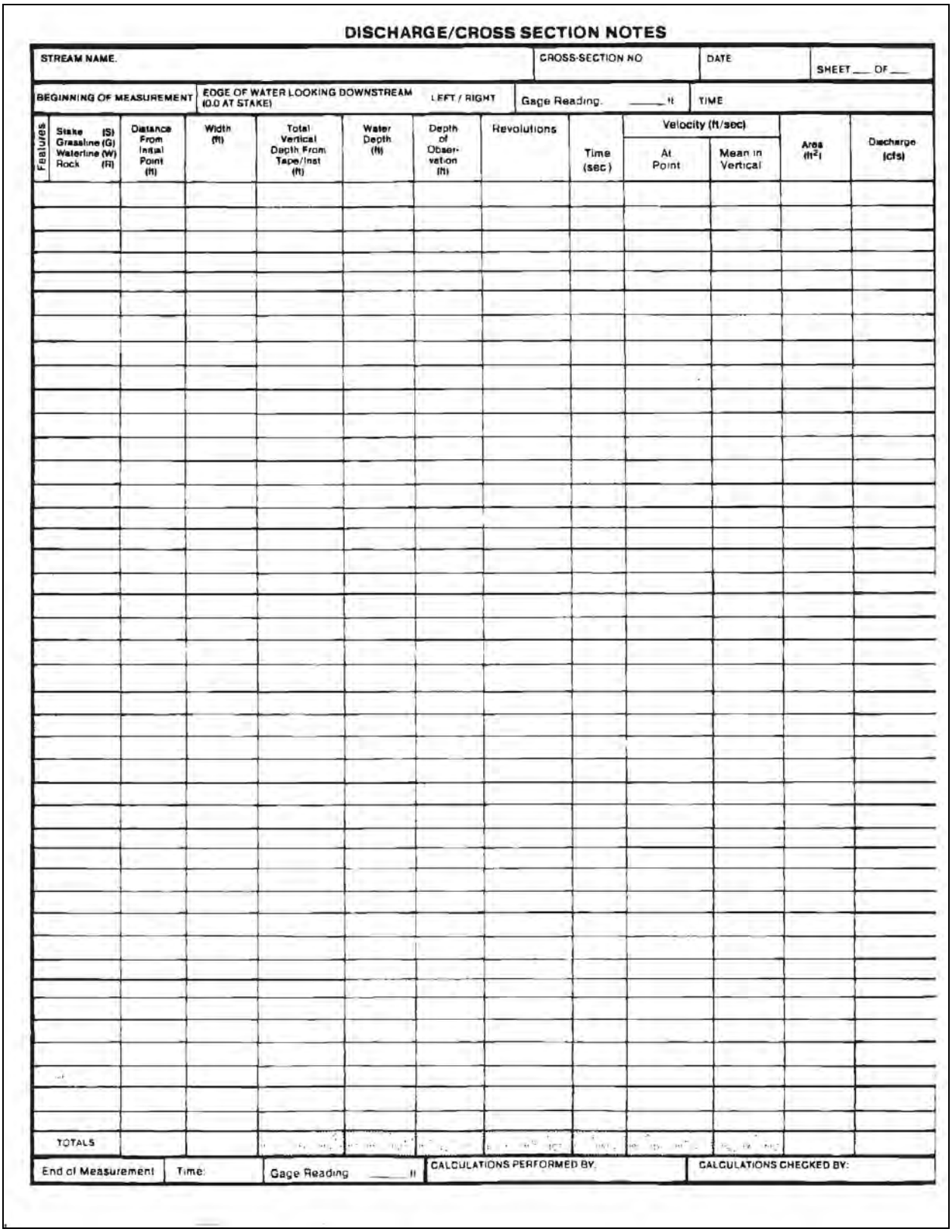
SPECIES (FILL IN)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	>15	TOTAL

AQUATIC INSECTS IN STREAM SECTION BY COMMON OR SCIENTIFIC ORDER NAME

COMMENTS

FORM #ISF FD 1-85

Figure B. Field data input sheet (Front Page)



DISCHARGE/CROSS SECTION NOTES

STREAM NAME.				CROSS-SECTION NO		DATE		SHEET ___ OF ___
BEGINNING OF MEASUREMENT	EDGE OF WATER LOOKING DOWNSTREAM (0.0 AT STAKE)		LEFT / RIGHT	Gage Reading. _____ ft		TIME		

Features: Stake (S) Grassline (G) Waterline (W) Rock (R)	Distance From Initial Point (ft)	Width (ft)	Total Vertical Depth From Tape/Inst (ft)	Water Depth (ft)	Depth of Observation (ft)	Revolutions	Time (sec)	Velocity (ft/sec)		Area (ft^2)	Discharge (cfs)
								At Point	Mean in Vertical		

The right side of the "Channel Profile Data" section is used to graphically depict the relative locations of the suspended tape and survey level, the direction of streamflow, and any photographic documentation of the field data collection effort. Photographs of the suspended tape are taken looking up, down, and across the stream.

Biologic sampling is summarized in the "Aquatic Sampling Summary" portion of the field form. Biologic data typically consists of a fish sample, collected by electrofishing, and an aquatic invertebrate sample. Captured fish are identified by species and measured to the nearest inch. A species-specific length-frequency distribution is created by placing a hashmark in the appropriate cell of the table as each fish is measured. Aquatic invertebrate sampling is summarized within the space provided at the bottom of this section.

All other pertinent field data is recorded in the "Comments" section of the field form. This section is often used to record weather conditions, water turbidity, or species-specific biomass estimates. This additional information helps characterize the field data when it is being analyzed in the office.

The "Discharge/Cross Section Notes" portion of the field form is used to record all of the hydraulic measurements associated with the discharge measurement (Figure C). A heading is provided to record the stream name, cross section number, date, edge of water looking downstream, the staging pin reading, and time at the beginning of the stream discharge measurement. The table below the heading is used to record "Features", "Distance From Initial Point", "Width", "Total Vertical Depth From Tape/Inst(rument)", and "Water Depth" channel geometry parameters at each cell vertical. Stream velocity measurements are recorded under the columns labeled "Depth of Observation", "Revolutions", "Time", and "Velocity" for each wet cell. All discharge measurement procedures are as outlined by Buchanan and Somers (1969).

The first and last channel geometry measurements are always taken at the cross section stakes. Channel geometry measurements should also be taken at the grassline-streambank and streambank-waterline intersections and at all distinguishable slope breaks between these two intersection points. The horizontal locations of the grassline-streambank and streambank-waterline intersections are also documented by placing a "G" and a "W" in the appropriate row of the "Features" column of the field form. Grassline is identified at the normal high water line, not flood stage, and is generally located below sedges and other plants that may survive submerged under high flows. The "Features" column is also used to document the horizontal locations of the two cross section stakes ("S") and any rocks ("R") or other features that may have an impact on the discharge measurement.

On streams with uniform bottom profiles (i.e., sand, cobble, etc.), channel geometry and discharge measurements are taken at fixed intervals within the wetted portion of the channel. The interval is varied in streams with boulder substrates to more accurately reflect changes in the velocity distribution with changes in channel bottom profile. The stream discharge measurement is divided into a minimum of 20 to 30 discharge cells, depending upon wetted stream width, with a minimum cell width of 0.3 feet. Sufficient measurements are taken to ensure that no more than 10% of the total streamflow occurs within a single discharge cell. Horizontal and vertical distances are taken

from the suspended tape and recorded to the nearest tenth of a foot. Stream velocity (ft/sec) within each cell is averaged and recorded.

The bottom of the "Discharge/Cross Section Notes" section is used to summarize the discharge measurement. Space is also provided to record the names of the persons responsible for the field data calculations, the staging pin reading, and time at the end of the stream discharge measurement.

Office Procedures

The CWCB uses a Microsoft Excel for Windows macro, called R2CROSS, to process the field data and model instream hydraulic parameters at streamflows above and below the field-measured discharge. The CWCB relies upon the biologic expertise of the cooperating agencies to interpret the output from R2CROSS and develop an initial, biologic instream flow recommendation. This initial recommendation is designed to address the unique biologic requirements of each stream without regard to water availability. After receiving the cooperating agencies' biologic recommendation, the CWCB staff evaluates stream hydrology to determine whether water is physically available for an instream flow appropriation.

Background on the R2CROSS Methodology

Three instream hydraulic parameters, average depth ($\bar{x}_d$), average velocity ($\bar{x}_v$), and percent wetted perimeter (*%WP*), are used to develop biologic instream flow recommendations in Colorado. The DOW has determined that by maintaining these three hydraulic parameters at adequate levels across riffle habitat-types, aquatic habitat in pools and runs will also be maintained for most life stages of fish and aquatic invertebrates (Nehring 1979).

The R2CROSS methodology uses Manning's equation to predict $\bar{x}_d$, $\bar{x}_v$, *%WP*, and other instream hydraulic parameters, at discharges both above and below the field-measured stream discharge. The methodology is both time and labor efficient, requires data from only a single stream transect, and has been found to produce similar results to more data intensive techniques (Nehring 1979) such as the Instream Flow Incremental Methodology (IFIM) developed by the U.S. Fish and Wildlife Service (Bovee 1982).

In 1973, the CWCB staff performed all Manning's equation calculations with a hand-held calculator. In 1981, the USFS released "*Program Documentation for R2-CROSS-81*" (Weatherred et al. 1981). This Fortran-based, mainframe computer program automated the repetitive task of manipulating and recalculating Manning's equation by hand. The CWCB used the USFS version of R2CROSS on the Colorado State University mainframe computer until 1985.

In 1986, the CWCB staff began development of a personal computer version of R2CROSS using the macro capabilities of Lotus 1-2-3. The CWCB found the R2CROSS macro to be advantageous because it ran on a personal computer and it could be customized to the specific needs of the CWCB. In February 2002, the CWCB staff upgraded the R2CROSS macro to Microsoft Excel for Windows. This latest version of R2CROSS is menu-driven (Figure D) and requires very little experience with

Microsoft Excel. The macro automatically formats the R2CROSS worksheet, initiates data entry, and performs all calculation and printing tasks.

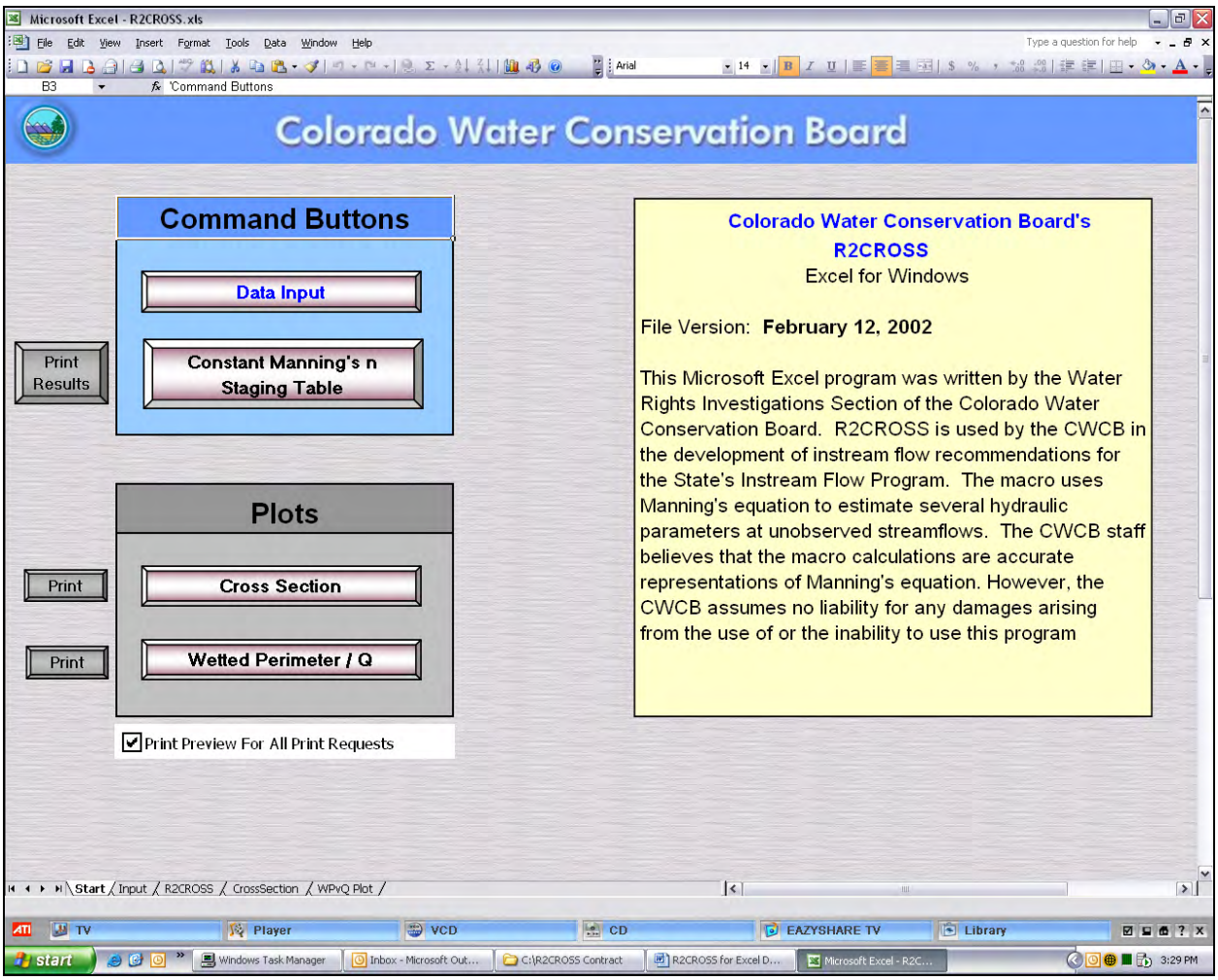
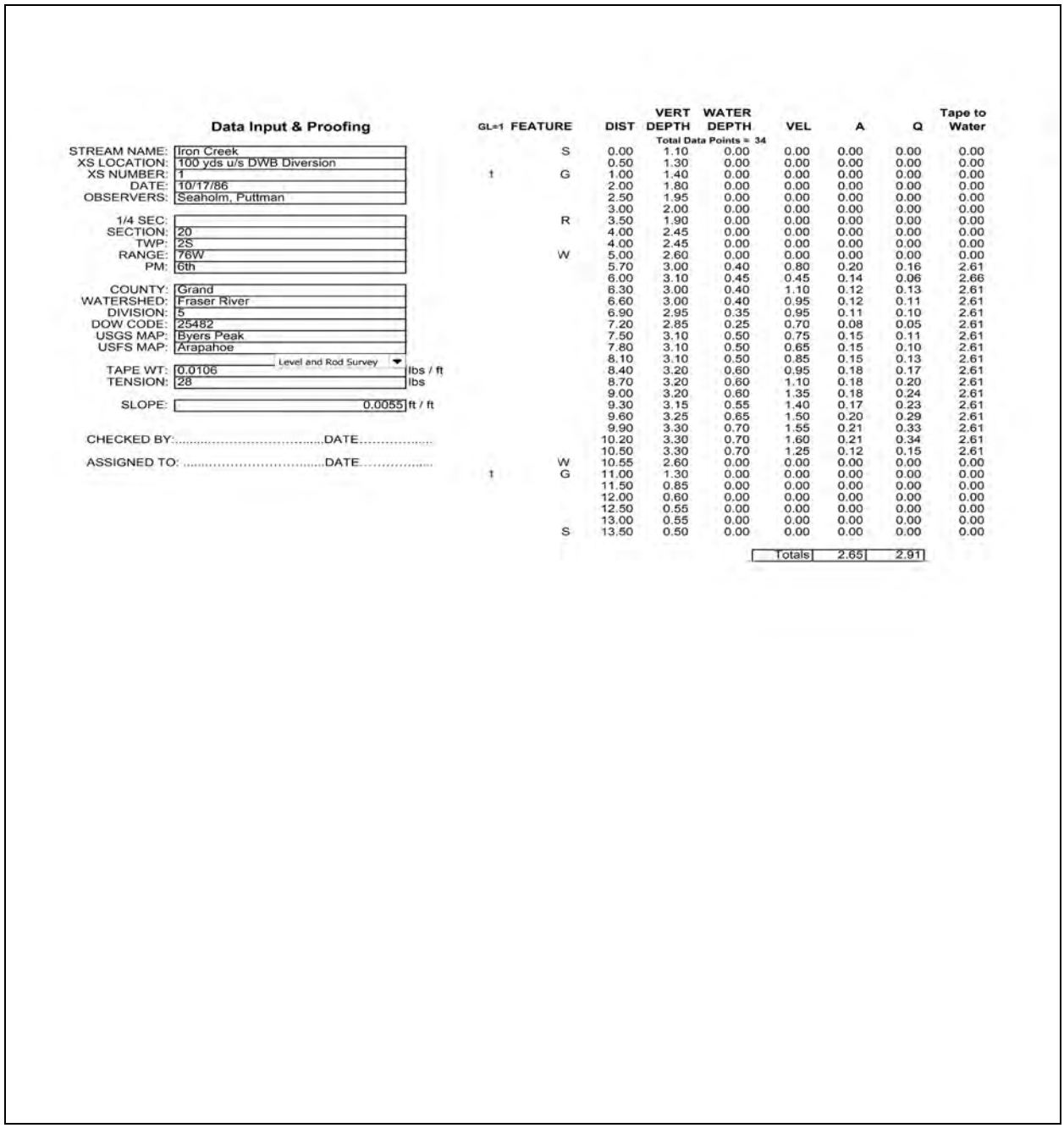


Figure D. R2CROSS menu in Microsoft Excel for Windows

Figures E through K provide an example of R2CROSS output from a typical Colorado stream named Iron Creek. Figure E is a "Proof Sheet" that is printed and inspected for data entry errors prior to performing final R2CROSS calculations. Final output consists of a five page printout (Figures F through J). Page one summarizes most of the stream location information, supplemental data, and channel profile data from the field form (Figure F). Page two summarizes the channel geometry/discharge field data set and values computed from the raw field data, including an estimate of Manning's "n" (Figure G). Page three consists of a water line comparison table which the program uses to interpolate the single water surface elevation that results in a calculated cross-sectional area equal to the field-measured cross-sectional area (Figure H). Page four is the staging table that is used by the cooperating agency to develop an initial, biologic instream flow recommendation (Figure I). The staging table provides estimates of modeled instream hydraulic parameters at stages above and below the measured discharge. Page five summarizes measured and calculated flows, waterlines, and depths (Figure J). It also presents estimates of mean velocity, Manning's "n", water slope, and

upper and lower streamflow limits within which the instream flow recommendation should fall. In general, hydraulic models based upon Manning's equation are most accurate when predicted flows fall within a range of 0.4 to 2.5 times measured flow (Bovee and Milhous 1978; Bovee 1982). Space is also provided for a narrative describing the basis for the initial instream flow recommendation and for the signatures of the personnel involved in making the recommendation. The macro can also be used to generate a plots of the stream cross section (Figure K) and Wetted Perimeter vs. Discharge (Figure L).



Data Input & Proofing

STREAM NAME:	Iron Creek
XS LOCATION:	100 yds u/s DWB Diversion
XS NUMBER:	1
DATE:	10/17/86
OBSERVERS:	Seaholm, Puttman
1/4 SEC:	
SECTION:	20
TWP:	2S
RANGE:	76W
PM:	6th
COUNTY:	Grand
WATERSHED:	Fraser River
DIVISION:	5
DOW CODE:	25482
USGS MAP:	Byers Peak
USFS MAP:	Arapahoe
	Level and Rod Survey
TAPE WT:	0.0106 lbs / ft
TENSION:	28 lbs
SLOPE:	0.0055 ft / ft

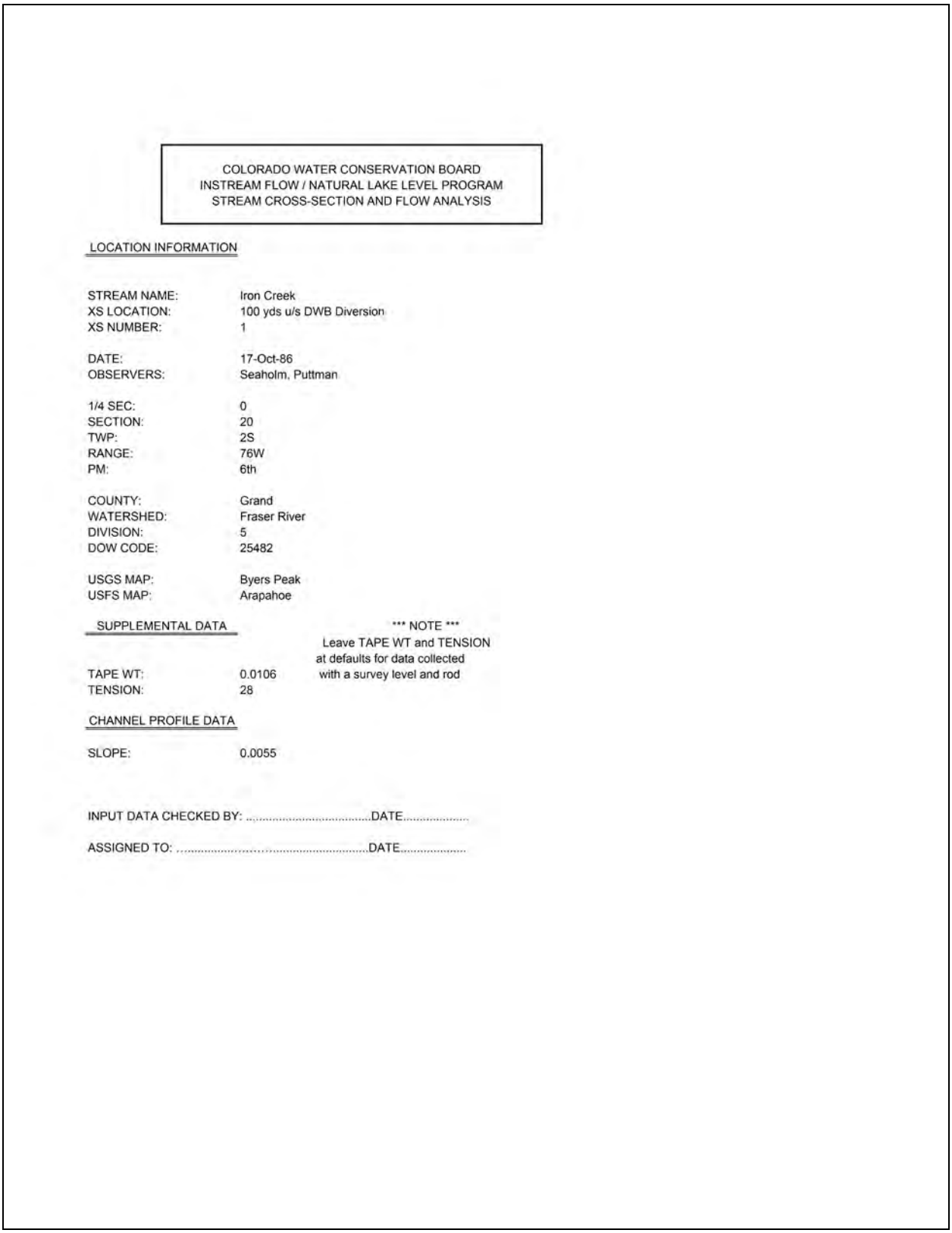
CHECKED BY:.....DATE.....

ASSIGNED TO: .....DATE.....

Total Data Points = 34

GL=1	FEATURE	DIST	VERT DEPTH	WATER DEPTH	VEL	A	Q	Tape to Water
	S	0.00	1.10	0.00	0.00	0.00	0.00	0.00
		0.50	1.30	0.00	0.00	0.00	0.00	0.00
t	G	1.00	1.40	0.00	0.00	0.00	0.00	0.00
		2.00	1.80	0.00	0.00	0.00	0.00	0.00
		2.50	1.95	0.00	0.00	0.00	0.00	0.00
		3.00	2.00	0.00	0.00	0.00	0.00	0.00
	R	3.50	1.90	0.00	0.00	0.00	0.00	0.00
		4.00	2.45	0.00	0.00	0.00	0.00	0.00
		4.00	2.45	0.00	0.00	0.00	0.00	0.00
	W	5.00	2.60	0.00	0.00	0.00	0.00	0.00
		5.70	3.00	0.40	0.80	0.20	0.16	2.61
		6.00	3.10	0.45	0.45	0.14	0.06	2.66
		6.30	3.00	0.40	1.10	0.12	0.13	2.61
		6.60	3.00	0.40	0.95	0.12	0.11	2.61
		6.90	2.95	0.35	0.95	0.11	0.10	2.61
		7.20	2.85	0.25	0.70	0.08	0.05	2.61
		7.50	3.10	0.50	0.75	0.15	0.11	2.61
		7.80	3.10	0.50	0.65	0.15	0.10	2.61
		8.10	3.10	0.50	0.85	0.15	0.13	2.61
		8.40	3.20	0.60	0.95	0.18	0.17	2.61
		8.70	3.20	0.60	1.10	0.18	0.20	2.61
		9.00	3.20	0.60	1.35	0.18	0.24	2.61
		9.30	3.15	0.55	1.40	0.17	0.23	2.61
		9.60	3.25	0.65	1.50	0.20	0.29	2.61
		9.90	3.30	0.70	1.55	0.21	0.33	2.61
		10.20	3.30	0.70	1.60	0.21	0.34	2.61
		10.50	3.30	0.70	1.25	0.12	0.15	2.61
	W	10.55	2.60	0.00	0.00	0.00	0.00	0.00
t	G	11.00	1.30	0.00	0.00	0.00	0.00	0.00
		11.50	0.85	0.00	0.00	0.00	0.00	0.00
		12.00	0.60	0.00	0.00	0.00	0.00	0.00
		12.50	0.55	0.00	0.00	0.00	0.00	0.00
		13.00	0.55	0.00	0.00	0.00	0.00	0.00
	S	13.50	0.50	0.00	0.00	0.00	0.00	0.00
					Totals	2.65	2.91	

Figure E. R2CROSS Proof Sheet – Iron Creek Example



COLORADO WATER CONSERVATION BOARD
INSTREAM FLOW / NATURAL LAKE LEVEL PROGRAM
STREAM CROSS-SECTION AND FLOW ANALYSIS

LOCATION INFORMATION

STREAM NAME:	Iron Creek
XS LOCATION:	100 yds u/s DWB Diversion
XS NUMBER:	1
DATE:	17-Oct-86
OBSERVERS:	Seaholm, Puttman
1/4 SEC:	0
SECTION:	20
TWP:	2S
RANGE:	76W
PM:	6th
COUNTY:	Grand
WATERSHED:	Fraser River
DIVISION:	5
DOW CODE:	25482
USGS MAP:	Byers Peak
USFS MAP:	Arapahoe

SUPPLEMENTAL DATA

		*** NOTE *** Leave TAPE WT and TENSION at defaults for data collected with a survey level and rod
TAPE WT:	0.0106	
TENSION:	28	

CHANNEL PROFILE DATA

SLOPE:	0.0055

INPUT DATA CHECKED BY: .....DATE.....

ASSIGNED TO: .....DATE.....

Figure F. Final R2CROSS Output (Page 1) – Iron Creek Example

STREAM NAME: Iron Creek
XS LOCATION: 100 yds u/s DWB Diversion
XS NUMBER: 1

DATA POINTS= 34

VALUES COMPUTED FROM RAW FIELD DATA

FEATURE	DIST	VERT DEPTH	WATER DEPTH	VEL	WETTED PERIM.	WATER DEPTH	AREA (Am)	Q (Qm)	% Q CELL
S	0.00	1.10	0.00	0.00	0.00		0.00	0.00	0.0%
	0.50	1.30	0.00	0.00	0.00		0.00	0.00	0.0%
1 G	1.00	1.40	0.00	0.00	0.00		0.00	0.00	0.0%
	2.00	1.80	0.00	0.00	0.00		0.00	0.00	0.0%
	2.50	1.95	0.00	0.00	0.00		0.00	0.00	0.0%
	3.00	2.00	0.00	0.00	0.00		0.00	0.00	0.0%
R	3.50	1.90	0.00	0.00	0.00		0.00	0.00	0.0%
	4.00	2.45	0.00	0.00	0.00		0.00	0.00	0.0%
	4.00	2.45	0.00	0.00	0.00		0.00	0.00	0.0%
W	5.00	2.60	0.00	0.00	0.00		0.00	0.00	0.0%
	5.70	3.00	0.40	0.80	0.81	0.40	0.20	0.16	5.5%
	6.00	3.10	0.45	0.45	0.32	0.45	0.14	0.06	2.1%
	6.30	3.00	0.40	1.10	0.32	0.40	0.12	0.13	4.5%
	6.60	3.00	0.40	0.95	0.30	0.40	0.12	0.11	3.9%
	6.90	2.95	0.35	0.95	0.30	0.35	0.11	0.10	3.4%
	7.20	2.85	0.25	0.70	0.32	0.25	0.08	0.05	1.8%
	7.50	3.10	0.50	0.75	0.39	0.50	0.15	0.11	3.9%
	7.80	3.10	0.50	0.65	0.30	0.50	0.15	0.10	3.4%
	8.10	3.10	0.50	0.85	0.30	0.50	0.15	0.13	4.4%
	8.40	3.20	0.60	0.95	0.32	0.60	0.18	0.17	5.9%
	8.70	3.20	0.60	1.10	0.30	0.60	0.18	0.20	6.8%
	9.00	3.20	0.60	1.35	0.30	0.60	0.18	0.24	8.4%
	9.30	3.15	0.55	1.40	0.30	0.55	0.17	0.23	7.9%
	9.60	3.25	0.65	1.50	0.32	0.65	0.20	0.29	10.1%
	9.90	3.30	0.70	1.55	0.30	0.70	0.21	0.33	11.2%
	10.20	3.30	0.70	1.60	0.30	0.70	0.21	0.34	11.6%
	10.50	3.30	0.70	1.25	0.30	0.70	0.12	0.15	5.3%
W	10.55	2.60	0.00	0.00	0.70		0.00	0.00	0.0%
1 G	11.00	1.30	0.00	0.00	0.00		0.00	0.00	0.0%
	11.50	0.85	0.00	0.00	0.00		0.00	0.00	0.0%
	12.00	0.60	0.00	0.00	0.00		0.00	0.00	0.0%
	12.50	0.55	0.00	0.00	0.00		0.00	0.00	0.0%
	13.00	0.55	0.00	0.00	0.00		0.00	0.00	0.0%
S	13.50	0.50	0.00	0.00	0.00		0.00	0.00	0.0%
TOTALS					6.49	0.7 (Max.)	2.65	2.91	100.0%

Manning's n = 0.0552
Hydraulic Radius= 0.407804906

Figure G. Final R2CROSS Output (Page 2) – Iron Creek Example

STREAM NAME: Iron Creek
XS LOCATION: 100 yds u/s DWB Diversion
XS NUMBER: 1

WATER LINE COMPARISON TABLE

WATER LINE	MEAS AREA	COMP AREA	AREA ERROR
	2.65	2.67	0.8%
2.36	2.65	4.25	60.4%
2.38	2.65	4.11	55.3%
2.40	2.65	3.98	50.3%
2.42	2.65	3.84	45.2%
2.44	2.65	3.71	40.2%
2.46	2.65	3.58	35.2%
2.48	2.65	3.45	30.3%
2.50	2.65	3.32	25.5%
2.52	2.65	3.20	20.7%
2.54	2.65	3.07	16.1%
2.56	2.65	2.95	11.6%
2.57	2.65	2.90	9.4%
2.58	2.65	2.84	7.2%
2.59	2.65	2.78	5.0%
2.60	2.65	2.72	2.9%
2.61	2.65	2.67	0.8%
2.62	2.65	2.61	-1.3%
2.63	2.65	2.56	-3.4%
2.64	2.65	2.50	-5.5%
2.65	2.65	2.45	-7.6%
2.66	2.65	2.39	-9.6%
2.68	2.65	2.28	-13.7%
2.70	2.65	2.18	-17.8%
2.72	2.65	2.07	-21.9%
2.74	2.65	1.96	-25.9%
2.76	2.65	1.86	-29.9%
2.78	2.65	1.75	-33.9%
2.80	2.65	1.65	-37.8%
2.82	2.65	1.54	-41.8%
2.84	2.65	1.44	-45.6%
2.86	2.65	1.34	-49.5%

WATERLINE AT ZERO
AREA ERROR = 2.611

Figure H. Final R2CROSS Output (Page 3) – Iron Creek Example

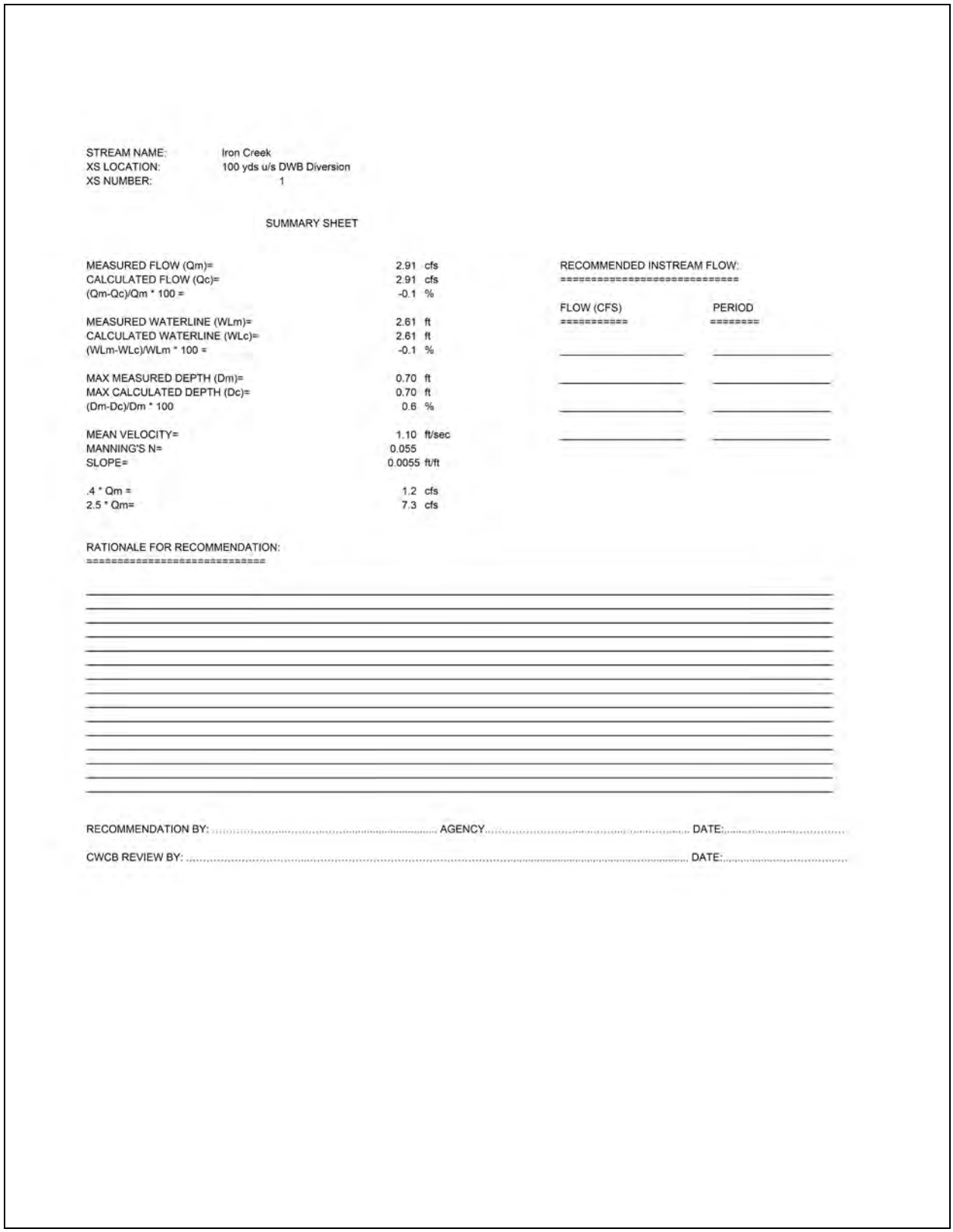
STREAM NAME: Iron Creek
XS LOCATION: 100 yds u/s DWB Diversion
XS NUMBER: 1

Constant Manning's n

GL = lowest Grassline elevation corrected for sag
STAGING TABLE *WL* = Waterline corrected for variations in field measured water surface elevations and sag

	DIST TO WATER (FT)	TOP WIDTH (FT)	AVG. DEPTH (FT)	MAX. DEPTH (FT)	AREA (SQ FT)	WETTED PERIM. (FT)	PERCENT WET PERIM (%)	HYDR RADIUS (FT)	FLOW (CFS)	AVG. VELOCITY (FT/SEC)
GL	1.40	9.97	1.22	1.90	12.13	12.13	100.0%	1.00	24.21	2.00
	1.61	9.38	1.08	1.70	10.12	11.35	93.6%	0.89	18.70	1.85
	1.66	9.23	1.05	1.65	9.65	11.17	92.0%	0.86	17.48	1.81
	1.71	9.09	1.01	1.60	9.19	10.98	90.5%	0.84	16.30	1.77
	1.76	8.95	0.98	1.55	8.74	10.79	89.0%	0.81	15.16	1.73
	1.81	8.80	0.94	1.50	8.30	10.60	87.4%	0.78	14.07	1.70
	1.86	8.62	0.91	1.45	7.86	10.38	85.5%	0.76	13.04	1.66
	1.91	8.41	0.88	1.40	7.43	10.12	83.4%	0.73	12.08	1.63
	1.96	7.90	0.89	1.35	7.03	9.54	78.6%	0.74	11.44	1.63
	2.01	7.16	0.93	1.30	6.65	8.74	72.0%	0.76	11.07	1.66
	2.06	7.10	0.89	1.25	6.29	8.62	71.0%	0.73	10.19	1.62
	2.11	7.04	0.84	1.20	5.94	8.50	70.0%	0.70	9.35	1.57
	2.16	6.97	0.80	1.15	5.59	8.38	69.0%	0.67	8.53	1.52
	2.21	6.91	0.76	1.10	5.24	8.25	68.0%	0.64	7.74	1.48
	2.26	6.85	0.72	1.05	4.90	8.13	67.0%	0.60	6.98	1.42
	2.31	6.79	0.67	1.00	4.56	8.01	66.0%	0.57	6.25	1.37
	2.36	6.72	0.63	0.95	4.22	7.89	65.1%	0.53	5.55	1.32
	2.41	6.66	0.58	0.90	3.89	7.77	64.1%	0.50	4.89	1.26
	2.46	6.58	0.54	0.85	3.56	7.63	62.9%	0.47	4.27	1.20
	2.51	6.23	0.52	0.80	3.24	7.25	59.7%	0.45	3.77	1.17
	2.56	5.88	0.50	0.75	2.93	6.86	56.5%	0.43	3.32	1.13
WL	2.61	5.55	0.48	0.70	2.65	6.48	53.4%	0.41	2.91	1.10
	2.66	5.45	0.43	0.65	2.37	6.33	52.2%	0.37	2.46	1.04
	2.71	5.36	0.39	0.60	2.10	6.18	50.9%	0.34	2.04	0.97
	2.76	5.27	0.35	0.55	1.84	6.03	49.7%	0.30	1.66	0.90
	2.81	5.18	0.30	0.50	1.57	5.88	48.5%	0.27	1.31	0.83
	2.86	5.08	0.26	0.45	1.32	5.72	47.1%	0.23	0.99	0.75
	2.91	4.78	0.22	0.40	1.07	5.33	43.9%	0.20	0.73	0.68
	2.96	4.47	0.19	0.35	0.84	4.94	40.7%	0.17	0.51	0.61
	3.01	3.73	0.17	0.30	0.63	4.11	33.9%	0.15	0.36	0.57
	3.06	3.36	0.13	0.25	0.45	3.66	30.2%	0.12	0.22	0.49
	3.11	2.41	0.12	0.20	0.29	2.63	21.7%	0.11	0.14	0.46
	3.16	2.22	0.08	0.15	0.18	2.39	19.7%	0.07	0.06	0.35
	3.21	1.05	0.08	0.10	0.08	1.15	9.5%	0.07	0.03	0.34
	3.26	0.88	0.04	0.05	0.03	0.93	7.6%	0.04	0.01	0.22

Figure I. Final R2CROSS Output (Page 4) – Iron Creek Example



STREAM NAME: Iron Creek
XS LOCATION: 100 yds u/s DWB Diversion
XS NUMBER: 1

SUMMARY SHEET

MEASURED FLOW (Qm)=	2.91	cfs
CALCULATED FLOW (Qc)=	2.91	cfs
(Qm-Qc)/Qm * 100 =	-0.1	%
MEASURED WATERLINE (WLm)=	2.61	ft
CALCULATED WATERLINE (WLc)=	2.61	ft
(WLm-WLc)/WLm * 100 =	-0.1	%
MAX MEASURED DEPTH (Dm)=	0.70	ft
MAX CALCULATED DEPTH (Dc)=	0.70	ft
(Dm-Dc)/Dm * 100	0.6	%
MEAN VELOCITY=	1.10	ft/sec
MANNING'S N=	0.055	
SLOPE=	0.0055	ft/ft
.4 * Qm =	1.2	cfs
2.5 * Qm=	7.3	cfs

RECOMMENDED INSTREAM FLOW:

FLOW (CFS)	PERIOD

RATIONALE FOR RECOMMENDATION:

RECOMMENDATION BY: ..... AGENCY ..... DATE: .....

CWCB REVIEW BY: ..... DATE: .....

Figure J. Final R2CROSS Output (Page 5) – Iron Creek Example

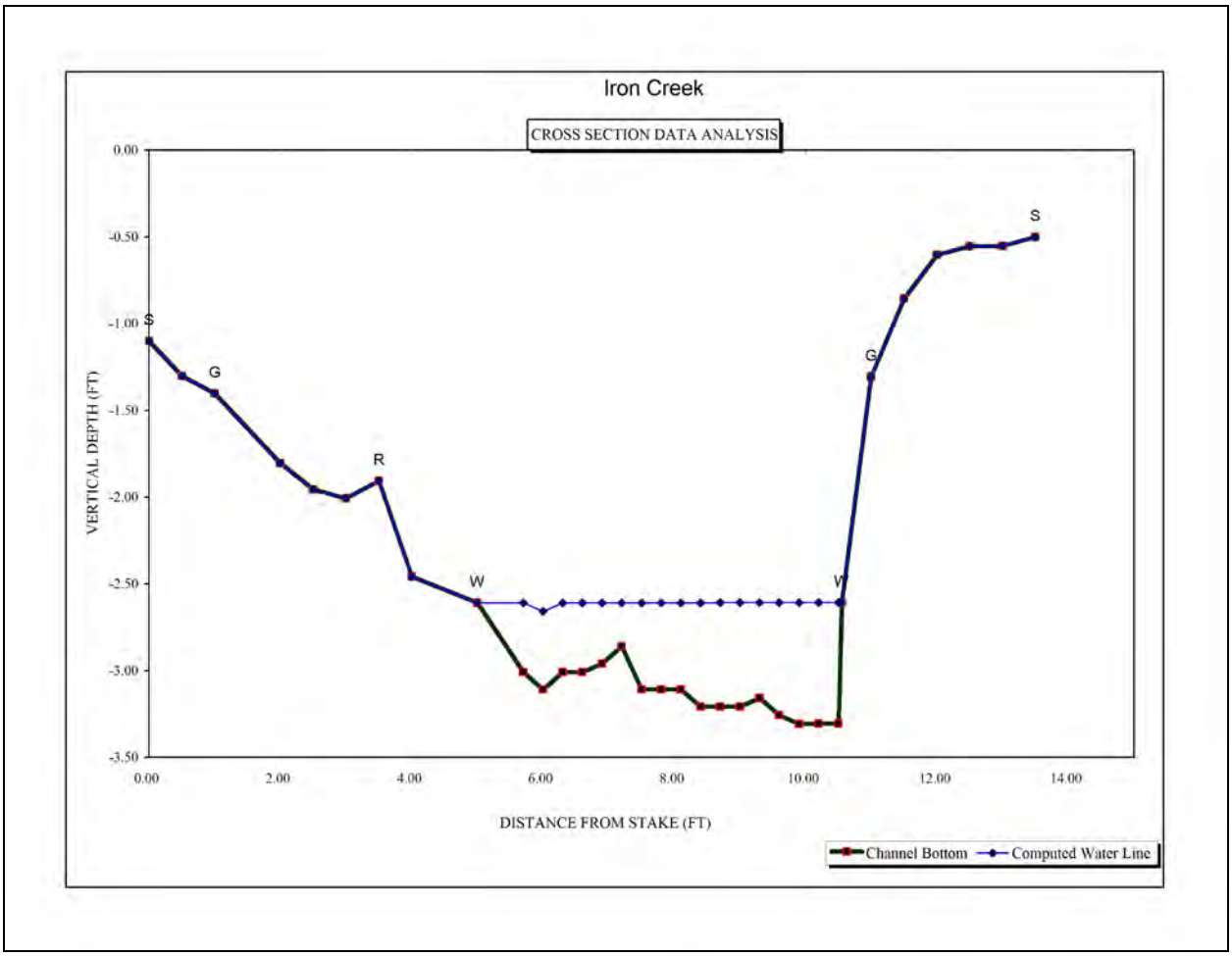


Figure K. Cross Section Plot from R2CROSS – Iron Creek Example

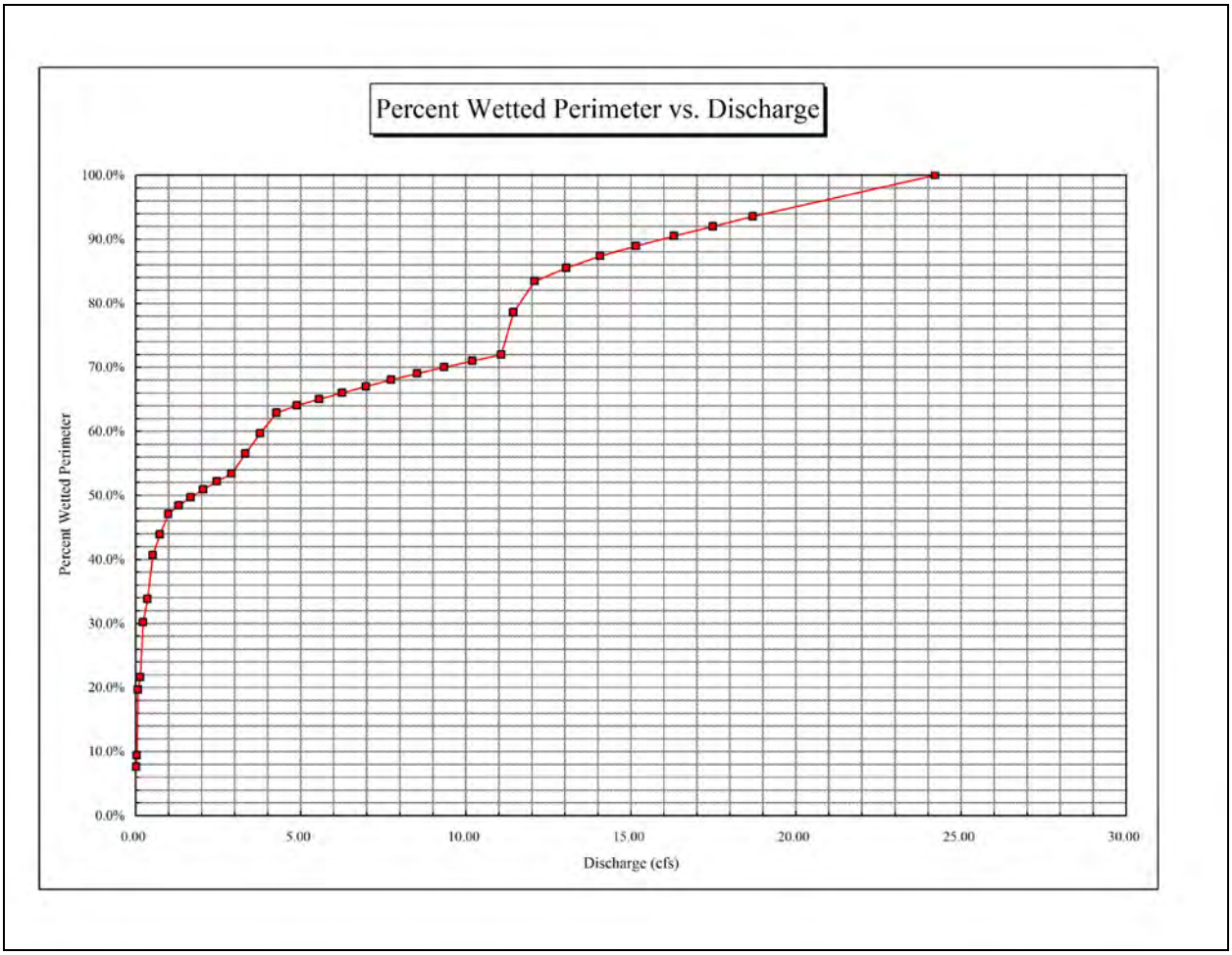


Figure L. Wetted Perimeter Plot from R2CROSS – Iron Creek Example

Biologic Instream Flow Recommendations

When using R2CROSS, biologic instream flow recommendations are based on maintaining three principal hydraulic criteria, $\bar{x}_d$, $\bar{x}_v$, and %WP, at adequate levels across the stream transect (Table 2). The $\bar{x}_d$ and %WP criteria are functions of stream top width and grassline-to-grassline wetted perimeter, respectively. A constant $\bar{x}_v$ of 1 ft/sec is recommended for all streams. The DOW has determined that these three parameters are good indices of flow-related stream habitat quality and that maintenance of these parameters at adequate levels across riffle habitat-types will also result in maintenance of adequate aquatic habitat in pools and runs for most life stages of fish and aquatic invertebrates (Nehring 1979).

The three critical hydraulic parameters are estimated within the R2CROSS staging table at various levels of discharge (Figure I). Biologic instream flow recommendations are developed by locating the modeled streamflow(s) in the R2CROSS staging table that satisfy the three hydraulic criteria summarized in Table 2. As stated above, Colorado's Instream Flow Program was created in 1973, since that time, the Program along with the science of determining instream flows has continued to evolve. For the Instream Flow Program to be successful, instream flow water rights must be able to balance the ever-changing needs and values of the public while honoring existing uses. The greatest asset of the Program, to date, has been its ability to evolve and meet those challenges.

Table 2. Criteria used to determine minimum flow requirements (Nehring 1979)

Stream Top Width (ft)[1]	Average Depth (ft)	Percent Wetted Perimeter (%)[1]	Average Velocity (ft/sec)
1-20	0.2	50	1.0
21-40	0.2-0.4	50	1.0
41-60	0.4-0.6	50-60	1.0
61-100	0.6-1.0	$\geq$ 70	1.0

[1] At bankfull discharge

In the early years of the Program, the DOW's instream flow recommendations consisted of only single year-round flow amounts. These single year-round flow amounts were based on meeting only two of the three critical hydraulic criteria identified by Nehring. For the first third of the Program, these initial flow recommendations were not adjusted due to water availability concerns. It was not until the passage of Senate Bill 414 (SB 414) in 1981, that future instream flow appropriations would require an evaluation of the existing physical water supply. In the mid 1980's, to incorporate these new changes into the Program and address other concerns being raised regarding the R2CROSS model (mainly the tendency of the R2CROSS model to overestimate the $\bar{x}_v$ criteria), DOW biologists modified the original instream flow methodology of recommending single year-round

flows and began developing "seasonal flow recommendations" which would incorporate all 3 of the identified critical criteria into the flow recommendations.

These seasonal flow recommendations are an attempt to mimic the natural flow regime, albeit, on a simplistic and much smaller scale. The DOW currently believes spring/summer flows require flow recommendations which meet all three of the critical hydraulic criteria and fall/winter flows require flow recommendations which meet two of the three critical hydraulic criteria, whenever possible. CDOW believes the development of these seasonal flow recommendations helps address the full range of hydrologic and hydraulic conditions required to maintain important stream characteristics and its associated aquatic community. Research has shown that single year-round minimum flows, when maintained as a long-term condition, cannot be expected to sustain the same fish populations or aquatic life as a natural flow regime, where low flow conditions occur infrequently and for shorter periods (Stalnaker and Wick 2000). Higher spring and summer flows provide the water and resultant habitat required to maintain the adjacent riparian zone, the geomorphology of the stream channel and additional habitat and protection for different life stages of the aquatic community. In addition, protection from increasing recreational uses such as rafting, kayaking, boating, tubing, swimming and fishing is gained during these flow periods. Higher spring and summer flows also provide water quality protection from other outside factors such as effluent discharges, high metal concentrations, excess sedimentation and water temperature increases. Aquatic biologists may modify summer and winter flow recommendations based upon biologic considerations such as stream conditions, species composition, and aquatic habitat quality.

These hydraulic criteria can be applied to the R2CROSS staging table from the Iron Creek example (Figure I) to develop an initial biologic instream flow recommendation. In this example, the grassline top width of Iron Creek is 9.97 ft. Therefore, the DOW criteria for an $\bar{x}_d$ of 0.2 feet would be satisfied at a flow of approximately 0.6 cfs. The *%WP* criterion of 50% would be met at a flow of around 1.75 cfs and an $\bar{x}_v$ of 1 ft/sec at a flow of 2.25 cfs. Based upon this analysis, a winter flow recommendation of 1.75 cfs would meet the $\bar{x}_d$ and *%WP* criteria and a summer flow recommendation of 2.25 cfs would satisfy all three criteria. These initial recommendations may be adjusted up or down based upon biologic judgment and expertise.

Water Availability Requirements

Once an initial biologic instream flow recommendation has been developed, the CWCB staff must determine whether water is physically available to satisfy the biologic recommendation. The staff uses stream gaging records to analyze physical water availability whenever possible. In the absence of a gage record, the staff may use standardized hydrologic techniques, such as basin area apportionment or synthetic streamflow modeling (Kircher et al. 1985), to estimate physical water availability. The staff may also conduct a review of the State Engineer's water rights tabulation and consult with Division Engineers and District Water Commissioners to determine the effect of senior diversions on a stream reach.

The water availability analyses may lead the CWCB staff to conclude that sufficient water is not available to meet the biologic recommendation. If the statutory water availability requirement cannot be satisfied, the CWCB must reject the instream flow recommendation.

Appropriating and Protecting an Instream Flow Water Right

The CWCB has adopted the "Rules Concerning the Colorado Instream Flow and Natural Lake Level Program." These Rules codified existing CWCB procedures for implementing the Instream Flow Program and established procedures for handling acquisition of water, water rights, and interests in water including conditional rights, modification of instream flows, and inundation of instream flow water rights. The CWCB's procedural requirements for appropriating and protecting instream flow water rights are also described in great detail within these Rules and Regulations. The procedural aspects of appropriating and protecting an instream flow water right are beyond the intended scope of this manuscript. Individuals who are interested in learning more about these procedures are encouraged to obtain a copy of the above-referenced Rules from the CWCB website at: http://cwcb.state.co.us/Streamandlake/Documents/ADOPTEDRULES11-15-2005.pdf .

Summary

The Colorado State Legislature enacted SB 97 in 1973. By "recognizing the need to correlate the activities of mankind with some reasonable preservation of the natural environment" (§ 37-92-102(3), C.R.S. (2002)), the Legislature sought to balance traditional water development with some reasonable protection of Colorado's natural environment. This is not a simple task in the semi-arid Western United States where water is a scarce and extremely valuable resource. The ongoing success of Colorado's Instream Flow Program assures that coordination between water development and protection of the natural environment will continue -- both now and into the future. . Since that time, the CWCB has completed instream flow appropriations on approximately 8,500 miles of Colorado streams.

The CWCB has adopted standardized field and office procedures for developing instream flow recommendations. This standardization helps to ensure that each instream flow recommendation is "necessary" and "reasonable", as required by state statute.R2CROSS is one of several instream flow assessment techniques employed by state and federal agencies to model instream hydraulic parameters. R2CROSS was chosen by the State of Colorado because it is time and labor efficient and produces comparable results to more costly instream flow assessment techniques. . The R2CROSS macro is also easy to use and requires very little in the way of computer hardware or software.

Biologic instream flow recommendations based upon output from R2CROSS are designed to maintain $\bar{x}_v$, $\bar{x}_d$, and *%WP* at critical levels across riffle habitat-types. It is assumed that by maintaining these critical hydraulic parameters across riffles, aquatic habitat in pools and runs is also preserved. In addition to biologic considerations, water must be physically available for the CWCB to file for an instream flow water right.

An instream flow water right requires a coordinated effort between various state and federal agencies, the public, and the CWCB. The culmination of these efforts is a decreed instream flow water right that is held by the CWCB on behalf of the people of Colorado to "preserve the natural environment to a reasonable degree."

R2CROSS Program Documentation

Program documentation for the R2CROSS macro is divided into two sections. The "Setup and Installation" section provides a brief description of the hardware and software requirements of the R2CROSS macro and copying the R2CROSS program to folders on a hard drive. "The R2CROSS Menu" provides more detailed program documentation for each of the menu choices within R2CROSS (Figure M). Users who are familiar with Microsoft Excel for Windows should have very little difficulty learning how to operate the R2CROSS macro.

Appendix A provides a brief description of the "Program Calculations" that are performed within the R2CROSS macro. Rather than emphasizing the technical aspects of these calculations, this appendix is intended to provide a fundamental understanding of the operations being performed within the macro.

Output from the R2CROSS macro was verified against several simple hand-calculated examples. More complex cross sections were verified by comparison with output from the MANSQ option of IFIM (Bovee 1982). Based on this verification process, it is our belief that the instream hydraulic parameters summarized in the R2CROSS staging table are accurate estimations based upon Manning's equation.

The CWCB hopes that the release of the R2CROSS macro will foster a greater understanding of this technical aspect of Colorado's Instream Flow Program. It is intended to be user-friendly. If you have any problems running the macro or questions regarding its operation, please feel free to contact the CWCB staff.

Setup and Installation

We have found that the R2CROSS macro runs efficiently on most IBM-compatible personal computers equipped with Microsoft Excel for Windows software. We recommend that an original copy of the R2CROSS.xls spreadsheet be stored in a location where it won't be overwritten. Additional copies can then be placed in other folders where individual stream flow datasets are being evaluated.

To initiate the R2CROSS macro, either double click on the R2CROSS.xls file or start Microsoft Excel for Windows , select "File"" and then "Open" from the Excel menu bar, and then navigate to the location where you saved the working copy of R2CROSS.xls.

Some users may find that the macro runs extremely slow when first installed. This is generally due to the security level setting on an individual's copy of Microsoft Excel. To increase the speed of the R2CROSS macro, it may be necessary to lower the security level of Excel. This can be accomplished by clicking the "Tools" menu choice in Excel and then selecting "Options" from the drop down menu. Click the "Security" tab and then the "Macro Security" button in the lower right hand corner of the graphic user interface. Select "Low" from the list of available macro security

choices. You may want to repeat this procedure and increase the macro security level of your computer back to its original level when you finish an R2CROSS session.

The R2CROSS Menu

Figure M shows the opening screen of R2CROSS. The functionality of the R2CROSS macro is intended to be fairly intuitive. Use the "Data Input" button to initiate and proof data entry. After data entry is complete, use the "Constant Manning's n Staging Table" button to generate and print R2CROSS output. The "Cross Section" and "Wetted Perimeter/Q" buttons can then be used to generate cross section and wetted perimeter vs. discharge plots.

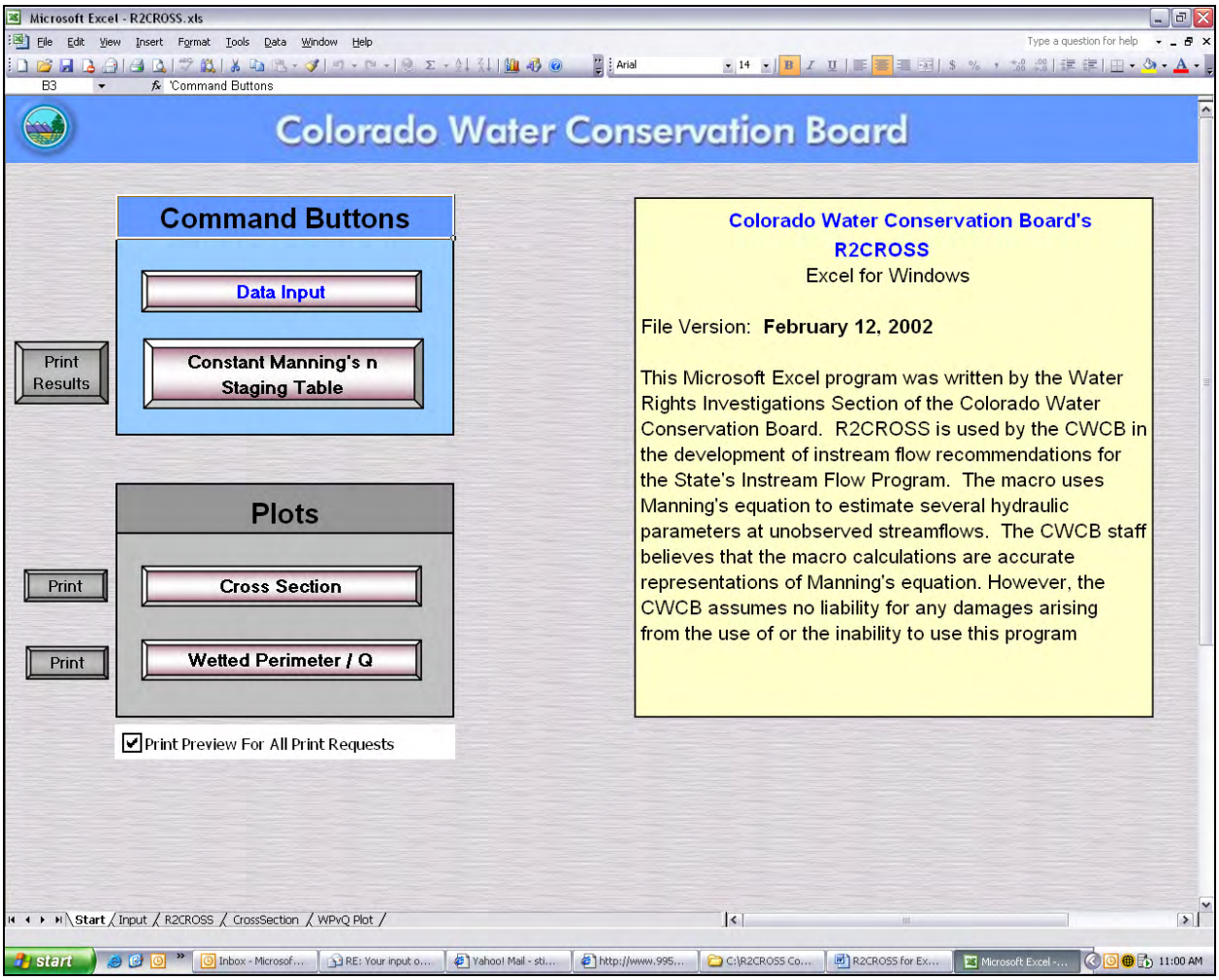


Figure M. R2CROSS Menu

Check the "Print Preview for All Print Requests" option if you want to preview all print requests before sending them to the printer. Uncheck the checkbox if you'd prefer to have all print requests sent directly to the printer without the opportunity to preview.

The "Print Results" and "Print" buttons can be used to send results of plots directly to the printer.

Data Input

Press the "Data Input" button to begin entering cross section data. Figure N shows the R2CROSS data input and proofing screen. Begin by entering the Stream Name, XS Location, etc in the appropriate cells of the spreadsheet. Use the "Enter" key on your keyboard to move the cursor down the column. After entering a Slope, use the Enter key to automatically move the cursor to the top of the "GL=1" column.

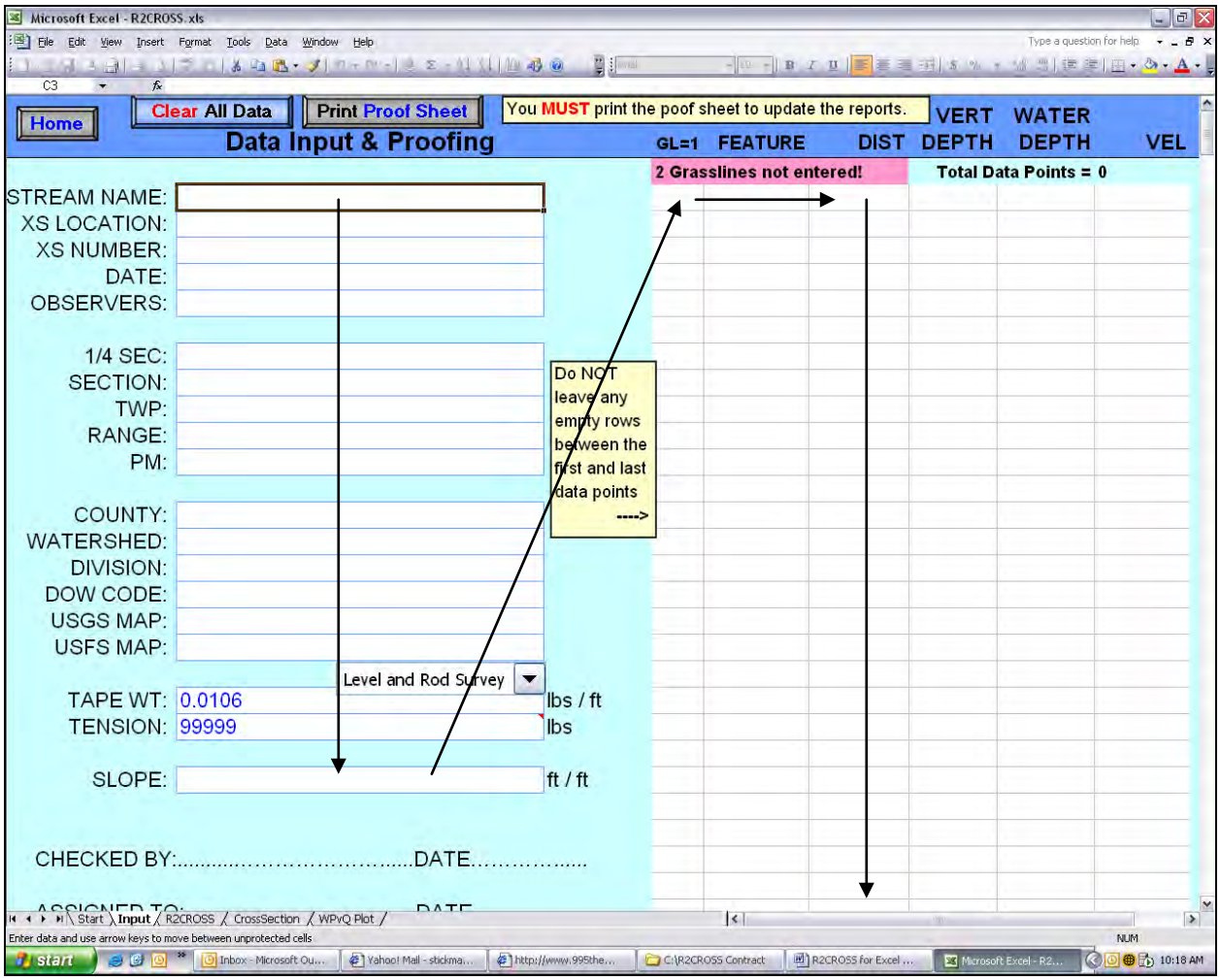


Figure N. R2CROSS Data Input and Proofing Screen

Use the arrow keys on your keyboard to move right into the "Dist" column. Enter all distances from the near bank cross section stake. This is most easily accomplished using the key pad on the right hand side of most computers. Ten-key typing skills will facilitate data entry. After entering the last "Dist" at the far bank cross section stake, scroll or use the arrow keys to move back to the top of the data entry form and verify that the "Total Data Points = *x*" displayed at the top of the data entry form are identical to the number of data points collected in the field. Correct any data entry errors in the "Dist" column.

Use the cursor, arrow keys, or Enter key to navigate through the remainder of the data entry form. R2CROSS requires that you enter a "1" in the "GL=1" for the grasslines on each side of the cross section. The "2 Grasslines not entered" warning will disappear when this requirement has been met.

Note that the standard Microsoft Excel functions like "Cut", "Copy", and "Paste" can be accessed by right-clicking on cells in the worksheet and selecting the desired choice from the Excel menu. In addition, standard Excel "drag and drop" functionality can by used to move single cells or blocks of cells within the data entry worksheet. Experience Excel users may find that using these functions greatly facilitates data entry and editing.

The final data entry screen for Iron Creek is provided as an example in Figure O. Note that the "2 Grasslines not entered" warning is gone and there are 34 Total Data Points on the Iron Creek transect.

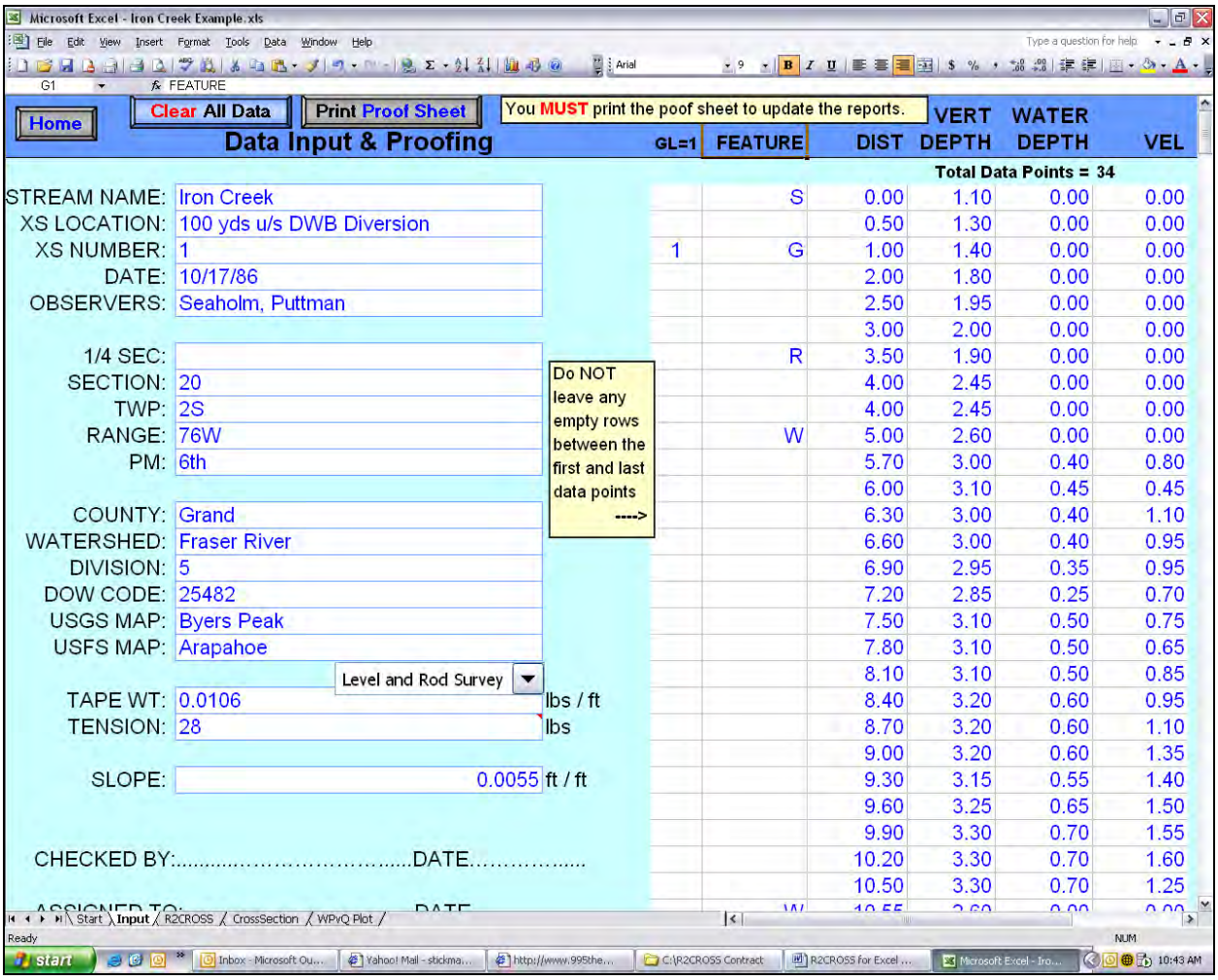


Figure O. Iron Creek Data Entry and Proofing Screen

When you are satisfied that all field data has been entered properly, press the "Print Proof Sheet" button. Pressing this button recalculates all computations in the spreadsheet and cycles to the Print

Proof Sheet option Use the standard Microsoft Windows options to Setup and Print Proof Sheet or Close" the print preview window. R2CROSS returns to the opening screen.

The "Home" button can also be used at anytime to return to the R2CROSS opening screen. However, the user should be aware that any changes made to the data entry form will only be revised in the calculations after pressing the "Print Proof Sheet" button.

Constant Manning's n Staging Table

Press the "Constant Manning's n Staging Table" button to preview the R2CROSS staging table. Press the "Home" key to return to the R2CROSS opening screen.

If the staging table appears to be correct, press the "Print Results" button to the left of the "Constant Manning's n Staging Table" button to print all 5 pages of R2CROSS output. You will be provided with an opportunity to preview the output pages if the "Print Preview For All Print Requests" box is checked. If it is not checked, the print request will go directly to the printer.

If the staging table does not appear to be correct, press the "Home" button and then the "Data Input" button to return to data entry/edit mode. Revise the cross section data as necessary and press the "Print Proof Sheet" button to recalculate the worksheet and inspect the proof sheet. Print the proof sheet if necessary.

The R2CROSS output from the Iron Creek example was presented previously in Figures F through J.

Cross Section and Wetted Perimeter/Q Plots

From the R2CROSS opening screen, press the "Cross Section" or "Wetted Perimeter/Q" buttons to preview these plots. Press "Home" to return to the opening screen or "Print" to send the plots to the printer.

Alternatively, press the "Print" button to the left of the "Cross Section" or "Wetted Perimeter/Q" buttons on the R2CROSS opening screen to send these plots to the printer. As with all print requests, you will have an opportunity to preview the plots if the "Print Preview For All Print Requests" is checked.

Cross Section and Wetted Perimeter plots from the Iron Creek example were presented previously in Figures K and L; respectively.

Starting a new R2CROSS analysis and exiting when finished

There are several ways to start a new R2CROSS analysis. One way is to open the R2CROSS.xls spreadsheet as described earlier and using the Excel "File" and "Save As" commands to rename the file and specify the folder location. Another way would be to press the "Data Input" button and then "Clear All Data" button.

Prior to exiting an R2CROSS analysis, use the Excel "File" and "Save As" commands to rename the file and specify a folder location. Data from an existing file can be retrieved by double clicking the

saved ".xls" file name or by using the Excel "File" and "Open" menu choices to navigate to the location of the a previously-saved R2CROSS data file.

Literature Cited

Bovee, K.D. 1982. A guide to stream habitat analysis using the Instream Flow Incremental Methodology. Instream Flow Information Paper No. 12. Washington, DC: U.S. Fish and Wildlife Service (FWS/OBS-82/26). 248pp.

Bovee, K.D. and R. Milhous. 1978. Hydraulic simulation in instream flow studies: Theory and techniques. Instream Flow Information Paper No. 5. Washington, DC: U.S. Fish and Wildlife Service (FWS/OBS -78/33). 143pp.

Buchanan, T.J. and W.P. Somers. 1969. Discharge measurements at gaging stations. Techniques of Water-Resources Investigations of the United States Geological Survey, Book 3, Chapter A8. United States Government Printing Office, Washington, D.C. 20402.

Benson, M.A., and T. Dalrymple. 1967. General field and office procedures for indirect discharge measurements. Techniques of Water-Resources Investigations of the United States Geological Survey, Book 3, Chapter A1. United States Government Printing Office, Washington, D.C. 20402.

Chow, V.T. 1959. Open-channel hydraulics. McGraw-Hill Book Company, New York. 680p.

Colorado Water Conservation Board. 1993. Statement of Basis and Purpose and Rules and Regulations Concerning the Colorado Instream Flow and Natural Lake Level Program. Department of Natural Resources. Denver, CO. 80203.

Grant, G.E., J.E. Duval, G.J. Koerper and J.L. Fogg. 1992. XSPRO: A channel cross-section analyzer. Technical Note 387. Bureau of Land Management. Denver, CO. 80225-0047.

Kircher, J.E., A.F. Choquette and B.D. Richter. 1985. Estimation of natural streamflow characteristics in western Colorado. Water-Resources Investigations Report 85-4086. United States Geological Survey. Box 25425, Denver Federal Center. Lakewood, CO 80225.

Laursen, H.I. 1978. Structural analysis. Second edition. New York. McGraw-Hill Book Company.

Merriman, D.C., and A.M. Janicki. 2005. Colorado's Instream Flow Program – How it works and why its's good for Colorado. 1313 Sherman Street, Room 721, Denver, CO 80203.

Nehring, R.B. 1979. Evaluation of instream flow methods and determination of water quantity needs for streams in the State of Colorado. Colorado Division of Wildlife. Fort Collins, CO.

Ray, G.A. and W.F. Megahan. 1979. Measuring cross sections using a sag tape: a generalized procedure. USDA Forest Service General Technical Report INT-47. Intermountain Forest and Range Experiment Station. U.S. Department of Agriculture. Ogden, UT. 84401.

Silvey, L. 1976. R-2 Cross Program: A sag-tape method of channel cross section measurement for use with instream flow determinations. United States Department of Agriculture, Forest Service Region 2. 11177 W. 8th Avenue. Lakewood, CO 80225.

Stalnaker and Wick.

Weatherred, J.D., H.L. Silvey and D.J. Pfankuch. 1981. Program documentation for R2-CROSS-81. Watershed Systems Development Group. United States Department of Agriculture, Forest Service. 3825 East Mulberry Street. Fort Collins, CO 80524.

Appendix A - Program Calculations

Some R2CROSS users may be interested in the calculations performed by the Microsoft Excel for Windows macro. The four major computations performed within the R2CROSS macro are sag-tape corrections, estimation of Manning's "n", calculation of a water line comparison table, and calculation of a staging table.

Sag-Tape Calculations.

Channel geometry measurements that are taken using the sag-tape methodology must be corrected to a level reference. R2CROSS uses catenary curve formulas to compute these corrections from a sagging tape that has been leveled at each end. The use of the catenary curve solution is based on the assumption that the suspended steel tape is analogous to a suspended cable placed under a unidirectionally distributed load (Laursen 1978).

The derivation of the catenary curve solution is beyond the scope of this manuscript. Basically, R2CROSS uses the length of tape in suspension, the tension applied to the tape, and the standard weight of one foot of tape to apply the necessary vertical distance corrections to each cell vertical within the cross section.

When using a level and stadia rod to survey channel geometry, the tape weight and tension defaults, supplied in the original R2CROSS.WK4 worksheet, will simulate an extremely light tape stretched at very high tension. This results in a sag correction of approximately zero at each cell vertical.

Use of Manning's Equation.

Manning's equation is defined as:

$$Q = \frac{1.486 * A * R^{2/3} * S^{1/2}}{n}$$

where;
Q = discharge (cfs);
A = cross-sectional area (ft^2);
R = hydraulic radius (ft);
S = slope (ft/ft); and
n = Manning's "n", a dimensionless coefficient of roughness.

Manning's equation is used in two separate R2CROSS calculations. It is first used to provide an initial estimate of Manning's "n" using the rearranged equation:

$$n = \frac{1.486 * A * R^{2/3} * S^{1/2}}{Q}$$

The parameters Q, A, R, and S are calculated from the raw field data and used to solve directly for "n". Once estimated, Manning's "n" remains constant throughout the remainder of the stream flow modeling.

The empirically-derived estimate of Manning's n and estimates of A, R, and S, are then used repeatedly in Manning's equation to solve for Q at each simulated water surface elevation within the staging table (Table 3).

Calculation of the Water Line Comparison Table.

R2CROSS uses two techniques for estimating cross-sectional area. One estimate is obtained by summing the product of "measured" water depth and cell width for all cells in the cross section (A_m). This technique allows independent water surface elevations within each cell and provides the most accurate estimate of cross-sectional area at the time the field measurement was made. However, this technique cannot be used to simulate a single, flat water surface elevation at computer-modeled stream discharges.

The second technique used to estimate cross-sectional area involves projecting a single water surface elevation across the stream channel. Channel bottom elevations are subtracted from this projected water surface elevation to obtain a "computed" water depth at each cell vertical. Cross-sectional area is obtained by summing the product of the "computed" water depth and cell width at each cell vertical (A_c). This technique constrains the water surface to a flat plane and is useful for simulating discharges above and below the field-measured discharge.

The water line comparison table (Figure H) iteratively calculates 31 separate estimates of A_c, using projected waterlines ranging from 0.25 feet above to 0.25 feet below the mean waterline measured in the field. The single water surface elevation that results in A_c equal to A_m is interpolated from the water line comparison table and is used in the staging table as the best estimate of the waterline at the field-measured discharge.

Calculation of the Staging Table.

The final product of the R2CROSS macro is the staging table (Figure I). In addition to the three critical biologic criteria ($\bar{x}_d$, *%WP*, and $\bar{x}_v$), R2CROSS also calculates incremental estimates of top width (TW), maximum depth (D_{max}), cross-sectional area (A), wetted perimeter (WP), hydraulic radius (R), and flow (Q) at a number of waterline elevations. The upper limit of the model occurs at bankfull discharge which is defined as the lower of the two grassline elevations measured in the field. The lower limit is either 1.75 feet below the waterline calculated in the waterline comparison table or stage of zero flow (the lowest field-measured channel profile), whichever is higher in elevation. The formulae for each of the parameters estimated in the staging table are summarized in Table 3.

Table 3. Hydraulic Formulae used in R2CROSS Staging Table

Parameter	Formula
Top Width (TW)	$\sum_{i=1}^{n} TW_i$
Average Depth ($\bar{x}_d$)	$\frac{A}{TW}$
Maximum Depth (D_{max})	$\underset{i=1}{\overset{n}{MAX}}(D_i)$
Area (A)	$\sum_{i=1}^{n} A_i$
Wetted Perimeter (WP)	$\sum_{i=1}^{n} WP_i$
Percent Wetted Perimeter (%WP)	$\frac{WP}{Bankfull\ WP} * 100$
Hydraulic Radius (R)	$\frac{A}{WP}$
Flow (Q)	$\frac{1.486 * A * R^{\frac{2}{3}} * S^{\frac{1}{2}}}{n}$
Average Velocity ($\bar{x}_v$)	$\frac{Q}{A}$

Exhibit 7

RANGE-WIDE

CONSERVATION AGREEMENT AND STRATEGY FOR

ROUNDTAIL CHUB *Gila robusta*,

BLUEHEAD SUCKER *Catostomus discobolus*,

AND FLANNELMOUTH SUCKER *Catostomus latipinnis*

Prepared for
Colorado River Fish and Wildlife Council

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Director

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TABLE OF CONTENTS

RANGEWIDE CONSERVATION AGREEMENT FOR ROUNDTAIL CHUB, BLUEHEAD SUCKER, AND FLANNELMOUTH SUCKER 3
I. Introduction 3
II. Goal 3
III. Objectives 3
IV. Other species involved 4
V. Involved parties 6
VI. Authority 7
VII. Conservation actions 9
VIII. Duration of agreement 13
IX. Policy for evaluation of conservation efforts (PECE) compliance 13
X. National Environmental Policy Act (NEPA) compliance 14
XI. Signatories 15
RANGEWIDE CONSERVATION STRATEGY FOR ROUNDTAIL CHUB, BLUEHEAD SUCKER, AND FLANNELMOUTH SUCKER 22
XII. Introduction 22
XIII. Background 23
XIV. Conservation guidelines 28
XV. Status assessment of roundtail chub, bluehead sucker, and flannelmouth sucker 39
XVI. Range-wide conservation of roundtail chub, bluehead sucker, and flannelmouth sucker 42
XVII. Conservation actions and adaptive management 43
Literature Cited 48
APPENDIX 1: Standard language required by the state of Arizona 59

RANGEWIDE CONSERVATION AGREEMENT FOR ROUNDTAIL CHUB, BLUEHEAD SUCKER, AND FLANNELMOUTH SUCKER

I. INTRODUCTION

This Conservation Agreement (Agreement) has been developed to expedite implementation of conservation measures for roundtail chub (*Gila robusta*), bluehead sucker (*Catostomus discobolus*), and flannelmouth sucker (*Catostomus latipinnis*), hereinafter referred to as the three species, throughout their respective ranges as a collaborative and cooperative effort among resource agencies. Threats that warrant the three species being listed as sensitive by state and federal agencies and that might lead to listing by the U.S. Fish and Wildlife Service as threatened or endangered under the Endangered Species Act of 1973, as amended (ESA), should be minimized through implementation of this Agreement. Additional state, federal, and tribal partners in this effort are welcomed, and such participation (as signatories or otherwise) is hereby solicited.

II. GOAL

The goal of this agreement is to ensure the persistence of roundtail chub, bluehead sucker, and flannelmouth sucker populations throughout their ranges.

III. OBJECTIVES

The individual state's signatory to this document will develop conservation and management plans for any or all of the three species that occur naturally within their state. Any future signatories may also choose to develop individual conservation and management plans, or to integrate their efforts with existing plans. The individual signatories agree to develop information and conduct actions to support the following objectives:

- Develop and finalize a conservation and management strategy (Strategy) acceptable to all signatories that will provide goals, objectives and conservation actions to serve as

consistent guidelines and direction for the development and implementation of individual state wildlfe management plans for these three fish species.

- Establish and/or maintain roundtail chub, flannelmouth sucker and bluehead sucker populations sufficient to ensure persistence of each species within their ranges.

    1) Establish measureable criteria to evaluate the number of populations required to maintain the three species throughout their respective ranges.

    2) Establish measureable criteria to evaluate the number of individuals required within each population to maintain the three species throughout their respective ranges.

- Establish and/or maintain sufficient connectivity between populations so that viable metapopulations are established and/or maintained.

- As feasible, identify, significantly reduce and/or eliminate threats to the persistence of roundtail chub, bluehead sucker, and flannelmouth sucker that: 1) may warrant or maintain their listing as a sensitive species by state and federal agencies, and 2) may warrant their listing as a threatened or endangered species under the ESA.

IV. OTHER SPECIES INVOLVED

This Agreement is primarily designed to ensure the persistence of roundtail chub, bluehead sucker, and flannelmouth sucker within their respective distributions. This will be achieved through conservation actions to protect and enhance these species and their habitats. Although these actions will be designed to benefit the three species, they may also contribute to the conservation of other native species with similar distributions.

Bonytail *(Gila elegans),* Colorado pikeminnow *(Ptychocheilus lucius),* humpback chub *(Gila cypha),* and razorback sucker *(Xyrauchen texanus)* are currently listed as endangered under the ESA. In the Upper Colorado River Basin, recovery of one or more of these species has been undertaken by the Recovery Implementation Program for Endangered Fish Species in the Upper Colorado River Basin and the San Juan River Basin Recovery Implementation Program. In the Lower Colorado River Basin, the Grand Canyon Monitoring and Research Center and the Lower

Colorado River Multi-Species Conservation Plan have committed to recovery actions for these species. Conservation actions for native fish in the Virgin River Basin are occurring under the direction of the Virgin River Resource Management and Recovery Program in Utah and the Lower Virgin River Recovery Implementation Team in Nevada and Arizona. Fish managed under these programs include the federally endangered woundfin *(Plagopterus argentissimus)* and Virgin River chub *(Gila seminuda),* as well as the Virgin spinedace *(Lepidomeda mollispinis mollispinis),* desert sucker *(Catostomus clarkii),* and flannelmouth sucker. Virgin spinedace is the subject species of a conservation agreement and is listed as a "conservation species" in Utah; it is also listed as "protected" in Nevada. The programs described above focus primarily on mainstem rivers where, in some cases, the three species spend parts of their life cycles. Although the three species are also found in tributary streams, conservation actions in these habitats have received less emphasis to date. Such actions are, therefore, likely to be the focus of state conservation and management plans developed as part of this Agreement. Any conservation actions implemented through existing recovery programs and/or this Agreement may benefit both the endangered fishes mentioned as well as the three species. The signatories will commit to implement conservation actions under this Agreement and Strategy that neither conflict with nor replicate any conservation actions that have been implemented, are being implemented, or will be implemented under any existing recovery program or conservation agreement.

Additionally, the Agreement may reduce threats to several native species that are not currently listed as threatened or endangered under the ESA, and thereby preclude the need for listing or re-listing in the future. Some of these native species include speckled dace *(Rhinichthys osculus),* Gila chub (*Gila intermedia*), headwater chub *(Gila nigra),* mountain sucker *(Catostomus platyrhynchus),* Zuni bluehead sucker *(Catostomus discobolus yarrowi),* Bonneville cutthroat trout *(Oncorhynchus clarkii utah),* Colorado River cutthroat trout *(Oncorhynchus clarkii pleuriticus),* Yellowstone cutthroat trout *(Oncorhynchus clarkii bouvieri),* mottled sculpin (*Cottus bairdi*), Paiute sculpin (*Cottus beldingi*), northern leopard frog *(Rana pipiens),* relict leopard frog *(Rana onca),* boreal toad *(Bufo boreas boreas),* Great Basin spadefoot *(Spea intermontana),* Great Plains toad *(Bufo cognatus),* New Mexico spadefoot *(Spea*

multiplicata), red-spotted toad *(Bufo punctatus),* Woodhouse toad *(Bufo woodhousei),* canyon treefrog *(Hyla arenicolor),* and western chorus frog *(Pseudacris triseriata).*

V. INVOLVED PARTIES

The following state agencies are committed to work cooperatively to conserve the roundtail chub, bluehead sucker, and flannelmouth sucker throughout their respective ranges, and have further determined that a consistent approach, as described in this Agreement, is most efficient for conserving the three species. The state agencies signatory to this document are:

Arizona Game and Fish Department

Colorado Division of Wildlife

Nevada Department of Wildlife

New Mexico Department of Game and Fish

Utah Division of Wildlife Resources

Wyoming Game and Fish Department

Coordinated participation by state wildlife agencies helps institutionalize range-wide conservation of the three fish species, but federal and tribal partners are being encouraged to participate, as well. The participation of all resource managers in the areas where these species are found is important for the long-term survival of the three species. Some language in this Agreement has been included in anticipation of eventual federal and tribal participation. Any edits proposed by potential conservation partners that will allow them to sign this Agreement and participate in conservation actions will be carefully considered and will only be incorporated with the consensus of the existing signatories. This Agreement may be amended at any time to include additional signatories. An entity requesting inclusion as a signatory shall submit its request to the Council in the form of a document defining its proposed responsibilities pursuant to this Agreement.

VI. AUTHORITY

- The signatory parties hereto enter into this Conservation Agreement and the proposed Conservation Strategy under Federal and State Law, as applicable. Each species' conservation status is designated by state wildlife authorities according to the following table (updated from Bezzerides and Bestgen 2002):

Species	State	Status
Bluehead sucker	Utah	Species of Concern
	Wyoming	Special Concern
Flannelmouth sucker	Colorado, Wyoming	Special Concern
	Utah	Species of Concern
Roundtail chub	New Mexico	Endangered
	Utah	Species of Concern
	Arizona, Colorado, Wyoming	Special Concern

- The signatory parties further note that this Agreement is entered into to establish and maintain an adequate and active program for the conservation of the above listed species.
- The signatory parties recognize that each state has the responsibility and authority to develop a conservation and management plan consistent with the goal and objectives of this Agreement. The purpose of these documents will be to describe

specific tasks to be completed toward achieving the goal and objectives of this Agreement.

- All parties to this Agreement recognize that they each have specific statutory responsibilities, particularly with respect to the management and conservation of these fish, their habitat and the management, development and allocation of water resources. Nothing in this Agreement or the proposed companion Strategy to be developed pursuant to this Agreement is intended to abrogate any of the parties' respective responsibilities.
- This Agreement is subject to and is intended to be consistent with all applicable Federal and State laws and interstate compacts (To this end, the State of Arizona has attached appendix 1.)
- The state of Wyoming and the Commission do not waive sovereign immunity by entering into this Agreement, and specifically retain immunity and all defenses available to them as sovereigns pursuant to Wyoming Statute 1-39-104(a) and all other state law.
- This instrument in no way restricts the parties involved from participating in similar activities with other public or private agencies, organizations or individuals.
- Revisions to this Agreement will be made only with approval of all signatories.
- This Agreement may be executed in several parts, each of which shall be an original, and which collectively shall constitute the same Agreement.

VII. CONSERVATION ACTIONS

The signatories will review and document existing and ongoing programmatic actions that benefit the three species. As signatories develop their individual management plans for conservation of the three species, each signatory may include but is not limited by or obligated to incorporate the following conservation actions:

1) Conduct status assessment of roundtail chub, bluehead sucker, and flannelmouth sucker.

2) Establish and maintain a database of past, present, and future information on roundtail chub, bluehead sucker, and flannelmouth sucker.

3) Determine roundtail chub, bluehead sucker, and flannelmouth sucker population demographics, life history, habitat requirements, and conservation needs.

4) Genetically and morphologically characterize populations of roundtail chub, bluehead sucker, and flannelmouth sucker.

5) Increase roundtail chub, bluehead sucker, and flannelmouth sucker populations to accelerate progress toward attaining population objectives for respective species.

6) Enhance and maintain habitat for roundtail chub, bluehead sucker, and flannelmouth sucker.

7) Control (as feasible and where possible) threats posed by nonnative species that compete with, prey upon, or hybridize with roundtail chub, bluehead sucker, and flannelmouth sucker.

8) Expand roundtail chub, bluehead sucker, and flannelmouth sucker population distributions through transplant activities or reintroduction to historic range, if warranted.

9) Establish and implement qualitative and quantitative long-term population and habitat monitoring programs for roundtail chub, bluehead sucker, and flannelmouth sucker.

10) Implement an outreach program (e.g., development of partnerships, information and education activities) regarding conservation and management of roundtail chub, bluehead sucker, and flannelmouth sucker.

Coordinating Conservation Activities

- Administration of the Agreement will be conducted by a range-wide Coordination Team. The team will consist of a designated representative from each signatory to this Agreement and may include technical and legal advisors and other members as deemed necessary by the signatories.
- As a first order of business, the chair of the Coordination Team will be selected from signatory state wildlife agency participants. Leadership will be reconsidered annually, and any member may be selected as Coordination Team Leader with a vote of the majority of the team. The chair will serve no more than two consecutive one-year terms.
- Authority of the Coordination Team will be limited to making recommendations to participating resource management agencies to address status, threats and conservation of roundtail chub, bluehead sucker, and flannelmouth sucker.
- The Coordination Team will meet at least once annually in October or November to develop range-wide priorities, review the annual conservation work plans developed by each agency, review conservation accomplishments resulting from implementation of conservation work plans, coordinate tasks and resources to most effectively implement the work plans, and review and revise the Strategy and states' conservation and management plans as required. They will report on progress and effectiveness of implementing the conservation and management strategies and plans. The Coordination Team will decide the annual meeting date and location.
- Coordination Team meetings will be open to the public. Meeting decision summaries and annual progress reports will be distributed to the Coordination Team and the signatories. Other interested parties may obtain minutes and progress reports upon request.

Implementing Conservation Schedule

- Development of the range-wide Conservation Strategy and states' conservation and management plans will begin no later than March 2004 and be completed no later than December 2004. A 10-year period will be necessary to attain sufficient progress toward objectives outlined in this Agreement, the range-wide Strategy, and the state plans, but the time required to complete conservation actions may be revised with consensus of the signatories.
- Conservation actions will be scheduled and reviewed on an annual basis by the signatories based on recommendations from the Coordination Team. Activities that will be conducted during the first three to five years of implementation will be identified in annual work plans within the states' conservation and management plans. The Strategy and states' conservation and management plans will be flexible documents and will be revised through adaptive management, incorporating new information as it becomes available.
- The state wildlife agency that has the Coordination Team Leader responsibility will coordinate team review of conservation activities conducted by participants of this Agreement to determine if all actions are in accordance with the Strategy and state conservation and management plans, and the annual schedule.
- Following a 10-year evaluation, the Agreement, Strategy, and associated states' conservation and management plans may be renewed.

Funding Conservation Actions

- Expenditures to implement this Agreement and Strategy will be identified in states' conservation and management strategies and are contingent upon availability of funding.
- Implementation funding will be provided by a variety of sources. Federal, state, and local sources will need to provide or secure funding to initiate procedures of the Agreement and Strategy, although nothing in this Agreement obligates any agency to any funding responsibilities. To date, various federal and state sources have contributed to

conservation efforts for the three fish species, including development of the Agreement and Strategy.

- Federal sources may include, but are not limited to, U.S. Forest Service, U.S. Fish and Wildlife Service, U.S. Bureau of Reclamation, Bureau of Land Management, Land and Water Conservation funds, and the Natural Resource Conservation Service. Nothing in this document commits any of these agencies to funding responsibilities.
- State funding sources may include, but are not limited to, direct appropriation of funds by the legislature, community impact boards, water resources revolving funds, state departments of agriculture, and state resource management agencies. Nothing in this document commits any of these agencies to funding responsibilities.
- Local sources of funding may be provided by water districts, Native American Affiliations, cities and towns, counties, local irrigation companies, and other supporting entities, and may be limited due to factors beyond local control.
- In-kind contributions in the form of personnel, field equipment, supplies, etc., will be provided by participating agencies. In addition, each agency will have specific tasks, responsibilities and proposed actions/commitments related to their in-kind contributions.
- It is understood that all funds expended in accordance with this Agreement are subject to approval by the appropriate local, state or Federal appropriations. This instrument is neither a fiscal nor a funds obligation document. Any endeavor involving reimbursement or contribution of funds between the parties to this instrument will be handled in accordance with applicable laws, regulations, and procedures, including those for government procurement and printing, if applicable. Such endeavors will be outlined in separate agreements (such as memoranda of agreement or collection agreements) that shall be made in writing by representatives of the parties and which shall be independently authorized by appropriate statutory authority. This instrument does not provide such authority. Specifically, this instrument does not establish authority for noncompetitive awards to the cooperator of any contract or other agreement. Any

contract or agreement for training or other services must fully comply with all applicable requirements for competition.

Conservation Progress Assessment.

- A range-wide assessment of progress towards implementing actions identified in this Agreement and each state conservation and management plan will be provided to the signatories by the Coordination Team in the first, fifth and tenth years of the Agreement and every fifth year thereafter as dictated by any extension of this instrument beyond ten years. The Coordination Team will compile the annual assessment from submittals prepared by members of the Coordination Team. Copies of the annual assessment will be provided to the signatories, and to interested parties upon request.

VIII. DURATION OF AGREEMENT

The term of this Agreement shall be for two consecutive five-year periods. The first five-year period will commence on the date all state signatories to this document are completed. Prior to the end of each five-year period, a thorough analysis and review of actions implemented for the three species will be conducted by the Coordination Team. If all signatories agree that sufficient progress has been made toward conservation and management of the roundtail chub, bluehead sucker, and flannelmouth sucker, this Agreement may be extended without additional signatures being required. Any involved party may withdraw from this Agreement on 60 days written notice to the other parties.

IX. POLICY FOR EVALUATION OF CONSERVATION EFFORTS (PECE) COMPLIANCE

Pursuant to the federal Policy for Evaluation of Conservation Efforts (PECE) guidelines, the signatory agencies acknowledge the role of PECE in providing structure and guidance in support of the effective implementation of this conservation program and will address PECE elements within their respective state conservation and management plans. They also acknowledge and support the principle that documented progress toward stable and increased

distribution, abundance, and recruitment of populations of the three species constitutes the primary index of effectiveness of this conservation program. Criteria describing population status and trends as well as mitigation of recognized threats comprise the primary basis for evaluation of conservation efforts conducted under this Agreement.

X. NATIONAL ENVIRONMENTAL POLICY ACT (NEPA) COMPLIANCE

The signatories anticipate that any survey, collection, or non-land disturbing research activities conducted through this Agreement will not constitute significant Federal actions under the NEPA, and will be given a categorical exclusion designation, as necessary. However, each signatory agency holds the responsibility to review planned actions for their area of concern to ensure conformance with existing land use plans, and to conduct any necessary NEPA analysis for those actions within their area.

XI. SIGNATORIES

Arizona Game and Fish Department
2221 W. Greenway Rd.
Phoenix, Arizona 85023-4399

02/23/04
Duane L. Shroufe — Date
Director

Colorado Division of Wildlife
6060 Broadway
Denver, Colorado 80216

3/22/04
for Russell George — Date
Director

Nevada Department of Wildlife
1100 Valley Rd.
Reno, Nevada 89512

3/5/04
for: Terry Crawforth — Date
Director

New Mexico Department of Game and Fish
P.O. Box 25112
Santa Fe, New Mexico 87504

4-15-04
Bruce Thompson — Date
Director

Utah Division of Wildlife Resources
1594 W. North Temple, Suite 2110
P.O. Box 1456301
Salt Lake City, Utah 84114-6301

Kevin K. Conway 2/4/04
Kevin K.Conway Date
Director

Wyoming Game and Fish Department
5400 Bishop Boulevard
Cheyenne, Wyoming 82006

for 3-12-04
Terry Cleveland Date
Director

Ron Arnold 3/11/04
Ron Arnold Date
Chief Fiscal Officer

Approval as to form:

T. Preston 3/11/04
Ted Preston Date
Assistant Attorney General

The following signatories support the goals, objectives, and actions of the Conservation Agreement for Roundtail Chub, Bluehead Sucker and Flannelmouth Sucker, version 10.4.4 and agree to support the conservation efforts described.

Alan L Kesterke

Bureau of Land Management
Wyoming State Office

April 8, 2005

Date

The following signatories support the goals, objectives, and actions of the Conservation Agreement for Roundtail Chub, Bluehead Sucker and Flannelmouth Sucker, version 10.4.4 and agree to support the conservation efforts described.

Jack Wisdy

Bureau of Land Management
Utah State Office

5/16/05

Date

The following signatories support the goals, objectives, and actions of the Conservation Agreement for Roundtail Chub, Bluehead Sucker and Flannelmouth Sucker, version 10.4.4 and agree to support the conservation efforts described.

Linda S.C. Rundell
State Director
Bureau of Land Management
New Mexico State Office

4/7/06
Date

The following signatories support the goals, objectives, and actions of the Conservation Agreement for Roundtail Chub, Bluehead Sucker and Flannelmouth Sucker, version 10.4.4 and agree to support the conservation efforts described.

National Park Service
Intermountain Region
12795 W. Alameda Parkway
P.O. Box 25287
Denver, Colorado 80225-0287

Michael D. Snyder
Acting Director

7/5/05
Date

-Signature Page-

This signature page is an appendix to the Range-Wide Conservation Agreement for Roundtail Chub, Bluehead Sucker, and Flannelmouth Sucker dated 27 January2004 ("Agreement").

The Jicarilla Apache Nation enters this Agreement pursuant to its inherent authority and pursuant to the Revised Constitution of the Jicarilla Apache Nation, Article XI, Powers of the Tribal Council. Nothing in this Agreement provides a basis for requiring the Jicarilla Apache Nation to comply with state law. Nothing in this Agreement diminishes the jurisdiction of the Jicarilla Apache Nation, including its legislative, regulatory, and judicial jurisdiction, nor does the Agreement waive the sovereign immunity of the Nation.

Jicarilla Apache Nation
Jicarilla Game and Fish Department
P.O. Box 507
Dulce, NM 87528

President Levi Pesata

5/10/06
Date

RANGEWIDE CONSERVATION STRATEGY FOR ROUNDTAIL CHUB, BLUEHEAD SUCKER, AND FLANNELMOUTH SUCKER

XII. INTRODUCTION

This conservation strategy (Strategy) has been developed to provide a framework for the long-term conservation of roundtail chub (Cyprinidae: *Gila robusta*), bluehead sucker (Catostomidae: *Catostomus discobolus*), and flannelmouth sucker (Catostomidae: *Catostomus latipinnis*), hereinafter referred to as the three species. Implementation of the Strategy is intended to be a collaborative and cooperative effort among resource agencies to support conservation of the three species throughout their respective ranges. This document provides goals, objectives, and conservation actions to serve as consistent guidelines and direction for the development and implementation of individual state wildlife management plans for the three species. These state conservation and management plans are being developed through an interagency and interested party involvement process. Specific tasks that affect the status of the three species are not reiterated in this document. Rather, we outline the general strategy summarizing the conservation actions to be taken to eliminate or significantly reduce threats and present an overall strategy for the long-term conservation of the three species.

Guidance for specific tasks in state conservation and management plans is summarized in this document. Specific tasks to be completed under the conservation actions set forth in this document will be detailed within respective state conservation and management plans. Likewise, specific tasks that have been completed toward achieving the objectives set forth in this document will also be detailed within the state conservation and management plans. Implementation of these tasks will identify and minimize threats to roundtail chub, bluehead sucker, and flannelmouth sucker that: 1) may warrant or maintain their listing as a sensitive species by state and federal agencies, and 2) may warrant their listing as a threatened or endangered species under the Endangered Species Act of 1973, as amended (ESA).

XIII. BACKGROUND

Geographic Setting

The Colorado River Basin (CRB) is home to 22 fish genera, at least 35 fish species and at least 26 endemic fish species, some of which have persisted for over 10 million years (Evermann and Rutter 1895, Miller 1959, Molles 1980, Minckley et al. 1986, Carlson and Muth 1989, Valdez and Carothers 1998, Bezzerides and Bestgen 2002). Geologic isolation, frequent drought and flood, widely ranging temperatures, and high sediment and solute loads in the CRB created a harsh environment that provided a unique setting for the evolution of a distinct group of endemic fishes (Behnke 1980, Ono et al. 1983, Minckley et al. 1986). The CRB is divided into upper and lower basins at Lee's Ferry in north central Arizona, near the Utah border. The San Juan, Colorado, and Green river basins form the upper CRB. In the lower CRB, the Colorado River flows through Grand Canyon National Park and forms state boundaries between Nevada, California and Arizona. Conjoining the Colorado River in Arizona are the Little Colorado and Gila rivers and the Virgin River joins the Colorado in Nevada. The three species occur in both upper and lower portions of the CRB.

The Bonneville Basin (Utah, Nevada, Wyoming, and Idaho) is an endorheic basin, wherein surface water collects from precipitation and upwelling groundwater, but no streams drain out of the basin (Hubbs et al. 1974). Historically, the Bonneville Basin had aquatic affinities with Hudson Bay, and several species stem from northeastern North American progenitors (Sigler and Sigler 1996 and references therein). During geologic history, the Bear River flowed into the Upper Snake River drainage (Columbia River Basin), but currently flows into the Bonneville Basin (Hubbs and Miller 1948; Sigler and Sigler 1996). The bluehead sucker historically occurred in both the CRB and the Bonneville Basin.

Species Descriptions, Life Histories and Hybrids

The three species share several morphological similarities commonly associated with hydrologically variable environments, including: 1) fusiform bodies, 2) leathery skins with embedded scales, and 3) large, often falcate fins. Such morphologic features, combined with

relatively long life spans, may be adaptations to the harsh, unpredictable physical environment of the CRB (Scoppettone 1988, Minckley 1991, Stearns 1993, Bezzerides and Bestgen 2002). Life history characteristics, distribution and abundance have been described for roundtail chub (Bestgen and Propst 1989, Brouder et al. 2000, Voeltz 2002), bluehead sucker (e.g., McAda 1977, Holden and Minckley 1980, McAda and Wydoski 1983, Cavalli 1999 and Bestgen 2000), and flannelmouth sucker (Chart 1987, Douglas and Marsh 1998, McKinney et al. 1999). Bluehead sucker are also discussed in Valdez (1990), Mueller et al. (1998), Brunson and Christopherson (2001), and Jackson (2001).

Roundtail Chub

Roundtail chub utilize slow moving, deep pools for cover and feeding. These fish are found in the mainstem of major rivers and smaller tributary streams. Roundtail chub utilize a variety of substrate types (silt, sand, gravel and rocks) and prefer murky water to clear (Sigler and Sigler 1996, Brouder et al. 2000). Roundtail chub partition habitat use by life stage [adult, juvenile, young-of-year (YOY)].

Juveniles and YOY are found in quiet water near the shore or backwaters with low velocity and frequent pools rather than glides and riffles. Juveniles avoid depths greater than 100 cm and YOY avoid depths greater than 50 cm. Juveniles use instream boulders for cover, while YOY are found in interstices between and under boulders or the slack-water area behind boulders (Brouder et al. 2000).

Adults generally do not frequent vegetation and avoid shallow water cover types (overhanging and shoreline vegetation) (Sigler and Sigler 1996, Brouder et al. 2000). Adults are found in eddies and pools adjacent to strong current and use instream boulders as cover (Sigler and Sigler 1996, Brouder et al., 2000). Adults occupy depths greater than 20 cm and select for velocities less than 20 cm/s. Adults may range 100 m or less over the course of a year, often in search of pool habitats (Siebert 1980; Brouder et al 2000).

Sigler and Sigler (1996) report that roundtail chub mature at five years of age and/or 254 mm to 305 mm in length and that spawning begins in June to early July when water temperatures reach 18.3 °C. However, Peter Cavalli, Wyoming Fish and Game Department, has collected

unpublished data (2004 personal communication) indicating that roundtail chub in Upper Green River drainage lakes may mature at sizes as small as 150 mm in water temperatures of 14.4 °C. Eggs from one female may be fertilized by three to five males over gravel in water up to 9.1 m. A 305 mm female can produce 10,000 eggs, 0.7 mm in diameter. The eggs are pasty white and adhesive, sticking to rocks and other substrate or falling into crevices (Sigler and Sigler 1996).

Roundtail chub are carnivorous, opportunistic feeders. Documented food items include aquatic and terrestrial insects, fish, snails, crustaceans, algae, and occasionally lizards (Sigler and Sigler 1996, Osmundson 1999, Bestgen 2000, Brouder 2001).

Bluehead Sucker

Bluehead sucker tend to utilize swifter velocity, higher gradient streams than those occupied by either flannelmouth sucker or roundtail chub. These fish are found in warm to cool streams (20 °C) with rocky substrates (Sigler and Sigler 1996, Bestgen 2000). Bluehead sucker do not do well in impoundments (Sigler and Sigler 1996, Bezzerides and Bestgen 2002). Bluehead sucker partition habitat use by life stage [adult, juvenile, young-of-year (YOY)]. Larval fish inhabit near-shore, low velocity habitats (Childs et al. 1998). As they age, they move to deeper habitats further away from shore, and with more cover (Childs et al. 1998).

Larval and early-juvenile bluehead sucker eat mostly invertebrates (Childs et al. 1998). At later life-stages, they are more opportunistic omnivores, consuming algae, detritus, plant debris, and occasionally aquatic invertebrates (Sigler and Sigler 1996, Osmundson 1999, and Bestgen 2000). This species feeds in riffles or deep rocky pools (McAda 1977, Sigler and Sigler 1996).

Bluehead sucker mature at two years of age and/or at 127 to 179 mm in length. Spawning occurs in shallow areas when water temperatures reach 15.6 °C. Time of spawning varies by elevation, i.e., spring and early summer at low elevations and warm water temperatures, and mid- to late summer at higher elevations and cooler temperatures (Sigler and Sigler 1996). Fecundity is related to length, body weight (Holden 1973), and water temperature (McAda 1977). A 38 to 44 cm female may produce over 20,000 eggs (Andreason 1973). Eggs

hatch in seven days at water temperatures of 18 to 21 °C (Holden 1973). Bluehead sucker, when disturbed during spawning, will compress to the bottom of the stream and can be captured by hand (Sigler and Sigler 1996). After hatching, larval fish drift downstream and seek out near-shore, slow-velocity habitats (Robinson et al. 1998).

Flannelmouth Sucker

Flannelmouth sucker reside in mainstem and tributary streams. Elements of flannelmouth habitat include 0.9 to 6.1 m deep murky pools with little to no vegetation, and deep runs and riffles (McAda 1977, Sigler and Sigler 1996, Bezzerides and Bestgen 2002). Substrates utilized consist of gravel, rock, sand, or mud (McAda 1977, Sigler and Sigler 1996). Flannelmouth sucker partition habitat use by life stage, with young fish occupying quiet, shallow riffles and near-shore eddies (Childs et al. 1998), and adults occupying deep riffles and runs. Many authors report that flannelmouth sucker do not prosper in impoundments (McAda 1977, Sigler and Sigler 1996, Bezzerides and Bestgen 2002); however, some lakes in the Upper Green River drainage in Wyoming supported large flannelmouth sucker populations historically (Baxter and Stone 1995; P. Cavalli, Wyoming Game and Fish Department, 2004 personal communication). Flannelmouth sucker are opportunistic, benthic omnivores consuming algae, detritus, plant debris, and aquatic invertebrates (McAda 1977, Sigler and Sigler 1996, Osmundson 1999, Bezzerides and Bestgen 2002). Food consumed depends on availability, season, and the individual's age class (McAda 1977, Sigler and Sigler 1996). Larval and early juveniles consume mostly invertebrates (Childs et al. 1998).

Flannelmouth suckers mature at four to five years of age. Males mature earliest (McAda 1977, Sigler and Sigler 1996). Females ripen at water temperatures of 10 °C, whereas males ripen earlier in the spring (6.1 to 6.7 °C) and remain fertile for longer periods than females (McAda 1977, Sigler and Sigler 1996). Seasonal migrations are made in the spring to suitable spawning habitat (Suttkus and Clemmer 1979, Sigler and Sigler 1996). McKinney et al. (1999; see also Chart 1987, Chart and Bergersen 1987, Bergersen 1992) documented long-range movements (ca. 98-231 km) among adult and sub-adult fish, although the roles these movements play in life history are unclear and need further investigation. Obstructions to movements such

as dams may also be an important consideration in the conservation of flannelmouth suckers. Flannelmouth suckers generally spawn for two to five weeks over gravel. A female will produce 9,000 to 23,000 adhesive, demersal eggs. After fertilization, the eggs sink to the bottom of the stream and attach to substrate or drift between crevices (Sigler and Sigler 1996). After hatching, larvae drift downstream and seek out near-shore, low-velocity areas (Robinson et al. 1998).

Hybrids

Potential hybridization among *Gila* species in the CRB has caused management agencies to carefully consider their conservation actions. In Utah, hybridization between humpback chub *(Gila cypha)* and bonytail *(G. elegans)* in Desolation and Gray Canyons of the Green River has been postulated by many observers. The Virgin River chub *(Gila seminuda)* found in the Muddy River has been historically treated as a subspecies of roundtail chub *(G. robusta)* and is thought to be a hybrid between the bonytail *(G. elegans)* and the Colorado roundtail chub *(G. r. robusta;* Maddux et al. 1995, Sigler and Sigler 1996 and references therein). In 1993, taxonomic revisions were accepted, and the Virgin River chub was asserted species status as *G. seminuda* (DeMarais et al. 1992, Maddux et al. 1995). The Virgin River chub is currently listed as endangered under the ESA.

Whether biologists and agencies recognize two species, two species and a hybrid form, three species, or some other combination has implications for how the fish are managed. Because roundtail chub are congeners with humpback chub and bonytail, the potential for hybridization with roundtail exists, although this has not been as well documented as the hybridization between humpback chub and bonytail (e.g., Valdez and Clemmer 1982, Kaeding et al. 1990, Dowling and DeMarais 1993, Douglas and Marsh 1998). Valdez and Clemmer (1982) have suggested that hybridization is a negative result of dramatic environmental changes, while Dowling and DeMarais (1993) and McElroy and Douglas (1995) suggest that hybridization among these species has occurred continually over geologic time, providing offspring with additional genetic variability. Barriers to hybridization among *Gila* species suggest that it is a paraphyletic genus (Coburn and Cavender 1992 and references therein). Putative roundtail chub in the Gila River drainage of New Mexico and Arizona was recently divided into three species,

G. robusta, *G. intermedia*, and *G. nigra* (Minckley and DeMarais 2000). Additional investigation of these relationships and resulting offspring is required and results may affect future conservation and management actions for roundtail chub and other *Gila* species. Hybridization between bluehead sucker and Rio Grande sucker (*C. plebius*) is thought to have produced the Zuni bluehead sucker (*C.d. yarrowi*), a unique subspecies found mainly in Rio Nutria, NM.

Douglas and Douglas (2003) report that both indigenous bluehead and flannelmouth sucker currently hybridize with invasive white sucker (*Catostomus commersoni*) in the Little Yampa Canyon region of the Yampa River, Colorado. Two hybrids between flannelmouth and bluehead sucker were also found in their study, which is extremely rare elsewhere in the CRB. Douglas and Douglas (2003) suggest backcrossing of fertile indigenous and invasive sucker hybrids as a mechanism that perpetuates introgressed genes. They also speculate that the species boundary between flannelmouth and bluehead suckers could be compromised as a result.

XIV. CONSERVATION GUIDELINES

This section presents a generalized discussion on conservation topics relevant to the conservation of the three fish species. Intended as a guide for development of state conservation plans, it does not specifically outline minimum requirements for development of such plans. Rather, the signatories recognize that the priority of issues discussed in this section may vary widely from state to state and that the feasibility of resolving management implications discussed herein is situation- and species-specific. Furthermore, it is likely that conservation issues discussed in these sections will frequently be interrelated. For example, genetic concerns will likely be addressed in concert with metapopulation, population viability, and nonnative fish issues. Likewise, nonnative fish control issues may impact habitat management, and in some instances, hybridization issues (e.g., occurrence of white sucker in the upper CRB), and so on. It is therefore desirable that state managers identify interrelationships between conservation issues and formulate their state plans accordingly.

Habitat Maintenance and Protection

Habitat is an important component of metapopulation and species survival. Loss of available habitat may lead to the loss of individuals or populations that in turn may cause loss of metapopulation dynamics. Important physical habitat characteristics may include (but are not limited to) substrate, instream habitat complexity**,** and flow regimes. Chemical characteristics may include (but are not limited to) instream pH, temperature, specific conductance, suspended solids, dissolved oxygen, major ions (e.g., carbonate), nutrients, and trace elements. If needed, the signatories will develop habitat improvement actions to support individual populations and metapopulation dynamics. Rigorous standards for habitat protection can be incorporated into state fishery and land use plans. Current guidelines exist for many agencies that can be incorporated into these efforts, including (but not limited to) Best Management Practices or other state water quality standards, Forest Plan Standards and Guidelines, National Park Service Natural Resources Management Guidelines (DO-77), and recommendations from related broad-scale assessments. Properly Functioning Condition (PFC) protocols are found in Bureau of Land Management publication TR 1737-15 (1998) "Riparian Area Management, a User Guide to Assessing Proper Functioning Condition and Supporting Science for Lotic Areas."

One of the most dramatic anthropogenic changes imposed on the CRB and Bonneville basins is alteration of natural flow regimes. Instream flow and habitat-related programs administered through existing recovery and conservation programs in upper and lower Colorado River basins can provide guidance for development of similar programs for the three species. Studies conducted by the Upper Colorado River Basin Endangered Fish Recovery Program can aid in identifying habitat requirements for main channel three species populations and select tributary populations (e.g., Chart and Lenstch 1999, Trammel et al. 1999, Muth et al. 2000, Osmundson 2001, Tyus and Saunders 2001, McAda 2003). Other examples of habitat management for tributary cypriniform populations have been proposed for the Virgin River (Lentsch et al. 1995; Lentsch et al. 2002).

Habitat availability for flannelmouth and bluehead sucker as a function of stream discharge was recently identified in Anderson and Stewart (2003). The goal of this study was to

derive biologically based instream flow recommendations for non-endangered native fish, which makes the study germane as a three species conservation guideline. Habitat quality and quantity were derived by relating output from two-dimensional (2-D) hydraulic models of mesohabitat availability (as a function of discharge) to patterns of fish abundance over a three-year period among three different systems (Dolores, Yampa, and Colorado rivers). The 2-D approach is advantageous over previous instream flow methods because it is not dependent on microhabitat suitability curves (and their attendant assumptions) for prediction of habitat availability. The higher level of spatial resolution attained by the 2-D allows for greater accuracy in habitat quantification. The 2-D approach as utilized in Anderson and Stewart (2003) is also advantageous because output is interpreted alongside relevant biological information such as non-native fish abundance and native fish size structure in the modeled stream reaches.

Nonnative fish control

Impacts of nonnative fish on native fish fauna of the Southwestern U.S. are dramatic. Of 52 species of fish currently found in the upper CRB, only 13 are native (six of these are endangered; U.S. Fish and Wildlife Service [FWS] 2003b). Native fish populations in the lower CRB have been similarly impacted by establishment of nonnative fish populations (Minckley et al. 2003). Direct and indirect impacts of nonnative fish on native fish fauna can be measured as changes in the density, distribution, growth characteristics, condition or behavior of both individual native fish and native fish populations (Taylor et al. 1984; Hawkins and Nesler 1991). These changes result from altered trophic relationships (predation, competition for food), spatial interactions (competition for habitat), habitat alteration, hybridization, and/or disease or parasite introductions.

All major recovery plans in the Southwestern U.S., including those of the San Juan River Basin Recovery Implementation Program (SJRIP; SJRIP, 1995), the Upper Colorado River Endangered Fish Recovery Program (UCREFRP; FWS 2003b), the June Sucker Recovery Implementation Program (JSRIP; FWS 1999), and the Virgin River Resource Management and Recovery Program (FWS 1995), identify control of nonnative fish species to alleviate competition with and/or predation on rare fishes as a necessary management action. Due to extensive use by the three species of lower-order streams throughout their range, however, states

may have to identify HUC-specific control measures for nonnative fish. Guidelines for development of nonnative fish management actions (Hawkins and Nesler 1991; Tyus and Saunders 1996; Lenstch et al. 1996; SWCA Inc. 2002) include:

1) Assessment of impacts of nonnative fish on native fish populations, including problem species and probable impact mechanisms.
2) Identification of spatial extent of impacted populations and potential nonnative source systems; prioritization of areas by severity and cost/benefit ratios.
3) Development of coordinated nonnative fish control strategies; identification of potential sport fishing conflicts.
4) Identification and use of effective nonnative control methods.
5) Development of programs to monitor results of nonnative control measures.
6) Assurance that I & E and outreach programs are in place to communicate intentions and findings to the public.

Tyus and Saunders (1996) identified three basic strategies for nonnative fish control in the upper CRB:

1) Prevention. Nonnative fish are prevented from entering a system by physical barriers or other control structures, removed directly from potential source water bodies, or prevented from being stocked through regulatory mechanisms.
2) Removal. Nonnative fish are removed directly from a system or forced out through creation of unfavorable habitat conditions.
3) Exclusion. Nonnative fish are excluded from preying upon or otherwise interfering with native fish through active management, particularly in nursery areas including, but not limited to, installation of barriers during rearing periods.

Strategies may be applied at the basin-wide level or applied to high priority areas within a specific body of water such as nursery or reproductive habitats where native offspring are most vulnerable to predation. Strategies for control of nonnative fish should be developed at the state level. Evaluations of state nonnative fish stocking policies can be found for Colorado (Upper Colorado River Endangered Fish Recovery Program 2002; Martinez et al., in review) and Utah (Holden et al. 1996; Upper Colorado River Endangered Fish Recovery Program 2002). Potential conflicts of nonnative fish control actions with sport fishing management may be difficult to resolve, and may require the development of regional coordinated sport and native fish management strategies. Such strategies often include sufficient monitoring to demonstrate results of nonnative fish control efforts. Outreach programs have been utilized to communicate these results to the public.

Nonnative fish control techniques, specifically applications to southwestern fisheries, have been identified by Lentsch et al. (1996) and SWCA Inc. (2002). Control techniques are categorized as mechanical (angling, commercial fishing, electrofishing, netting), chemical (rotenone, antimycin), biological (introduce predator/competitor, genetically altered individuals, or disease), physical (barriers, screens), physicochemical (habitat modification), or some combination of these. Based on a survey of available literature, SWCA Inc. (2002) identified use of a combination of techniques as the most effective means of controlling nonnative fish abundance. All approaches require a prior knowledge of the target species life history and the physical characteristics of the system they reside in. Documentation of a positive native fish population response to control efforts poses a formidable challenge to managers, but one that ultimately must be addressed.

Population Viability

One of the most fundamental and difficult questions that a wildlife conservation program can address is whether a wild population of animals will persist into the future. Evaluation of the viability of populations may consider available information from the past, the current condition of the species, and the degree of known threats. Population viability analysis also considers what is known about population genetics and demographics, e.g. the probability that very small populations will inbreed and be lost.

This Strategy does not prescribe any one specific method of population viability analysis. Instead, all state signatories agree to develop their own manner of estimating population viability, recognizing the importance of overlapping methods where feasible and applicable. In addition, is it recognized that additional information will be acquired over the course of the Agreement and will thus be adaptive in their approach for estimating population viability. The Strategy identifies the following population viability factors that may be considered, although other appropriate factors may be added to this list in the future:

1. Known and potential threats
2. Available habitat(s)
3. Habitat stability
4. Genetic stability
5. Metapopulation connectivity and stability
6. Reproductive opportunity and potential, including recruitment into the effective population
7. Potential to expand population sizes and distribution

Population viability is a function of population demographics (size and age structure), population redundancy (number and distribution), habitat carrying capacity (resource limitations), and genetic stability (inbreeding and genetic diversity; Franklin 1980; Soulé 1980; Shaffer 1987; Allen et al. 1992). Viable, self-sustaining populations are characterized as having a negligible chance of extinction over century time scales, are large enough to be sustained through historical environmental variation, are large enough to maintain genetic diversity, and maintain positive recruitment near carrying capacity. Establishment of functioning metapopulations (see next section) can fulfill several of these criteria, including stabilization of population dynamics (Wilcox and Murphy 1985, Hanski and Gilpin 1991), increasing range-wide genetic heterogeneity (Simberloff and Abele 1976), and decreasing probability of population losses through environmental and demographic stochasticity (Roff 1974, Wilcox and Murphy 1985).

Metapopulation Dynamics and Function

A metapopulation consists of a series of populations existing in discrete habitat patches linked by migration corridors. Although individual populations should be managed and protected, some degree of interconnectedness among populations (i.e., a metapopulation) is needed to maintain genetic exchange and stabilize population dynamics (Meffe 1986; Wilcox and Murphy 1985, Hanski and Gilpin 1991). Metapopulations stabilize local population dynamics by: 1) allowing genetic exchange among local populations and thereby increasing genetic heterogeneity (Simberloff and Abele 1976); 2) decreasing vulnerability of populations to losses through environmental and demographic stochasticity (Roff 1974, Wilcox and Murphy 1985); and 3) increasing resistance of populations to changes in deterministic variables (birth, survival and death rates; Connell and Sousa 1983; Rieman and McIntyre 1993). Metapopulation dynamics and persistence depend on species life history, connectivity between habitat patches, and the amount and rate of change in available habitat. A metapopulation may thrive as long as immigration (or recruitment) is greater than extinction (or mortality), the amount of habitat remains the same or increases, and populations remain connected. Metapopulations facilitate exchange of genetic material among populations. If migration is prevented over time, populations that were once connected can follow different evolutionary paths for adaptation to local environments. Migrating breeders within a metapopulation help slow or prevent inbreeding depression by maintaining genetic diversity and contributing genetic material not represented in local populations.

Metapopulations can stabilize populations throughout their range. Stream reaches depopulated following stochastic or anthropogenic events may re-populate from connecting, neighboring populations as long as sufficient migration corridors are maintained. However, diversions, dams, and dewatering within stream systems decrease the amount of connectivity between populations of aquatic species. Corridors require sufficient flows, at least during migration periods, and cannot exceed maximum migration distances. Diversions and dams eliminate connectivity by blocking fish migration routes. Dewatering a stream reach may also temporally reduce the amount of available habitat within a stream and, depending on life history, impact survival of the species in question. Potential management actions may include improving

and protecting migration corridors that provide connectivity between historically connected populations, moving fish beyond impassable barriers to simulate historical migration patterns, and improving, protecting, and expanding available flows and habitat. Metapopulation issues (together with conservation genetics) involving interstate waters should be addressed through coordination among the bordering states and with cooperative work between federal land management agencies and state agencies.

Conservation Genetics

Genetic issues vary throughout the range of the three species. Rather than identify issues here for each state, state conservation plans should contain their own prioritization conservation genetics issues among the three species. However, the general goals of range-wide conservation genetics should be to preserve available genetic diversity, including identifying and preserving genetically distinct populations as well as those providing redundancy of specific genetic material across the species' range. Genetically distinct populations should receive special management consideration. Effective conservation and management of the three fish species requires knowledge of the levels of genetic diversity that exist both within and among populations (Chambers and Bayless 1983; Hamrick 1983; Meffe 1986; Soulé 1986, Hallerman 2003). Small, fragmented populations are at greatest risk of genetic diversity loss due to increased frequency of rare, deleterious alleles *within* the population and consequent decreased ability to respond to environmental changes (Lande 1988). *Among* population variation indicates a historical lack of gene flow and subsequently the opportunity for local adaptation, although rapid outbreeding among such groups can cause reductions in relative fitness of offspring. Aquatic systems in the CRB and the Bonneville Basin have undergone large-scale anthropogenic changes in the last 150 years, including alteration of natural hydrology, temperature regime, sediment loads and community composition through introductions of exotic species. System fragmentation, species range contraction, and local declines in population size resulting from these changes can impact genetic diversity within and among populations. Protection of genetic diversity can be accomplished through protection of existing populations, maintenance or re-establishment of migration corridors, transplants of fish from other areas (augmenting existing populations or re-establishing lost populations), or other means.

A first step toward a conservation and management program is to identify genetically distinct populations or management units within individual state boundaries and among interstate waters. As the signatories to this Strategy assess the status of the three species, genetic diversity of the populations should be evaluated, including review of available data and literature on genetic structuring and identification of necessary morphologic and molecular data needed to make management decisions regarding the species' biological requirements. Genetic (and probably metapopulation-related) issues involving interstate waters should be addressed as such, and coordination among the bordering states is necessary to resolve these issues.

No single approach is best to determine the levels of differentiation within and among populations and it is best to incorporate a variety of different kinds of information for each population. For example, geographic, molecular and morphological or meristic data can all provide important quantitative information on population differences (Chambers 1980; Vrijenhoek et al. 1985; Meffe 1986). Conservation and management actions for divergent populations of the three species may be based on the results of these analyses in conjunction with other fish population assessment tools, such as population estimates, population viability analysis, life history information, distributions, and habitat analysis. From a genetic perspective, identification and designation of populations may include 1) analysis of nuclear DNA markers, 2) mitochondrial DNA analysis, and 3) meristic and morphologic traits. The signatories will work together as appropriate to ensure that genetic techniques and tools can be used during range-wide assessments.

The signatories will review available peer-reviewed and gray literature sources for data regarding genetic structuring of the three species. In the absence of information to the contrary, populations from neighboring hydrologic units (taken from the U.S.G.S. Hydrologic Unit Code, or HUCs) will be assumed more similar to each other and more distinct from populations of the same species distributed farther away. Populations within the same HUC are presumably more similar to each other than to populations of the same species from neighboring HUCs. These assumptions and any relevant management recommendations will be evaluated as additional data become available. Additional data can be used to help identify the most genetically unique populations as well as those HUCs where the greatest diversity among populations of one or

more of the three species is distributed. Unless data to the contrary are developed, populations with greater proportions of heterozygotes will be designated more diverse and resilient to environmental change than those of greater proportions of homozygotes (Reed and Frankham 2003, Hallerman 2003).

Hybrids

Fitness is defined herein as a species' ability to thrive and reproduce in its environment and respond to environmental change. While the ability to respond to environmental change is often impossible to predict, geneticists generally agree that genetically diverse populations exhibit high degrees of fitness. Conversely, populations with less diversity are less fit as they have fewer alleles that may be expressed in response to changing environmental conditions (Reed and Frankham 2003). There are examples of detrimental hybridization whereby fitness of either species does not increase or decline. In fishes, high fecundity and external fertilization increase the probability of hybridization, which may have given rise to some of the species we recognize today. The ability to hybridize does not always lead to the loss of one or more species. Persistent, long-term hybridization among species has been documented between flannelmouth suckers and razorback suckers (Buth et al. 1987). The observation that many of the various *Gila* species native to the CRB share alleles suggests ongoing hybridization between roundtail chub and other chubs (DeMarais et al. 1992, Dowling and DeMarais 1993). By incorporating additional non-deleterious alleles, hybridization may confer additional fitness or increased ability to respond to environmental stressors. As available habitat has been reduced from historic times, especially due to impoundment and reduced flows, the likelihood of hybridization among closely related species has increased.

There are two documents which could potentially affect the states' conservation and management actions regarding populations comprised partly by hybrids: 1) The Proposed Policy on the Treatment of Intercrosses and Intercross Progeny (Intercross Policy; 61 FR 4709); and 2) The Policy Regarding the Recognition of Distinct Population Segments Under the Endangered Species Act (DPS Policy; 61 FR 4722). Under the non-binding Intercross Policy, the FWS has responsibility for conserving hybrids under ESA (intercrosses) if 1) offspring share traits that characterize the taxon of the listed parent, and 2) offspring more closely resembles the listed

parent's taxon than an entity intermediate between it and the other known or suspected non-listed parental stock. The Intercross Policy proposes the use of the term "intercross" to represent crosses between individuals of varying taxonomic status (species, subspecies, and distinct population segments). Under this proposed policy, populations can contain individuals that represent the protected species and intercrosses between the protected species and another.

While the intercross policy has not been formally adopted, the FWS has scientifically developed intercross policy concepts in completing their 12-month finding for westslope cutthroat trout (WCT; FWS 2003a). They justified inclusion of hybridized fish in their assessment of WCT if such fish conformed morphologically to published taxonomic descriptions. While such fish may have a genetic ancestry derived by up to 20% from other fish species, the FWS concluded that they also possessed the same behavioral and ecological characteristics of genetically pure fish. They stress, however, that additional criteria should be evaluated, including whether the individual is hybridized with a native or introduced fish and the geographic extent of hybridization. Similar to portions of the FWS testimony, Peacock and Kirchoff (2004) recommended that hybridization policies be flexible enough to allow for conservation of hybridized fish, if in fact genetically pure populations are rare. These concepts could have significant influence in the interpretation of genetic and biological data on roundtail chub, which are suspected to hybridize with endangered *Gila* species (*G. elegans, G. cypha*) in certain regions of the CRB.

The DPS Policy requires the FWS to consider three elements in decisions regarding the status of a possible DPS: 1) discreteness of the population segment in relation to the remainder of the species to which it belongs; 2) the significance of the population segment to the species to which it belongs, and 3) the population segment's conservation status in relation to ESA standards for listing. The policy recognizes the importance of unique management units to the conservation of the species and that management priorities can vary across a species' range according to the importance of those population segments. Taken together, the Intercross and DPS policies require that conservation actions for the species be completed by compiling standardized information for each population such that the influence of hybridization and other unique characteristics of the population segments can be identified (Lenstch et al. 2000).

Signatories should review the literature available on hybridization and adequacy of existing data to characterize the degree of hybridization and its impact on fitness among the three species. If additional data are required, additional research on this subject should be conducted. Additional research may characterize genetic structure of the populations, quantify the degree of hybridization, and evaluate whether hybridization appears to be decreasing, maintaining or increasing fitness. If hybridization (whether with nonnative or native species) is decreasing fitness, then management actions to reduce deleterious hybridization may be implemented.

XV. STATUS ASSESSMENT OF ROUNDTAIL CHUB, BLUEHEAD SUCKER, AND FLANNELMOUTH SUCKER

Distribution

The roundtail chub, bluehead sucker, and flannelmouth sucker are three of the least-studied fishes native to the CRB and the Bonneville Basin. Available literature suggests that the three species were common to all parts of the CRB until the 1960s (Sigler and Miller 1963, Jordan and Evermann 1869, Minckley 1973). There have been no range-wide distribution or status assessments for any of these three species preceding the current review of Bezzerides and Bestgen (2002), which concludes that distributions of all three fish species have contracted 50%, on average, from their historic distributions.

Roundtail chubs are found in Wyoming in tributaries to the Green River and in several lakes in the upper portion of the basin. Extant, but declining roundtail chub populations in Utah occur in the Escalante and San Rafael rivers; portions of the middle and upper San Juan River and some tributaries; the Colorado River from Moab to Silt, Colorado; the Fremont River; the Green River from the Colorado River confluence upstream to Sand Wash and from Jensen to Echo Park; the White River from the Green River confluence upstream to near Meeker, Colorado (Bezzerides and Bestgen 2002); and the Duchesne River from the Green River confluence upstream to Myton (Brunson 2001). Roundtail chub presently occur in the lower Colorado River basin in Arizona and New Mexico, in tributaries of the Little Colorado River and Bill Williams River, and in the Gila River and tributaries (Voeltz 2002). Lee et al. (1980) also recorded occurrences in northern Mexico, which was anecdotally confirmed by personal communications

in 2001 with S. Contreras-Balderas (Bioconservacíon A.C., Monterrey, Nuevo Leon) and A. Varela-Romero (Universidad de Sonora, Hermosillo). Fishes formerly considered roundtail chub outside the Colorado River basin in Mexico are now considered a different species, *Gila minacae* (S. Norris, California State University Channel Islands, personal communication 2004).

Although little information exists on distribution of bluehead sucker (but see McAda 1977, Holden and Minckley 1980, and McAda and Wydoski 1983), they historically occurred in large rivers and tributaries in the CRB (including the Colorado, Green, and San Juan river sub-basins), the Bonneville Basin in Utah, the Snake River Basin in Idaho, Nevada, and Utah (Lee et al. 1980; Ryden 2001), and the Little Colorado River Basin in Arizona and New Mexico (Minckley 1973). Bluehead sucker are found in portions of the Bonneville and Snake River Basins in Wyoming (Baxter and Stone 1995) as well mainstem habitats and several tributaries to the Colorado and Green rivers.

Bluehead sucker populations occur in the Escalante, Dirty Devil, and Fremont rivers (Colorado River tributaries) and in the San Rafael, Price, and Duchesne rivers (Green River tributaries); in the Weber and upper Bear River drainages; in the mainstem Green River from the Colorado River confluence upstream to Lodore, Colorado; in the White River from the Green River confluence upstream to near Meeker, Colorado; in the Yampa River from the Green River confluence upstream to Craig, Colorado; in the San Juan River, Utah, New Mexico and Colorado; in the Colorado River from Lake Powell upstream to Kremmling, Colorado; in the Dirty Devil River in Utah; and in the Dolores River from the Colorado River confluence upstream to McPhee Reservoir, Colorado (Holden and Stalnaker 1974; Sigler and Sigler 1996; Bezzerides and Bestgen 2002). Bluehead sucker also occur in the following tributaries to the Colorado River in Grand Canyon: Bright Angel Creek, Little Colorado River (including headwater tributaries Nutrioso Creek, East, West, and South Fork of the Little Colorado River, East Clear Creek, and Chevelon Creek), Clear Creek, Shinumo Creek, Kanab Creek, and Havasu Creek.

Flannelmouth sucker occur above Flaming Gorge Reservoir in the Green River and its tributaries as well as in some naturally occurring lakes in this drainage. Flannelmouth sucker are

currently found in the Escalante and Fremont rivers (Colorado River tributaries), the San Rafael, Price and Duchesne rivers (Green River tributaries); the mainstem San Juan River and tributaries; the Colorado River from Lake Powell upstream to near Glenwood Springs, Colorado; the Gunnison River in Colorado; the Dolores River; the Green River from the Colorado River confluence upstream to Flaming Gorge Reservoir; in the Dirty Devil River in Utah; and the Yampa and White rivers upstream from their confluences with the Green River. Populations of flannelmouth sucker also exist in the main channel Colorado River below Glen Canyon Dam and in the Virgin River. Flannelmouth sucker also occur in the following Grand Canyon tributaries during portions of their life cycle: Paria River, Bright Angel Creek, Kanab Creek, Shinumo Creek, Havasu Creek and the Little Colorado River including Nutrioso Creek and possibly other headwater tributaries (Little Colorado sucker may or may not be genetically distinct from flannelmouth sucker). Flannelmouth sucker are also common below Davis Dam (Mueller and Wydoski 2004) on the lower Colorado River. Although flannelmouth sucker populations usually do not persist in impoundments (Sigler and Sigler 1996; Bezzerides and Bestgen 2002), individuals were recently documented in Lake Havasu and Lake Mead, Lower Colorado River (Mueller and Wydoski 2004, Arizona Game and Fish Department, unpublished).

Status

Available information indicates that roundtail chubs now occupy approximately 45% of their historical range in the CRB. In the upper CRB (New Mexico, Colorado, Utah, and Wyoming), it has been extirpated from approximately 45% of their historical range, including the Price River (Cavalli 1999) and portions of the San Juan River, Gunnison River, and Green River (Bezzerides and Bestgen 2002). Data on smaller tributary systems are largely unavailable, and population abundance estimates are available only for short, isolated river reaches (Bezzerides and Bestgen 2002). In the lower CRB, current estimates of roundtail chub distribution are as low as 18% of their former range (Voeltz 2002). A petition to list the lower Colorado River Basin roundtail chub under the ESA was filed in April 2003 and the finding from the Fish and Wildlife Service is expected in 2006. Roundtail chub are listed as a species of concern by the states of Arizona, Utah, Wyoming, and Colorado. The state of New Mexico lists roundtail chub as endangered.

Bluehead suckers presently occupy approximately 50% of their historically occupied range in the CRB. In the upper CRB (Utah, Wyoming, Colorado and New Mexico), bluehead suckers currently occupy approximately 45% of their historical habitat. Recent declines of bluehead suckers have occurred in the White River below Taylor Draw Dam (Utah and Colorado) and in the upper Green River (Holden and Stalnaker 1975; Bezzerides and Bestgen 2002). Bluehead sucker have been extirpated in the Gunnison River, Colorado above the Aspinall Unit Reservoirs (Wiltzius 1978). Bluehead sucker were documented in the Escalante River during the mid to late 1970's, but were absent from samples collected in recent years (Mueller et al. 1998). Bluehead sucker are listed as a species of concern by the states of Utah and Wyoming. In Wyoming, hybridization with white sucker appears to be compromising the genetic purity of several populations of bluehead sucker.

Recent investigation of historical accounts, museum specimens, and comparison with recent observations suggests that flannelmouth suckers occupy approximately 50% of their historic range in the upper CRB (Utah, Wyoming, Colorado, and New Mexico; Bezzerides and Bestgen 2002). Their relative abundance in the Green River tributaries is not well known. Populations have declined since the 1960's due to impoundment in the mainstem Green River in Wyoming (Flaming Gorge, Fontenelle Reservoir) and in the Colorado River in Glen Canyon, Utah (Lake Powell). Flannelmouth sucker are listed as species of concern by the states of Arizona, Utah, Colorado, and Wyoming.

XVI. RANGE-WIDE CONSERVATION OF ROUNDTAIL CHUB, BLUEHEAD SUCKER, AND FLANNELMOUTH SUCKER

Goal

The goal of this strategy is to outline measures that the states can implement and expand upon to ensure the persistence of roundtail chub, bluehead sucker, and flannelmouth sucker populations throughout their ranges as specified in the Conservation Agreement, and to provide guidance in the development of individual state conservation plans. The range-wide strategy will be reviewed by the signatories every five years to ensure the incorporation of new adaptive management strategies or to alter portions of the strategy to better-fit existing conditions.

Objectives

The individual state signatories to the Conservation Agreement for the three species (signatories) will develop conservation and management plans for any or all of the three species that occur naturally within their states. Any future signatories may also choose to develop individual conservation and management plans or to integrate their efforts with existing plans. The individual signatories agree to develop information and conduct actions to support the following objectives:

- Establish and/or maintain roundtail chub, flannelmouth sucker and bluehead sucker populations sufficient to ensure persistence of each species within their ranges.
    1) Establish measureable criteria to evaluate the number of populations necessary to maintain the three species throughout their respective ranges.
    2) Establish measureable criteria to evaluate the number of individuals necessary within each population to maintain the three species throughout their respective ranges.
- Establish and/or maintain sufficient connectivity between populations so that viable metapopulations are established and/or maintained.
- As feasible, identify, significantly reduce and/or eliminate threats to the persistence of roundtail chub, bluehead sucker, and flannelmouth sucker that: 1) may warrant or maintain their listing as a sensitive species by state and federal agencies, and 2) may warrant their listing as a threatened or endangered species under the ESA.

XVII. CONSERVATION ACTIONS AND ADAPTIVE MANAGEMENT

The signatories will review and document existing and ongoing programmatic actions that benefit the three species. Signatories will identify information gaps regarding species distribution, status, and life history requirements, and develop research and analysis programs to fill those gaps. Through coordination with other states, the signatories to the Conservation Agreement will develop and implement conservation and management plans for each state. The

signatories agree that the goals and objectives are appropriate across the respective ranges of the three species, though they acknowledge that as more information is gathered, the objectives may change with a consensus of the signatories to better allow for implementation of the Agreement according to the new information. Signatories also agree to incorporate the preceding conservation actions into their conservation and management plans as applicable, though each management plan should also incorporate the ability to adapt to new information and to incorporate new information where necessary. As signatories develop their individual management plans for conservation of the three species, each signatory may include but is not limited or obligated to incorporate the following conservation actions within their plans:

1) Conduct status assessment of roundtail chub, bluehead sucker, and flannelmouth sucker.
    - Identify concurrent programs that benefit the three fish species. Monitor and summarize activities and progress.
    - Establish current information regarding species distribution, status, and habitat conditions as the baseline from which to measure change.
    - Identify threats to population persistence.
    - Locate populations of the subject species to determine status of each.
2) Establish and maintain a database of past, present, and future information on roundtail chub, bluehead sucker, and flannelmouth sucker.
    - Establish format and maintain compatible databases. Signatories have identified the need to maintain a range-wide database as the primary means to conduct a range-wide assessment.
    - Establish and maintain bibliography of subject species.
3) Determine roundtail chub, bluehead sucker, and flannelmouth sucker population demographics, life history, habitat requirements, and conservation needs.

- Determine current population sizes of subject species and/or utilize auxiliary catch and effort data to identify trends in relative abundance.
- Identify subject species habitat requirements and current habitat conditions through surveys and studies of hydrological, biological and watershed features.
- Determine if existing flow recommendations and regimes are adequate for all life stages of the subject species. Develop appropriate flow recommendations for areas where existing flow regimes are inadequate.
- Where additional data is needed to determine appropriate management actions, conduct appropriate, focused research and apply results.

4) Genetically and morphologically characterize populations of roundtail chub, bluehead sucker, and flannelmouth sucker.

- Determine if known information is adequate to answer management questions related to conservation genetics and assess need for additional genetic characterization of subject species.
- Apply new information to management strategies.
- Review the literature available on hybridization and adequacy of existing data to characterize the degrees of threats to conservation of the three species posed by hybridization.
- Develop genetic management plans for all three species that outline maintenance of species at the population level and discuss application to reestablishment efforts.

5) Increase roundtail chub, bluehead sucker, and flannelmouth sucker populations to accelerate progress toward attaining population objectives for respective species.

- Assure regulatory protection for three species is adequate within the signatory states.

6) Enhance and maintain habitat for roundtail chub, bluehead sucker, and flannelmouth sucker.

- Enhance and/or restore connectedness and opportunities for migration of the subject species to disjunct populations where possible.
- Restore altered channel and habitat features to conditions suitable for the three species.
- Provide flows needed for all life stages of the subject species.
- Maintain and evaluate fish habitat improvements throughout the range.
- Install regulatory mechanisms for the long-term protection of habitat (e.g., conservation easements, water rights, etc.).

7) Control (as feasible and where possible) threats posed by nonnative species that compete with, prey upon, or hybridize with roundtail chub, bluehead sucker, and flannelmouth sucker.

- Determine where detrimental actions occur between the subject species and sympatric nonnative species.
- Control detrimental nonnative fish where necessary and feasible.
- Evaluate effectiveness of nonnative control efforts.
- Develop multi-state nonnative stocking procedure agreements that protect all three species and potential reestablishment sites.

8) Expand roundtail chub, bluehead sucker, and flannelmouth sucker population distributions through transplant, augmentation (i.e., use of artificially propagated stock), or reintroduction activities as warranted using a genetically based augmentation/reestablishment plan.

9) Establish and implement qualitative and quantitative long-term population and habitat monitoring programs for roundtail chub, bluehead sucker, and flannelmouth sucker.

- Develop and implement monitoring plan for the subject species.
- Evaluate conditions of populations using baseline data.
- Develop and implement habitat monitoring plan for the subject species.
- Evaluate habitat conditions using baseline data.

10) Implement an outreach program (e.g., development of partnerships, information and education activities) regarding conservation and management of roundtail chub, bluehead sucker, and flannelmouth sucker.

LITERATURE CITED

Allen, E.J., J.M. Harris, and L.J.S. Allen. 1992. Persistence-time models for use in viability analyses of vanishing species. Journal of Theoretical Biology 155:33-53.

Anderson, R.M., and G. Stewart. 2003. Riverine fish flow investigations. Biologically based instream flow recommendations for the Yampa River, the Colorado River in the 15-mile reach, and the Dolores River. Final Report to CDOW, Federal Aid project F-289-R6. Fort Collins, CO.

Andreason, J.K. 1973. Reproductive life history of *Catostomus ardens* and *Catostomus discobolus* in the Weber River, Utah. M.S. Thesis, Department of Zoology, Brigham Young University.

Baird, S.F., and C. Girard. 1853a. Descriptions of new species of fishes collected by Mr. John H. Clark, on the U.S. and Mexican Boundary Survey, under Lt. Col. Jas. D. Graham. Proceedings of the Academy of Natural Sciences of Philadelphia, 4:387-390.

Baxter, G.T., and M.D. Stone. 1995. Fishes of Wyoming. Wyoming Game and Fish Department, Cheyenne.

Behnke, R.J. 1980. The impacts of habitat alterations on the endangered and threatened fishes of the Upper Colorado River Basin. Pages 204-216, *In*: Energy Development in the Southwest, Volume 2. Walter O. Spofford, Jr., Alfred L. Parker, and Allen V. Kneese, editors. Resources for the Future, Inc. Baltimore, Maryland.

Bestgen, K.R. 2000. Personal communication with Director of Colorado State University's Larval Fish Lab, Fort Collins, Colorado.

Bestgen, K.R., and D.L. Propst. 1989. Distribution, status, and notes on the ecology of *Gila robusta* (Cyprinidae) in the Gila River drainage, New Mexico. The Southwestern Naturalist, 34(3):402-412.

Bezzerides, N., and K.R. Bestgen. 2002. Draft Final Report: Status Review of Roundtail Chub *Gila robusta*, Flannelmouth Sucker *Catostomus latipinnis*, and Bluehead Sucker *Catostomus discobolus* in the Colorado River Basin. Submitted to U.S. Department of the Interior, Bureau of Reclamation, Salt Lake City, Utah. Larval Fish Laboratory Contribution 118, Colorado State University, Ft. Collins.

Brouder, M.J., D.D. Rogers, and L.D. Avenetti. 2000. Life history and ecology of the roundtail chub *(Gila robusta)* from two streams in the Verde River Basin. Technical Guidance Bulletin No. 3 – July 2000. Arizona Game and Fish Department Research Branch, Federal Aid in Sportfish Restoration Project F-14-R, Phoenix.

Brunson, R. E. 2001. Early life-stage and fish community investigations in the Duchesne River 1997 – 1999. Draft report for the Upper Colorado River Recovery Program. Utah Division of Wildlife Resources, Vernal.

Brunson, R. and K. Christopherson. 2001. Development of a northern pike control program in the Middle Green River. Annual Report to Upper Colorado River Recovery Implementation Program. Utah Division of Wildlife Resources, Vernal.

Buth, D.G., R.W. Murphy, and L. Ulmer. 1987. Population differentiation and introgressive hybridization of the flannelmouth sucker and of hatchery and native stocks of the razorback sucker. Transactions of the American Fisheries Society 116:103-110.

Carlson, C.A., and R.T. Muth. 1989. Colorado River: lifeline of the American southwest. Pages 220-239 *In*: Proceedings of the international large rivers symposium. D. P. Dodge, editor. Special Publication 106. Canadian Fisheries Aquatic Sciences, Ottawa, Ontario, Canada.

Cavalli, P.A. 1999. Fish community investigations in the Lower Price River, 1996-1997. Final Report to the Recovery Implementation Program for the Endangers Fish Species in the Upper Colorado River Basin. Project No. 78. Utah Division of Wildlife Resources, Salt Lake City, Utah.

Chambers, S.M. 1980. Genetic divergence between populations of *Goniobasis* (Pleiroceridae) occupying different drainage systems. Malacologia 20:63-81.

Chambers, S.M., and J.W. Bayless. 1983. Systematics, conservation and the measurement of genetic diversity. Pages 349-363 in: C.M. Schonewald-Cox et al., eds., Genetics and Conservation. Benjamin/Cummings Publishing Co., Menlo Park, CA.

Chart, T.E. 1987. The initial effect of impoundment on the fish community of the White River, Colorado. Master's thesis, Colorado State University, Ft. Collins, Colorado.

Chart, T.E. and E.P. Bergersen. 1992. Impact of mainstream impoundment on the distribution and movements of the resident flannelmouth sucker (Catostomidae: *Catostomus latipinnis*) population in the White River, Colorado. Southwestern Naturalist, 37:9-15.

Chart, T.E., and L. Lenstch. 1999. Flow effects on humpback chub (Gila cypha) in Westwater Canyon. Project Aspinall-46. Utah Division of Wildlife Resources, Salt Lake City, UT.

Childs, M.R., R.W. Clarkson, and A.T. Robinson. 1998. Resource use by larval and early juvenile native fishes in the Little Colorado River, Grand Canyon, Arizona. Transactions of the American Fisheries Society 127:620-629.

Coburn, M.M. and T.M. Cavender. 1992. Interrelationships of North American Cyprinid Fishes, *in* R.L. Mayden (ed.). Systematics, Historical Ecology, and North American Freshwater Fishes. Stanford University Press, Stanford, California.

Connell, J.H. and W.P. Sousa. 1983. On the evidence needed to judge ecological stability or persistence. The American Naturalist 121(6):789-823.

Cope, E.D. 1872. Recent reptiles and fishes. Report on the reptiles and fishes obtained by the naturalists of the expedition. Pages 432-443 *In*: Part IV: Special Reports, in: Preliminary report of the U.S. Geological Survey of Wyoming and portions of contiguous territories, by F. V. Hayden.

DeMarais, B.D., T.E. Dowling, M.E. Douglas, W.L. Minckley and P.C. Marsh. 1992. Origin of Gila seminude (Teleostei: Cyprinidae) through introgressive hybridization: implications for evolution and conservation. Proceedings of the National Academy of Sciences, USA 89:2747-2751.

Douglas, M.R. and M.E. Douglas. 2003. Yampa River hybrid sucker genetic assessment. Department of Fishery and Wildlife Biology, Colorado State University, Fort Collins, CO.

Douglas, M.E., and P.C. Marsh. 1998. Population and survival estimates of *Catostomus latipinnis* in Northern Grand Canyon, with distribution and abundance of hybrids with *Xyrauchen texanus*. Copeia, 1998(4):915-925.

Dowling, T.E. and B.D. DeMarais. 1993. Evolutionary significance of introgressive hybridization in cyprinid fishes. Nature 362:444-446.

Evermann, B.W., and C. Rutter. 1895. The fishes of the Colorado Basin. U.S. Fish Commission Bulletin, 14:473-486.

Franklin, R. (ed.). 1983. Heterosis: reappraisal of theory and practice. Springer-Verlag, Berlin.

Hallerman, E.M. 2003. Population Viability Analysis. Pages 403-417 in E.M. Hallerman, ed. Population genetics: Principles and Applications for Fisheries Scientists. American Fisheries Society, Bethesda, Maryland.

Hamrick, J.L. 1983. The distribution of genetic variation within and among natural plant populations. Pages 335-348 in: C.M. Schonewald-Cox et al., eds., Genetics and Conservation. Benjamin/Cummings Publishing Co., Menlo Park, CA.Hanski, I. And M.E. Gilpin. 1991. Metapopulation dynamics: brief history and conceptual domain. Biological Journal of the Linnaean Society 42:3-16.

Hawkins, J.A. and T.P. Nesler. 1991. Nonnative fishes of the Upper Colorado River Basin: an issue paper. Final Report. Larval Fish Laboratory, Colorado State University, Fort Collins, CO.

Holden, P.B. 1973. Distribution, abundance and life history of the fishes in the upper Colorado River Basin. A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Wildlife Science (Ecology). Utah State University, Logan, Utah.

Holden, P.B. and Clair B. Stalnaker. 1975. Distribution and abundance of mainstream fishes of the middle and upper Colorado River basins, 1967-1973. Transactions of the American Fisheries Society 104(2):217-231.

Holden, P.B., and W.L. Minckley. 1980. *Catostomus discobolus* Cope, bluehead sucker. *In*: Atlas of North American Freshwater Fishes. D.S. Lee, C.R. Gilbert. C.H. Hocutt, R.E. Jenkins, D.E. McAllister, and J.R. Stauffer, Jr. (eds.). 1981. North Carolina State Museum of Natural History.

Holden, P.B., S.J. Zucker, P.D. Abate, and R.A. Valdez. 1996. Assessment of the effects of fish stocking in the state of Utah: past, present and future. Bio/West, Inc., Logan, UT.

Hubbs, C.L., and R.R. Miller. 1948. The zoological evidence, *in*: The Great Basin with Emphasis on Glacial and Postglacial Times. University of Utah Biological Series X(7), Salt Lake City.

Hubbs, C.L., R.R. Miller, and L.C. Hubbs. 1974. Hydrographic History and Relict Fishes of the North-Central Great Basin. Memoirs of the California Academy of Sciences VII, San Francisco.

Jackson, J.A. 2001. Evaluation of Stocked Larval Colorado Pikeminnow into the San Juan River: 2000. Utah Division of Wildlife Resources, Moab Field Station, Moab, Utah.

Jordan, D.S., and B.W. Evermann. 1896. The fishes of North and Middle America: a descriptive catalogue of the species of fish-like vertebrates found in the waters of North America, north of the isthmus of Panama. Part 1. Bulletin of the United States National Museum. No. 47. Government Printing Office, Washington, D.C.

Kaeding, L.R., B.D. Burdick, P.A. Schrader, and C.W. McAda. 1990. Temporal and spatial relations between the spawning of humpback chub and roundtail chub in the upper Colorado River. Transactions of the American Fisheries Society. 119:135-144.

Lande, R. 1988. Genetics and demography in biological conservation. Science (241):1455-1460.

Lee, D.S., C.R. Gilbert, C.H. Hocutt, R.E. Jenkins, D.E. McAllister, J.R. Stauffer, Fr. 1980, et seq. Atlas of North American Freshwater Fishes. North Carolina Biological Survey Publication #1980-12. North Carolina State Museum of Natural History, Raleigh.

Lentsch, L.D., M.J. Perkins, and H. Maddux. 1995. Virgin Spinedace Conservation Agreement and Strategy. Publication 95-13, Utah Division of Wildlife Resources, Salt Lake City, UT.

Lenstch, L.D., R.T. Muth, P.D. Thompson, B.G. Hoskins and T.A. Crowl. 1996. Options for selective control of nonnative fishes in the Upper Colorado River Basin. Final report publication number 96-14, Utah Division of Wildlife Resources, Salt Lake City, UT.

Lenstch, L.D., C.A. Toline, J. Kershner, J.M. Hudson, and J. Mizzi. 2000. Range-wide conservation agreement and strategy for Bonneville cutthroat trout (Oncorhyncus clarki utah). Publication 00-19, Utah Division of Wildlife Resources, Salt Lake City, UT.

Lenstch, L.D., M.J. Perkins, H. Maddux and T.C. Hogrefe. 2002. Virgin Spinedace Conservation Strategy. Publication 02-22, Utah Division of Wildlife Resources, Salt lake City, UT.

Maddux, H.R., J.A. Mizzi, S.J. Werdon, and L.A. Fitzpatrick. 1995. Overview of the proposed critical habitat for the endangered and threatened fishes of the Virgin River Basin. Department of the Interior, U.S. Fish and Wildlife Service, Salt Lake City, Utah.

Martinez, P.J., and N.P. Nibbelink. In review. Colorado nonnative fish stocking regulation evaluation. Colorado Division of Wildlife Resources, Grand Junction, CO.

McAda, C.W. 1977. Aspects of the life history of three Catostomids native to the Upper Colorado River Basin. Master's thesis, Utah State University, Logan, Utah.

McAda, C.W. and R.S. Wydoski. 1983. Maturity and fecundity of the bluehead sucker, *Catostomus discobolus* (Catostomidae), in the Upper Colorado River Basin, 1975-76. The Southwestern Naturalist, 28(1):120-123.

McAda, C.W. 2003. Flow recommendations to benefit endangered fishes in the Colorado and Gunnison rivers. Project 54, Upper Colorado River Endangered Fish Recovery Program. U.S. Fish and Wildlife Service, Grand Junction, CO.

McElroy, D.M. and M.E. Douglas. 1995. Patterns of morphological variation among endangered populations of *Gila robusta* and *Gila cypha* (Teleostei: Cyprinidae) in the Upper Colorado River basin. Copeia 1995(3): 636-649.McKinney, T., S.R. Rogers, and W.R. Persons. 1999. "Ecology of flannelmouth sucker in the Lee's Ferry tailwater, Colorado River, Arizona. Great Basin Naturalist 59:259-265.

Meffe, G.K., 1996. Conservation genetics and the management of endangered fishes. Fisheries 11(1): 14-23.

Miller, R.R. 1959. Origin and affinities of the Freshwater Fish Fauna of Western North America. Pages 187-222, *In*: Zoogeography. C. L. Hubbs, editor. American Association for the Advancement of Science Publication 51.

Minckley, W.L. 1973. Fishes of Arizona. Arizona Game and Fish Department, Sims Printing Company, Inc., Phoenix, Arizona.

Minckley, W.L. 1991. Native fishes of the Grand Canyon: an obituary? Pages 124-177, *In*: Colorado River Ecology and Dam Management, Proceedings of a Symposium May 24-25, 1990, Santa Fe, New Mexico. National Academy Press, Washington, D.C.

Minckley, W.L., Dean A. Henderson, and Carl E. Bond. 1986. Geography of western North American freshwater fishes: description and relationships to intracontinental tectonism. Pages 519-613, *In*: The Zoogeography of North American Freshwater Fishes. Charles H. Hocutt and E. O. Wiley, editors. John Wiley and Sons, New York.

Minckley, W.L. and B.D. DeMarais. 2000. Taxonomy of chubs (Teleostei, Cyprinidae, Genus *Gila*) in the American Southwest with comments on conservation. Copeia 2000(1):251-256.

Minckley, W.L., P.C. Marsh, J.E. Deacon, T.E. Dowling, P.W. Hedrick, W.J. Matthews, and G. Mueller. 2003. A Conservation Plan for Native Fishes of the Lower Colorado River. BioScience 53(3): 219-234.

Molles, M. 1980. The impacts of habitat alterations and introduced species on the native fishes of the Upper Colorado River Basin. Pages 163-181, *In:* Energy Development in the Southwest, Volume 2. Walter O. Spofford, Jr., Alfred L. Parker, and Allen V. Kneese, editors. Resources for the Future, Inc. Baltimore, Maryland.

Mueller, G., L. Boobar, R. Wydoski, K. Comella, and Q. Bradwisch. 1998. Aquatic survey of the Lower Escalante River, Glen Canyon National Recreation Area, Utah, June 22-26, 1998. Preliminary report of the National Park Service and the Utah Division of Wildlife Resources.

Mueller, G.L., and R. Wydoski. 2004. Reintroduction of the Flannelmouth Sucker in the Lower Colorado River. North American Journal of Fisheries Management 24(1): 41–46.

Muth, R.T., and seven others. 2000. Flow and temperature recommendations for endangered fishes in the Green River downstream of Flaming Gorge Dam. Final report, Upper Colorado River Endangered Fish Recovery Program. Lakewood, CO.

Ono, R.D., J.D. Williams, and A.Wagner. 1983. Vanishing fishes of North America. Stone Wall Press, Inc. Washington, D.C.

Osmundson, D.B. 1999. Longitudinal variation in fish community structure and water temperature in the Upper Colorado River: implications for Colorado pikeminnow habitat suitability. Final Report for Recovery Implementation Program, Project No. 48. U.S. Fish and Wildlife Service, Grand Junction, Colorado.

Peacock, M.M., and V. Kirchoff. 2004. Assessing the conservation value of hybridized cutthroat trout populations in the Quinn River drainage, Nevada. Transactions of the American Fisheries Society 133:309-325.

Reed. D.H. and R. Frankham. 2003. Correlation between fitness and genetic diversity. Conservation Biology 17(1) :230-237.

Rieman, B.E., and J.D. McIntyre. 1993. Demographic and habitat requirements for conservation of bull trout. USDA Forest Service, Intermountain Research Station, Ogden, Utah. General Technical Report INT-302.

Robinson, A.T., R.W. Clarkson, and R.E. Forrest. 1998. Dispersal of larval fishes in a regulated river tributary. Transactions of the American Fisheries Society 127 :772-786.

Roff, D.A. 1974. The analysis of a population model demonstrating the importance of dispersal in a heterogeneous environment. Oecologia 15 :259-275.

Ryden, D.W. 2001. Long term results of sub-adult and adult large-bodied fishes in the San Juan River in 2000. U.S. Fish and Wildlife Services, Colorado River Fishery Project, Grand Junction, Colorado.

San Juan Recovery Implementation Program. 1995. Program Document, Cooperative Agreement, Long Range Plans, and Side-by-Side Analysis: San Juan/Upper Colorado Programs. U.S. Fish and Wildlife Service, Albuquerque, NM.

Scoppettone, G.G. 1988. Growth and longevity of the Cui-ui and longevity of other Catostomids and Cyprinids in western North America. Transactions of the American Fisheries Society, 117:301-307.

Shaffer, M.L. 1987. Minimum viable populations: coping with uncertainty. Pages 69-86 in: Soulé, M.E., (ed.). Viable populations for conservation. Cambridge University Press, Cambridge, Massachusetts.

Siebert, D.J. 1980. Movements of fishes in Aravaipa Creek, Arizona. M.S. Thesis, Arizona State University, Tempe.

Sigler, W.F. and R.R. Miller. 1963. Fishes of Utah. Utah State Department of Fish and Game, Salt Lake City, Utah.

Sigler, W.F. and J.W. Sigler. 1996. Fishes of Utah: A Natural History. University of Utah Press, Salt Lake City.

Simberloff, D. and L.G. Abele. 1976. Refuge design and island biogeographic theory: effects of fragmentation. The American Naturalist 120(1)41-50.

Stearns, S.C. 1993. The evolution of life histories. Oxford University Press, New York. 249p.

Soulé, M.E. (ed.). 1980. Threshold for survival: maintaining fitness and evolutionary potential. Pages 151-170 in: Soulé, M.E. and B.A. Wilcox, eds., Conservation biology: an evolutionary-ecological approach. Sinauer Associates, Massachusetts.

Soulé, M.E. (ed.). 1986. Conservation Biology: the Science of Scarcity and Diversity. Sinauer Associates, Massachusetts.

SWCA, Inc., Environmental Consultants. 2002. Nonnative fish control feasibility study to benefit June sucker in Utah Lake. SWCA, Inc., Environmental Consultants, Salt Lake City, UT.

Suttkus, R.D. and G.H. Clemmer. 1977. The humpback chub, Gila cypha, in the Grand Canyon area of the Colorado River. Occasional Papers of the Tulane University Museum of Natural History 1:1-30

Trammell, M.E., and seven others. 1999. Flaming Gorge studies: Assessment of Colorado pikeminnow nursery habitat in the Green River. Project 33, Upper Colorado River Endangered Fish Recovery Program. Utah Division of Wildlife Resources, Salt Lake City, UT.

Taylor, J.N., W.R. Courtenay, Jr., and J.A. McMann. 1984. Known impacts of exotic fish introductions in the continental United States. Pages 322-373 in W.R. Courtenay, Jr. and J.R. Stauffer, Jr., editors. Distribution, biology, and management of exotic fishes. The John Hopkins University Press. Baltimore, MD.

Tyus, H.M. and J.F. Saunders. 1996. Nonnative fishes in the Upper Colorado River Basin and a strategic plan for their control. Final report to the Recovery Implementation Program for Endangered Fish Species in the Upper Colorado River Basin. Cooperative agreement 14-18-0006-95-923. U.S. Fish and Wildlife Service, Denver, CO.

Tyus, H.M. and J.F. Saunders. 2001. An evaluation of the role of tributary streams for endangered fishes in the upper Colorado River basin, with recommendations for future recovery actions. Center for Limnology, University of Colorado, Boulder, CO.

Upper Colorado River Endangered Fish Recovery Program 2002. Nonnative fish control workshop: summary, conclusions and recommendations. Program Director's Office, UCREFRP, Lakewood, CO.

U.S. Fish and Wildlife Service. 1995. Virgin River Fishes Recovery Plan. U.S. Fish and Wildlife Service, Denver, CO.

U.S. Fish and Wildlife Service. 1999. June sucker (Chasmistes liorus) recovery plan. U.S. Fish and Wildlife Service, Denver, CO.

U.S. Fish and Wildlife Service. 2003a. Endangered and threatened wildlife and plants: reconsidered finding for an amended petition to list the westslope cutthroat trout as threatened throughout its range. Federal Register 68(152):46989-47009.

U.S. Fish and Wildlife Service. 2003b. Section 7 consultation, sufficient progress and historic projects agreement and Recovery Implementation Program Recovery Action Plan (RIPRAP). U.S. Fish and Wildlife Service, Denver, CO.

Valdez, R.A. and G.C. Clemmer. 1982. Life history and prospects for recovery of the humpback chub and bonytail chub, *in* W.H. Miller, H.M. Tyus, and C.A. Carlson (eds.) Fishes of the Upper Colorado River System: Present and Future. Western Division, American Fisheries Society, Bethesda, Maryland.

Valdez, R.A. 1990. The endangered fish of Cataract Canyon. Final Report of Bio-West, Inc., to U.S. Bureau of Reclamation, Salt Lake City, Utah.

Valdez, R.A., and Steven W. Carothers. 1998. The aquatic ecosystem of the Colorado River in Grand Canyon: Grand Canyon Data Integration Project Synthesis Report. Dorothy A. House, editor. Prepared for the U.S.D.I. Bureau of Reclamation, Salt Lake City, Utah, by SWCA, Inc., Environmental Consultants, Flagstaff, Arizona.

Vrijenhoek, R.C., M.E. Douglas, and G.K. Meffe. 1985. Conservation genetics of endangered fish populations in Arizona. Science 228:400-402.

Voeltz, J.B. 2002. Roundtail chub (*Gila robusta*) status survey of the lower Colorado River Basin. Technical Report 186, Arizona Game and Fish Department, Phoenix.

Wilcox, B.A. and D.D. Murphy. 1985. Conservation strategy: effects of fragmentation on extinction. American Naturalist 125:879-887.

Williams, S., and W.T. Hogarth. 2003. Policy for Evaluation of Conservation Efforts When Making Listing Decisions. Federal Register 68(609): 15100 – 15115.

Wiltzius, W.J. Fish Culture and Stocking in Colorado, 1872-1978. Colorado Division of Wildlife, 1985.

APPENDIX 1: STANDARD LANGUAGE REQUIRED BY THE STATE OF ARIZONA

The Arizona Game and Fish Commission, acting through its administrative agency, the Arizona Game and Fish Department, enters into this Agreement under authority of A.R.S. § 17-231.B.7).

The following stipulations are hereby made part of this Agreement, and where applicable must be adhered to by all signatories to this Agreement.

- **ARBITRATION: To the extent required pursuant to A.R.S. § 12-1518, and any successor statutes, the parties agree to use arbitration, after exhausting all applicable administrative remedies, to resolve any dispute arising out of this agreement, where not in conflict with Federal Law.**

- **CANCELLATION: All parties are hereby put on notice that this agreement is subject to cancellation pursuant to A.R.S. § 38-511.**

- **OPEN RECORDS: Pursuant to A.R.S. § 35-214 and § 35-215, and Section 41.279.04 as amended, all books, accounts, reports, files and other records relating to the contract shall be subject at all reasonable times to inspection and audit by the State for five years after contract completion. Such records shall be reproduced as designated by the State of Arizona.**

The following signatories support the goals, objectives, and actions of the Conservation Agreement for Roundtail Chub, Bluehead Sucker, and Flannelmouth Sucker, version 10.4.4 and agree to support the conservation efforts described.

Sally Wisely

Sally Wisely
State Director
Bureau of Land Management
Colorado State Office

10/4/07

Date

STATE OF COLORADO

Colorado Water Conservation Board
Department of Natural Resources
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John W. Hickenlooper
Governor

Mike King
DNR Executive Director

Jennifer L. Gimbel
CWCB Director

NOTICE

To: Instream Flow Subscription Mailing Lists

Subject: Proposed 2014 Instream Flow Appropriations
Water Divisions 1, 2, 4, 5 and 6

Date: March 12, 2013

Pursuant to ISF Rule 5c of the Rules Concerning the Colorado Instream Flow and Natural Lake Level Program, this notice identifies the streams to be considered for instream flow appropriations in 2014. At the January 2014 meeting of the Colorado Water Conservation Board (CWCB), staff may request that the Board form its intent to appropriate instream flow water rights for the streams listed on the attached Instream Flow Appropriation List. The attached list contains a description of the Instream Flow (ISF) Recommendations including stream name, watershed, county, upper terminus, lower terminus, length, and USGS quad sheet name(s).

Please note that the attached list includes 9 new recommendations that were received in January 2013 and 29 recommendations that were received in previous years. The older recommendations did not move forward in previous years due to the need for additional scientific data and/or ongoing attempts to address stakeholder issues.

Copies of the Instream Flow Recommendations and Appendices of data submitted into the Official CWCB Record are available for review by the public during regular business hours (8:00 a.m. - 5:00 p.m.) at the Colorado Water Conservation Board's Office, located at 1313 Sherman Street, Room 723, Denver, Colorado, 80203. In addition to the CWCB office, copies of the Instream Flow and Natural Lake Level Recommendations are available online at:

http://cwcb.state.co.us/environment/instream-flow-program/Pages/2014ProposedInstreamFlowAppropriations.aspx

In addition to the above Instream Flow Recommendations and Appendices, staff may rely on any additional data, exhibits, testimony, or other information submitted by any party as part of the Official CWCB Record to support its Instream Flow Recommendations.

It should also be noted that, pursuant to the ISF Rules:

5d. (3)
(a) The Board may change flow amounts of contested ISF appropriations based on information received during the public notice and comment period.

(b) Staff will maintain, pursuant to Rule 5e.(3), an ISF Subscription Mailing List for each water division composed of the names of all persons who have sent notice to the Board Office that they

wish to be included on such list for a particular water division. Any person desiring to be on the ISF Subscription Mailing List(s) must send notice to the Board Office.

(c) Any meetings held between Staff and members of the public will be open to the public. Staff may provide Proper Notice prior to any such meetings and may provide notice to persons on the ISF Subscription Mailing List(s).

(d) Any Notice to Contest must be received at the Board office no later than March 31, 2014, or the first business day thereafter. All Notices of Party status and Contested Hearing Participant status must be received at the Board office no later than April 30, 2014 or the first business day thereafter.

(e) Staff will announce its Final Staff ISF Recommendation concerning contested appropriations at the September 2014 Board meeting and will send notice of the Final Staff Recommendation to all persons on the Contested Hearing Mailing List.

(f) The Board may take final action on any uncontested ISF appropriations at the May 2014 Board meeting.

Should you wish to comment on the proposed Instream Flow Recommendations, you may do so by writing Jeff Baessler of the Board's staff at the address given above or by sending your comments by email to jeffrey.baessler@state.co.us, or rob.viehl@state.co.us. It should be noted that while your appearance at any meeting is welcome, such an appearance is not necessary for your concerns to be recognized. Staff will take your comments into account and, if you so request, will present them to the Board in your absence. If you are not currently on the Board's Instream Flow Subscription Mailing List and you would like to be, please contact the Board's Office at the address given above.

Div	Stream	Watershed	County	Length (miles)	Upper Terminus	Lower Terminus	Quad Sheet(s)
1	Coal Creek	St. Vrain	Boulder	6.10	Boulder County Open Space Boundary	Louisville Wastewater Treatment Outfall	Louisville, Lafayette
1	Coal Creek	St. Vrain	Boulder	1.70	Louisville Wastewater Treatment Outfall	Pumping station #2	Louisville, Lafayette
1	Graves Creek	Lone Tree - Owl	Larimer	2.68	Colorado-Wyoming border	South Line S27 T12N R68w	Carr West, Round Butte
1	Shell Creek	Upper Laramie	Larimer	6.28	headwaters	Shell Creek Ditch hdgt.	Crazy Mountain, Sand Creek Pass
1	Spottlewood Creek #1	Cache La Poudre	Larimer	2.03	NW S29 T12N R68W	NW S33 T12N R68W	Round Butte
1	Spottlewood Creek #2	Cache La Poudre	Larimer	1.61	NW S 34 T 11N R68W	SW S34 T11N R68W	Carr SW, Carr West
1	Lone Tree Creek	Lone Tree - Owl	Weld	2.88	NW S29 T12N R67W	SE S31 T12N R67W	Carr West
1	North Clear Creek	Clear	Gilpin	1.23	confl. Chase Gulch	Wastewater Treatment Plant	Black Hawk
1	North Clear Creek	Clear	Gilpin	6.55	Wastewater Treatment Plant	confl. Clear Creek	Black Hawk, Squaw Pass
2	West Beaver Creek	Upper Arkansas	Freemont, Teller	7.50	confl. Douglas Gulch	confl. East Beaver Creek	Big Bull Mtn, Phantom Canyon
2	Beaver Creek	Upper Arkansas	Freemont	8.90	confl. East Beaver Creek	confl. unnamed tributary	Phantom Canyon, Mount Pittsburg
2	Arkansas River	Upper Arkansas	Pueblo	9.13	outlet of Fish Hatchery	confl. Fountain Creek	North West Pueblo
2	Apishapa River	Apishapa	Las Animas	4.50	Headwaters	confl. Herick Canyon Creek	Cucharas Pass, Herlick Canyon
4	Hot Springs Creek (increase)	Tomichi	Gunnison	5.78	confl. Spring Creek	LL Bush No. 4 hdgt.	Pitkin, Doyleville

4	Oh-Be-Joyful (increase)	East-Taylor	Gunnison	2.11	confl. unnamed tributary	confl. Slate River	Oh-Be-Joyful
4	Slate River (increase)	East-Taylor	Gunnison	4.08	confl. Poverty Gulch	confl. Oh-Be-Joyful	Oh-Be-Joyful
4	Slate River (increase)	East-Taylor	Gunnison	5.30	confl. Oh-Be-Joyful	confl. Coal Creek	Oh-Be-Joyful, Gothic
4	East creek	Lower Gunnison	Mesa	5.34	confl. North East Creek	confl. Gunnison River	Whitewater
4	Granite Creek	Lower Dolores	Mesa	5.79	confl. two unnamed tributaries	Colorado-Utah border	Steamboat Mesa, Two V Basin
4	Ute Creek	Lower Dolores	Mesa	7.90	Headwaters	confl. West Creek	Pine Mtn, Gateway
4	Dolores River	Lower Dolores	Montrose, Mesa	33.74	confl. San Miguel	confl. West Creek	Red Canyon, Roc Creek, Juanita Arch, Gateway
5	Eagle River (increase)	Eagle	Eagle	3.80	confl. Cross Creek	confl. Gore Creek	Minturn
5	Dry Fork Roan Creek	Parachute-Roan	Garfield	7.61	confl. South Dry Fork and North Fork Dry Fork	confl. Roan Creek	Long Point, Wagon Track Ridge
5	East Fork Parachute Creek	Parachute-Roan	Garfield	2.46	confl. Bull Gulch	confl. Ben Good Creek	Forked Gulch
5	Left Fork Carr Creek	Parachute-Roan	Garfield	6.43	Headwaters	Franklin No. 2 Ditch hdgt.	Henderson Ridge
5	Beaver Creek	Colorado Headwaters-Plateau	Mesa	6.50	Headwaters	Rifle Town Intake	North Mamm Peak
5	Beaver Dams Creek	Colorado Headwaters-Plateau	Mesa	1.60	Headwaters	confl. East Divide Creek	Quaker Mesa
5	East Divide Creek	Colorado Headwaters-Plateau	Mesa, Garfield	3.50	confl. Gennings Creek	confl. Camp Creek	Quaker Mesa, Center Mtn
5	East Divide Creek	Colorado Headwaters-Plateau	Garfield	9.40	confl. Camp Creek	confl. June Creek	Center Mtn, Gibson Guclh
5	West Divide Creek	Colorado Headwaters-Plateau	Mesa	8.10	confl. Little Beaver Creek	confl. Mosquito Creek	Quaker Mesa, Flatiron Mtn
5	Meadow Creek	Colorado Headwaters-Plateau	Garfield	8.20	Outlet Meadow Creek Reservoir	confl. Main Elk Creek	Meadow Creek Lake, Deer Creek Point
6	Piceance Creek	Piceance-Yellow	Rio Blanco	7.70	confl. with Dry Fork	confl. White River	Barcus Creek SE, White River City
6	Yellow Creek	Piceance-Yellow	Rio Blanco	4.74	Springs in NWNE S12, T1N R98W, 6PM	confl. Barcus Creek	Barcus Creek SE,
6	Yellow Creek	Piceance-Yellow	Rio Blanco	7.11	confl. Barcus Creek	confl. White River	Barcus Creek, Barcus Creek SE, Rough Gulch
6	Willow Creek (Increase)	Upper Yampa	Routt	4.65	outlet of Steamboat Lake	confl. Beaver Creek	Hahns Peak
6	Willow Creek (Increase)	Upper Yampa	Routt	1.32	confl. Beaver Creek	confl. Lester Creek	Hahns Peak

Exhibit 9

STATE OF COLORADO

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John W. Hickenlooper
Governor

Mike King
DNR Executive Director

Jennifer L. Gimbel
CWCB Director

NOTICE

To: Instream Flow Subscription Mailing Lists

Subject: Proposed 2014 Instream Flow Appropriations
Water Divisions 1, 4, and 5

Date: November 5, 2013

Pursuant to ISF Rule 5c of the Rules Concerning the Colorado Instream Flow and Natural Lake Level Program, this notice identifies the streams to be considered for instream flow appropriations in 2014. At the January 2014 meeting of the Colorado Water Conservation Board (CWCB), staff may request that the Board form its intent to appropriate instream flow water rights for the streams listed on the attached Instream Flow Appropriation List. The attached list contains a description of the Instream Flow (ISF) Recommendations including stream name, watershed, county, upper terminus, lower terminus, length, and USGS quad sheet name(s).

Copies of the Instream Flow Recommendations and Appendices of data submitted into the Official CWCB Record are available for review by the public during regular business hours (8:00 a.m. - 5:00 p.m.) at the Colorado Water Conservation Board's Office, located at 1313 Sherman Street, Room 723, Denver, Colorado, 80203. In addition to the CWCB office, copies of the Instream Flow and Natural Lake Level Recommendations are available online at:

http://cwcb.state.co.us/environment/instream-flow-program/Pages/2014ProposedInstreamFlowAppropriations.aspx

In addition to the above Instream Flow Recommendations and Appendices, staff may rely on any additional data, exhibits, testimony, or other information submitted by any party as part of the Official CWCB Record to support its Instream Flow Recommendations.

It should also be noted that, pursuant to the ISF Rules:

5d. (3)
(a) The Board may change flow amounts of contested ISF appropriations based on information received during the public notice and comment period.

(b) Staff will maintain, pursuant to Rule 5e.(3), an ISF Subscription Mailing List for each water division composed of the names of all persons who have sent notice to the Board Office that they wish to be included on such list for a particular water division. Any person desiring to be on the ISF Subscription Mailing List(s) must send notice to the Board Office.

(c) Any meetings held between Staff and members of the public will be open to the public. Staff may provide Proper Notice prior to any such meetings and may provide notice to persons on the ISF Subscription Mailing List(s).

(d) Any Notice to Contest must be received at the Board office no later than March 31, 2014, or the first business day thereafter. All Notices of Party status and Contested Hearing Participant status must be received at the Board office no later than April 30, 2014 or the first business day thereafter.

(e) Staff will announce its Final Staff ISF Recommendation concerning contested appropriations at the September 2014 Board meeting and will send notice of the Final Staff Recommendation to all persons on the Contested Hearing Mailing List.

(f) The Board may take final action on any uncontested ISF appropriations at the May 2014 Board meeting.

Should you wish to comment on the proposed Instream Flow Recommendations, you may do so by writing Jeff Baessler of the Board's staff at the address given above or by sending your comments by email to jeffrey.baessler@state.co.us, or rob.viehl@state.co.us. It should be noted that while your appearance at any meeting is welcome, such an appearance is not necessary for your concerns to be recognized. Staff will take your comments into account and, if you so request, will present them to the Board in your absence. If you are not currently on the Board's Instream Flow Subscription Mailing List and you would like to be, please contact the Board's Office at the address given above.

Div	Stream	Watershed	County	Length (miles)	Upper Terminus	Lower Terminus	Quad Sheet(s)
1	Shell Creek	Upper Laramie	Larimer	6.25	Headwaters	BLM Boundary	Crazy Mountain, Sand Creek Pass
1	North Clear Creek	Clear	Gilpin	5.98	confl. Chase Gulch	Municipal Wastewater Treatment Plant	Black Hawk
1	North Clear Creek	Clear	Gilpin	1.78	Municipal Wastewater Treatment Plant	confl. Clear Creek	Black Hawk, Squaw Pass
4	Hot Springs Creek (increase)	Tomichi	Gunnison	3.46	Outlet Hot Springs Creek Reservoir	LL Bush No. 4 hdgt.	Pitkin, Doyleville
4	Oh-Be-Joyful (increase)	East-Taylor	Gunnison	1.66	confl. unnamed tributary	confl. Slate River	Oh-Be-Joyful
4	Slate River (increase)	East-Taylor	Gunnison	3.69	confl. Poverty Gulch	confl. Oh-Be-Joyful	Oh-Be-Joyful
4	Slate River (increase)	East-Taylor	Gunnison	5.63	confl. Oh-Be-Joyful	confl. Coal Creek	Oh-Be-Joyful, Gothic
4	East Creek	Lower Gunnison	Mesa	5.38	confl. North East Creek	confl. Gunnison River	Whitewater
4	Granite Creek	Lower Dolores	Mesa	5.79	confl. two unnamed tributaries	Colorado-Utah border	Steamboat Mesa, Two V Basin
4	Ute Creek	Lower Dolores	Mesa	7.87	Headwaters	confl. West Creek	Pine Mtn, Gateway
4	Dolores River	Lower Dolores	Montrose, Mesa	34.21	confl. San Miguel	confl. West Creek	Red Canyon, Roc Creek, Juanita Arch, Gateway
5	Dry Fork Roan Creek	Parachute-Roan	Garfield	7.66	confl. South Dry Fork and North Fork Dry Fork	confl. Roan Creek	Long Point, Wagon Track Ridge
5	East Fork Parachute Creek	Parachute-Roan	Garfield	2.46	confl. Bull Gulch	confl. Ben Good Creek	Forked Gulch
5	Left Fork Carr Creek	Parachute-Roan	Garfield	6.43	Headwaters	Franklin No. 2 Ditch hdgt.	Henderson Ridge
5	Beaver Creek	Colorado	Mesa	6.48	Headwaters	Rifle Town Intake	North Mamm Peak

		Headwaters-Plateau					
5	Beaver Dam Creek	Colorado Headwaters-Plateau	Mesa	1.60	Headwaters	confl. East Divide Creek	Quaker Mesa
5	East Divide Creek	Colorado Headwaters-Plateau	Mesa, Garfield	3.52	confl. Gennings Creek	confl. Camp Creek	Quaker Mesa, Center Mtn
5	East Divide Creek	Colorado Headwaters-Plateau	Garfield	9.51	confl. Camp Creek	confl. June Creek	Center Mtn, Gibson Guclh
5	West Divide Creek	Colorado Headwaters-Plateau	Mesa	8.44	confl. Little Beaver Creek	confl. Mosquito Creek	Quaker Mesa, Flatiron Mtn
5	Meadow Creek	Colorado Headwaters-Plateau	Garfield	8.21	Outlet Meadow Creek Reservoir	confl. Main Elk Creek	Meadow Creek Lake, Deer Creek Point

STATE OF COLORADO

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Mike King
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James Eklund
CWCB Director

NOTICE

To: Instream Flow Subscription Mailing Lists

Subject: Proposed 2014 Instream Flow Appropriations in Water Divisions 1, 4 and 5

Date: February 4, 2014

At its January 27-28, 2014 regular meeting, the Colorado Water Conservation Board (CWCB) declared its intent to appropriate instream flow water rights for the 18 streams listed on the attached instream flow appropriation list. The attached list contains a description of the instream flow recommendations, including: stream name, water division, watershed, county(s), upper terminus, lower terminus, length, USGS quad sheet name(s) and recommended instream flow amounts. Copies of the Instream Flow Recommendation Summary Reports and Appendices submitted into the Official CWCB Record are available for review during regular business hours (8:00 a.m. - 5:00 p.m.) at the CWCB's office, located at 1313 Sherman Street, Room 721, Denver, Colorado, 80203. This information is also available on the CWCB website at: http://cwcb.state.co.us/environment/instream-flow-program/Pages/2014ProposedInstreamFlowAppropriations.aspx

In addition to the above Instream Flow Recommendation Summary Reports and Appendices, staff may rely on any additional data, exhibits, testimony, or other information submitted by any party as part of the Official CWCB Record to support its Instream Flow Recommendations. Rule 5d.(3) of the CWCB's Rules Concerning the Colorado Instream Flow and Natural Lake Level Program, as shown below, governs the Board's standard procedures for ISF appropriations. Please note that the dates shown below in sub-paragraphs (d), (e), and (f) were modified for the Dolores River appropriation. The modified Rule 5d.(3) dates for the Dolores River appropriation are set forth in the last paragraph of this notice. Rule 5d.(3) provides that:

(a) The Board may change flow amounts of contested ISF appropriations based on information received during the public notice and comment period.

(b) Staff will maintain, pursuant to Rule 5e.(3), an ISF Subscription Mailing List for each water division composed of the names of all persons who have sent notice to the Board Office that they wish to be included on such list for a particular water division. Any person desiring to be on the ISF Subscription Mailing List(s) must send notice to the Board Office.

(c) Any meetings held between Staff and members of the public will be open to the public. Staff may provide Proper Notice prior to any such meetings and may provide notice to persons on the ISF Subscription Mailing List(s).

(d) Any Notice to Contest must be received at the Board office no later than March 31, 2014. All Notices of Party status and Contested Hearing Participant status must be received at the Board office no later than April 30, 2014.

(e) Staff will announce its Final Staff Instream Flow Recommendation concerning contested appropriations at the September 2014 Board meeting and, prior to that meeting, will send notice of the Final Staff Recommendation to all persons on the Contested Hearing Mailing List.

(f) The Board may take final action on any uncontested ISF appropriations at the May 2014 Board meeting.

A notice to contest an ISF appropriation must be made in writing and contain the following information: (a) Identification of the Person(s) requesting the hearing;(b) Identification of the ISF appropriation(s) at issue; and, (c) The contested facts and a general description of the data upon which the Person will rely to the extent known at that time.

Should you wish to comment on the proposed Instream Flow Recommendations, you may do so by writing Jeff Baessler of the Board's staff at the address given above or by sending your comments by email to jeffrey.baessler@state.co.us. It should be noted that while your appearance at any meeting is welcome, such an appearance is not necessary for your concerns to be recognized. Staff will take your comments into account and, if you so request, will present them to the Board in your absence. If you are not currently on the Board's Instream Flow Subscription Mailing List and you would like to be, please contact the Board's Office at the address given above.

Please note that on January 28, 2014, the CWCB formed its intent to appropriate an instream flow water right on the Dolores River but established a modified schedule. Notices to Contest for this appropriation must be received at the CWCB office no later than February 2, 2015. All Notices of Party status and Contested Hearing Participant status must be received at the Board office no later than March 4, 2015. The Board may take final action if this appropriation is uncontested at its March 2015 Board meeting.

Div	Stream	Watershed	County	Length (miles)	Upper Terminus	Lower Terminus	Quad Sheet(s)	Flow (CFS)
1	Shell Creek	Upper Laramie	Larimer	6.25	Headwaters	BLM Boundary	Crazy Mountain, Sand Creek Pass	1.0 (11/1-3/31) 1.1 (4/1-10/31)
4	Hot Springs Creek (increase)	Tomichi Creek	Gunnison	3.46	Outlet Hot Springs Creek Reservoir	LL Bush No. 4 hdgt.	Pitkin, Doyleville	2.4 (5/1-7/21)
4	Oh Be Joyful Creek (increase)	East-Taylor	Gunnison	1.66	confl. unnamed tributary	confl. Slate River	Oh Be Joyful Creek	3.0 (4/1-4/30) 14.0 (5/1-7/15) 3.0 (7/16-8/15)
4	Slate River (increase)	East-Taylor	Gunnison	3.69	confl. Poverty Gulch	confl. Oh Be Joyful Creek	Oh Be Joyful Creek	30.0 (5/1-7/15)
4	Slate River (increase)	East-Taylor	Gunnison	5.63	confl. Oh-Be-Joyful Creek	confl. Coal Creek	Oh Be Joyful, Gothic	45.0 (5/1-7/15)
4	East Creek	Lower Gunnison	Mesa	4.94	confl. North East Creek	East Creek Ditch hdgt.	Whitewater	1.6 (3/15-6/30) 0.25 (7/1-3/14)
4	East Creek	Lower Gunnison	Mesa	0.37	East Creek Ditch hdgt.	confl. Gunnison River	Whitewater	1.6 (3/15-5/31)
4	Granite Creek	Lower Dolores	Mesa	5.79	confl. two unnamed tributaries	Colorado-Utah border	Steamboat Mesa, Two V Basin	2.7 (4/1-6/30) 0.5 (7/1-3/31)

4	Ute Creek	Lower Dolores	Mesa	7.87	Headwaters	confl. West Creek	Pine Mtn, Gateway	2.0 (4/1-6/15) 0.3 (6/16-3/31)
4	Dolores River	Lower Dolores	Montrose, Mesa	34.21	confl. San Miguel River	confl. West Creek	Red Canyon, Roc Creek, Juanita Arch, Gateway	200 (3/16-4/14) 900 (4/15-6/14) 400 (6/15-7/15) 200 (7/16-8/14) 100 (8/15-3/15)
5	Beaver Creek	Colorado Headwaters-Plateau	Garfield	8.11	Headwaters	Dame Ditch hdgt.	North Mamm Peak	0.7 (12/1-4/30) 4.75 (5/1-6/30) 2.85 (7/1-7/31) 1.0 (8/1-11/30)
5	East Divide Creek	Colorado Headwaters-Plateau	Mesa, Garfield	3.49	confl. Gennings Creek	confl. Camp Creek	Quaker Mesa, Center Mtn	1.4 (4/1-4/15) 4.8 (4/16-6/30) 1.5 (7/1-7/15) 1.2 (7/16-7/30) 0.3 (8/1-3/31)
5	East Divide Creek	Colorado Headwaters-Plateau	Garfield	9.45	confl. Camp Creek	confl. June Creek	Center Mtn, Gibson Gulch	3.0 (4/1-4/15) 7.2 (4/16-6/30) 3.0 (7/1-7/31) 1.1 (8/1-3/31)
5	East Fork Parachute Creek	Parachute-Roan	Garfield	1.28	confl. Bull Gulch	BLM boundary	Forked Gulch	5.0 (4/15-6/30) 0.65 (7/1-4/14)
5	Left Fork Carr Creek	Parachute-Roan	Garfield	6.43	Headwaters	Franklin No. 2 Ditch hdgt.	Henderson Ridge	0.75 (11/1-3/31) 2.0 (4/1-8/31) 1.0 (9/1-10/31)
5	Meadow Creek	Colorado Headwaters-Plateau	Garfield	8.21	Outlet Meadow Creek Reservoir	confl. Main Elk Creek	Meadow Creek Lake, Deer Creek Point	1.3 (10/1-3/31) 2.1 (4/1-9/30)
5	Beaver Dam Creek	Colorado Headwaters-Plateau	Mesa	1.60	Headwaters	confl. East Divide Creek	Quaker Mesa	0.14 (11/1-4/30) 0.9 (5/1-8/31) 0.35 (9/1-10/31)
5	West Divide Creek	Colorado Headwaters-Plateau	Mesa	8.11	confl. Little Beaver Creek	confl. Mosquito Creek	Quaker Mesa, Flatiron Mtn	4.2 (3/15-4/15) 14.1 (4/16-7/15) 4.2 (7/16-7/31) 1.14 (8/1-3/14)

Exhibit 11

STATE OF COLORADO

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James Eklund

TO: Colorado Water Conservation Board Members

FROM: Jeff Baessler
Stream and Lake Protection Section

DATE: November 6, 2013

SUBJECT: **Agenda Item 14, November 19-20, 2013 Board Meeting – Stream and Lake Protection Section – Notice of 2014 Instream Flow Recommendations in Water Divisions 1, 4 and 5.**

Summary

This is an informational item that provides notice of recommended stream segments that staff may bring to the Board in January 2014 with a recommendation that the Board form its intent to appropriate instream flow (ISF) water rights. No Board action is required.

Discussion

Pursuant to ISF Rule 5c., the Colorado Water Conservation Board is providing notice that the following 20 stream segments are being considered for ISF appropriations in 2014. At the January 2014 CWCB meeting, Staff may request that the Board form its intent to appropriate ISF water rights on some or all these streams. These streams were previously noticed at the Board's March 2013 meeting.

Division	Stream Name	County(ies)	Recommender(s)*
1	**North Clear Creek** *Confl. Chase Gulch to Municipal WWTP*	Gilpin	CDPHE, CPW
1	**North Clear Creek** *Municipal WWTP to Confl. Clear Creek*	Gilpin	CDPHE, CPW
1	**Shell Creek** *Headwaters to BLM Boundary*	Larimer	BLM
4	**Hot Springs Creek** (ISF Increase) *Outlet Hot Springs Reservoir to Confl. LL Bush Ditch #4*	Gunnison	BLM

Division	Stream Name	County(ies)	Recommender(s)*
4	**Oh-Be-Joyful Creek** (ISF Increase) *Confl. Unnamed Tributary to Confl. Slate River*	Gunnison	BLM
4	**Slate River** (ISF Increase) *Confl. Poverty Gulch to Confl. Oh-Be-Joyful Creek*	Gunnison	BLM
4	**Slate River** (ISF Increase) *Confl. Oh-Be-Joyful Creek to Confl. Coal Creek*	Gunnison	BLM
4	**East Creek** *Confl. North Fork East Creek to Confl. Gunnison River*	Gunnison	BLM
4	**Granite Creek** *Confl. Unnamed Tributary to Utah-Colorado Border*	Gunnison	BLM
4	**Ute Creek** *Headwaters to Confl. West Creek*	Gunnison	BLM
4	**Dolores River** *Confl. San Miguel River to Confl. West Creek*	Mesa, Montrose	BLM
5	**Dry Fork Roan Creek** *Confl. North Dry Fork Creek & South Dry Fork Creek to Confl. Roan Creek*	Garfield	BLM
5	**East Divide Creek** *Confl. Camp Creek to Confl. June Creek*	Garfield	CPW
5	**East Fork Parachute Creek** *Confl. Bull Gulch to Confl. Ben Good Creek*	Garfield	BLM
5	**Left Fork Carr Creek** *Headwaters to Franklin No. 2 Ditch Headgate*	Garfield	BLM
5	**Meadow Creek** *Outlet Meadow Creek Reservoir to Confl. Main Elk Creek*	Garfield	CPW
5	**Beaver Creek** *Headwaters to Rifle Town Intake*	Garfield	CPW
5	**Beaver Dam Creek** *Headwaters to Confl. East Divide Creek*	Mesa	CPW
5	**West Divide Creek** *Confl. Little Beaver Creek to Confl. Mosquito Creek*	Mesa	CPW
5	**East Divide Creek** *Confl. Gennings Creek to Confl. Camp Creek*	Mesa, Garfield	CPW

* CPW (Colorado Parks and Wildlife), BLM (Bureau of Land Management), and CDPHE (Colorado Department of Public Health and Environment)

The detailed recommendations and appendices for these streams can be found on the CWCB website at:http://cwcb.state.co.us/environment/instream-flow program/Pages/2014ProposedInstreamFlowAppropriations.aspx

This is an informational item, with no Board action requested.

Exhibit 12

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Jennifer L. Gimbel
CWCB Director

TO: Colorado Water Conservation Board Members

FROM: Jeff Baessler
Stream and Lake Protection Section

DATE: March 1, 2013

SUBJECT: **Agenda Item 29, March 19-20, 2013, Board Meeting**
Stream and Lake Protection Section – Instream Flow Appropriation Recommendations for January 2014

Introduction and Staff Recommendation

Pursuant to Rule 5c. of the Rules Concerning the Colorado Instream Flow and Natural Lake Level Program ("ISF Rules"), the Staff is providing notice that the following 28 stream segments have been recommended for instream flow ("ISF") appropriations in 2014. At the January 2014 CWCB meeting, Staff may request that the Board form its intent to appropriate ISF water rights on these streams.

Please note that the list below includes 9 new recommendations and 29 recommendations that were received in previous years. The older recommendations did not move forward in previous years due to the need for additional scientific data and/or ongoing attempts to address stakeholder issues. In addition, the Stream and Lake Protection Section was only able to process two recommendations in 2012 due to staff retirements at both CWCB and CPW. In 2014, staff will recommend that the Board move forward on the recommendations for which staff is able to reasonably address all outstanding issues. Staff is currently working with the recommending entities to prioritize this list of recommendations.

This is an informational item with no Board action required.

DATE RECEIVED	WATER DIV.	STREAM NAME	STAKEHOLDER RECOMMENDATION	COUNTY
2/13/08	1	Coal Creek *(Boulder County Open Space Boundary to Louisville Wastewater Treatment outfall)*	City of Louisville, CPW	Boulder
2/13/08	1	Coal Creek *(Louisville Wastewater Treatment outfall to Lafayette pumping station #2)*	City of Louisville & CPW	Boulder
3/7/11	1	North Clear Creek *(Confl. Chase Gulch to Confl. Wastewater Treatment Plant)*	CPW & CDPHE	Gilpin
3/7/11	1	North Clear Creek	CPW & CDPHE	Gilpin

		(Confl. Wastewater Treatment Plant to Confl. Clear Creek)		
2/22/12	1	Graves Creek *(Wyoming Stateline to South Line S27 T12N R68W)*	City of Fort Collins & CPW	Larimer
2/22/12	1	Shell Creek *(Headwaters to Shell Creek Ditch)*	BLM	Larimer
2/22/12	1	Spottlewood Creek #1 *(NW S29 T12N R68W to Road at NW S33 T12N R68W)*	City of Fort Collins & CPW	Larimer
2/22/12	1	Spottlewood Creek #2 *(NW S34 T11N R68W to SW S34 T11N R68W)*	City of Fort Collins & CPW	Larimer
2/22/12	1	Lone Tree Creek *(NW S29 T12N R67W to SE S31 T12N R67W)*	City of Fort Collins & CPW	Weld
2/24/09	2	Beaver Creek *(Confl. East & West Beaver Creeks to Confl. Patton Canyon)*	CPW	Fremont
2/24/09	2	West Beaver Creek *(Confl. Douglas Gulch to Confl. East Beaver Creek)*	CPW	Fremont, Teller
2/24/09	2	Baker Creek *(headwaters to USFS Boundary)*	CPW	Huerfano
2/24/09	2	Bonnett Creek *(headwaters to USFS Boundary)*	CPW	Huerfano
2/16/11	2	Apishapa River *(Headwaters to Confl. Herlick Canyon Creek)*	CPW	Las Animas
2/16/11	2	Arkansas River *(Outlet of Fish Hatchery to Confl. Fountain Creek)*	CPW & City of Pueblo	Pueblo
1/30/13	4	Hot Springs Creek (ISF Increase) *(Confl. Spring Creek to Confl. LL Bush Ditch #4)*	BLM	Gunnison
1/30/13	4	Oh-Be-Joyful Creek (ISF Increase) *(Confl. Unnamed Tributary to Confl. Slate River)*	BLM	Gunnison
1/30/13	4	Slate River (ISF Increase)*(Confl. Poverty Gulch to Confl. Oh-Be-Joyful Creek)*	BLM	Gunnison
1/30/13	4	Slate River (ISF Increase)*(Confl. Oh-Be-Joyful Creek to Confl. Coal Creek)*	BLM	Gunnison
1/30/13	4	East Creek *(Confl. North Fork East Creek to Confl. Gunnison River)*	BLM	Mesa
2/22/12	4	Granite Creek *(Confl. Unnamed Tributary to Utah-Colorado border)*	BLM	Mesa
2/16/11	4	Ute Creek *(Headwaters to Confl. West Creek)*	BLM	Mesa
1/30/13	4	Dolores River *(Confl. San Miguel River to Confl. West Creek)*	BLM	Mesa, Montrose
11/29/04	5	Eagle River (ISF Increase)*(Confl Cross Creek to Confl Gore Creek)*	CPW	Eagle
1/30/13	5	Dry Fork Roan Creek*(Confl. North Dry Fork Creek & South Dry Fork Creek to Confl. Roan Creek)*	BLM	Garfield
2/16/11	5	East Divide Creek *(Confl. Camp Creek to Confl. June Creek)*	CPW	Garfield
1/30/13	5	East Fork Parachute Creek*(Confl. Bull Gulch to Confl. Ben Good Creek)*	BLM	Garfield
1/30/13	5	Left Fork Carr Creek*(Headwaters to Franklin*	BLM	Garfield

		No. 2 Ditch Headgate)		
2/16/11	5	Meadow Creek *(Outlet Meadow Creek Reservoir to Confl. Main Elk Creek)*	CPW	Garfield
2/16/11	5	Beaver Creek *(Headwaters to Rifle Town Intake)*	CPW	Garfield
2/16/11	5	Beaver Dam Creek *(Headwaters to Confl. East Divide Creek)*	CPW	Mesa
2/16/11	5	West Divide Creek *(Confl. Little Beaver Creek to Confl. Mosquito Creek)*	CPW	Mesa
2/16/11	5	East Divide Creek *(Confl. Gennings Creek to Confl. Camp Creek)*	CPW	Mesa, Garfield
2/21/07	6	Piceance Creek *(Confl. Dry Fork to Confl. White River)*	BLM & CPW	Rio Blanco
2/21/07	6	Yellow Creek *(Confl. Barcus Creek to Lambert Springs)*	BLM	Rio Blanco
2/21/07	6	Yellow Creek *(Confl. Lambert Springs to Confl. White River)*	BLM	Rio Blanco
2/22/12	6	Willow Creek (ISF Increase) *(Outlet of Steamboat Lake to Confl. Beaver Creek)*	BLM	Routt
2/22/12	6	Willow Creek (ISF Increase) *(Confl. Beaver Creek to Confl. Lester Creek)*	BLM	Routt

*CPW (Colorado Parks and Wildlife), BLM (Bureau of Land Management), CDPHE (Colorado Department of Public Health and Environment)

The detailed recommendations and appendices for these streams will be posted on the CWCB website at:
http://cwcb.state.co.us/environment/instream-flow-program/Pages/2014ProposedInstreamFlowAppropriations.aspx

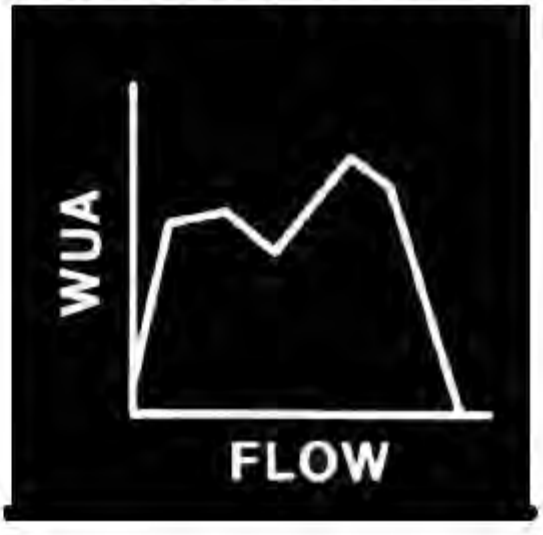




PHABSIM for Windows

User's Manual and Exercises
Midcontinent Ecological Science Center
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Acknowledgments

This document evolved from IF310 course materials developed and revised numerous times since 1984. Several individuals made significant contributions to the Windows® version of the software and this version of the manual in the following order. All are employees of the Midcontinent Ecological Science Center (MESC), U.S. Geological Survey (USGS), unless otherwise noted. Mr. John Bartholow wrote early versions of the laboratory exercises. Mr. Ken Bovee provided revision and insight to habitat suitability curve development and testing. Dr. Robert Milhous wrote the original PHABSIM programs. He also wrote the PHABSIM Version 2 (DOS) reference manual with assistance from Ms. Marlys Updike and Ms. Dianne Schneider (Milhous et al., 1989). Substantial portions of this text and of the Version 2 class text were taken or adapted from that earlier work. Dr. Thomas Hardy, Utah State University, consolidated and expanded on earlier course materials to provide a working draft of the PHABSIM Version 2 (DOS) class text under contract to the MESC. Substantial portions of the text in this document (in all chapters and in the laboratory exercises) are adapted from that draft. Dr. Sam Williamson contributed numerous insights into the techniques and strategy of habitat modeling and wrote the descriptive text for those ideas. Mr. Jeff Sandelin designed and programmed the Windows® interface and made numerous contributions to the text while employed under a support services contract. Ms. Julianne Brown, also a support services contractor, performed extensive testing of the programs to ensure results were correct and congruent with the previous version of the software. Mr. Jim Henriksen provided numerous insightful review comments and text revisions while using the PHABSIM for Windows programs. Dr. Terry Waddle supervised the design and testing of this software version. He also contributed substantial new text material while editing this version of the manual and laboratory exercises to reflect the overarching IFIM concept and the PHABSIM for Windows structure.

Preface

A Brief History of PHABSIM

In the 1970's a major change in terminology regarding maintaining streamflow to protect aquatic organisms in streams was introduced. To some, the change was considered merely semantic. But to those whose pioneering work led to the change, it was both substantive and significant. The change was from common usage of the term "low flow" or "minimum flow" to the common usage of the term "instream flow." During the early 1970's, the *Water Resources Research Catalog* served as an index of most of the ongoing research related to water resources, with each project identified by several key words. As late as 1975, the *Catalog* contained no research projects under the key words "instream flow," while at the same time, there were many studies using the key words "low flow."

The typical description of the concept of "low flow" in those days was something like this:

> "Water is taken out of the stream for a variety of uses, such as irrigated agriculture, municipal and industrial. Low flow means that amount of water that must be left in the stream for the fish. With anything less than the low flow, the fish will die."

In a thoughtful piece published in the April 1991 edition of *Rivers*, Harvey Doerksen recalled how Don Tenant, then an aquatic biologist for the State of Montana, described the shortcomings of the "low flow" concept in human terms:

> After many years, I still have a vivid recollection of a photographic slide that [Don Tennant] showed as part of his presentation at a conference. It was a picture of a family of perhaps half a dozen people crowded into a small bathroom. ... The point that Don wished to make was simply this: in the short run, a population of fish in the stream can make out quite well with an extreme low flow event, just as a family can tolerate the closeness that comes with crowding into a small bathroom. Over extended periods, however, the low flow could not be tolerated any better by a population of fish than sustained proximity could be tolerated by a family in a crowded bathroom. And yet, that very concept of maintaining a sustained low residual flow was the prevailing approach to protecting fish habitat.

One of the serious problems with the "low flow" approach was that biologists distinguished only between two relative conditions with respect to fish habitats: the level below which disaster would occur, and everything else. However, other water users made incremental assessments of their need. An irrigation district, for example, could project water quantity needs for any increment of irrigated acreage, but the biologists at the time did not have the technology to do similar incremental assessments of the potential impacts of various irrigated acreage scenarios.

In the late 1970's the U.S. Fish and Wildlife Service (FWS), through what then was its Office of Biological Services, received funding from the Environmental Protection Agency (EPA) to establish the Cooperative Instream Flow Service Group, which incorporated the combined talents of people from several federal and state agencies. The Group's central charge was to develop methods for quantifying the biological effects of altered streamflows.

The result of a concerted effort on the part of the Instream Flow Group was the Instream Flow Incremental Methodology (IFIM) (Stalnaker et al., 1995; Bovee et al., 1998), of which the Physical Habitat Simulation System (PHABSIM) is a major component. This new technology was highly significant for at least two reasons. First, it allowed fishery biologists to *negotiate* acceptable flow levels with other instream and out-of-stream water users *from among a variety of possible scenarios*, in the same way that the other users had been doing for years.

Second, the change in the prevailing terminology from “low flow” to “instream flow use” meant that biologists no longer were trying to find that magical flow level below which a stream should not be dewatered. Instead, they were in a position to assert instream flow *needs* for fish habitats and other environmental values. Furthermore, they could do so in terms of the seasonal life cycle needs of the fish (or other aquatic organisms) over the annual hydrograph. This change was thus an instrument through which fish and associated environmental values were viewed as legitimate water users among many, instead of merely a residual, after the water users had been served.

This change was not easy, nor did it occur overnight. In developing PHABSIM, the Instream Flow Group drew on several developments in instream habitat assessment that were available at the time. Two developments were of particular importance, the Washington Method (Collings et al., 1972) and the univariate curve concept. The Washington Method provided the concept of mapping depth and velocity conditions over gravel bars and applying binary suitability functions for salmon spawning in streams in the Pacific Northwest. The area of a gravel bar suitable for spawning was evaluated at several measured discharges by calculating the area having a suitability value of 1 for both depth and velocity. Approximate suitable spawning area for unmeasured intermediate flows was estimated by interpolation.

Binary suitability functions (the observed condition is assigned a value of 0 or 1, unsuitable or suitable) produced a value of 0 for some stream areas that, although not optimally suitable, were observed being used by salmon. The use of a univariate suitability function, which ranked various depths or rates of flow velocity on a 0 to 1 scale and allowed a smooth function covering the entire range of conditions, was proposed by Waters (1976).

The Washington Method, even when modified to include the univariate curve approach, requires numerous empirical measurements at different discharges. This limits the number of discharges for which habitat can be evaluated and the number of study areas that can feasibly be evaluated with time, manpower, and budget constraints.

The Instream Flow Group combined standard one-dimensional hydraulic simulation techniques with the Washington Method and the univariate curve concept to produce PHABSIM. PHABSIM uses the hydraulic simulation models to predict depth and velocity at unmeasured flows using basic physical and engineering principles that were standard practice in the 1970’s. The resulting software suite multiplied surface area for a section of stream by the univariate suitability curve values for depth, velocity, and channel condition to arrive at a habitat index called Weighted Usable Area.

This software suite was first implemented on Control Data Corporation mainframe computers accessed by terminals connected over telephone lines. The software consisted of numerous small piecemeal programs that were cost-effective to develop and use in the mainframe environment. Numerous small files were required for data input and numerous output files were produced. This placed a major burden on users of the software to manage large numbers of files with often similar (but slightly different) contents. It also produced a legacy of program names such as IFG-4.

During 1984 and 1985 the PHABSIM program suite was moved to microcomputers. A basic menu-driven interface for the PHABSIM program was developed in 1989. The PHABSIM Version 2 (DOS) (Milhous et al., 1989) programs were distributed until September 2000 as the standard version of PHABSIM software.

With the advent of the Windows graphical user interface, it became evident that the PHABSIM program suite would serve a wider audience if input data and model results could be displayed graphically during an application of the software. Development of the Windows interface for PHABSIM fulfills commitments made to the U.S. Fish and Wildlife Service in the mid-1990's. Two principle goals were pursued while developing PHABSIM for Windows: (1) to keep the functionality of all core programs and retain backward compatibility to PHABSIM Version 2, and (2) to simplify the bookkeeping and calibration processes. We sought to both improve clarity of the various options for each program and graphically display the results of applying each program. The ability to view plots of model results during the calibration and option selection processes greatly speeds up calibration and increases understanding of the effects of selecting various habitat simulation options.

To ensure the quality of PHABSIM for Windows, extensive testing and comparison with the DOS-based PHABSIM Version 2 was performed. Several data sets were run through both versions and all options of all programs were run and compared. In addition, both English and metric units were tested to ensure that entire analyses could be reliably conducted in metric units. Our emphasis was on retaining the full set of PHABSIM analytical functions and extensively testing the programs rather than on adding program enhancements.

Use of This Document

This document is a combined self-study textbook and reference manual. The material is presented in the general order of a PHABSIM study placed within the context of an IFIM application. The document may also be used as reading material for a lecture-based course. This manual provides documentation of the various PHABSIM programs so every option of each program is treated.

This text is not a guidebook for organization and implementation of a PHABSIM study. Use of PHABSIM should take place in the context of an IFIM application. See Bovee et al. (1998) for guidance in designing and performing a PHABSIM study as part of a larger IFIM application.

The document concludes with a set of 12 laboratory exercises. Users are strongly encouraged to work through the laboratory exercises prior to applying the software to a study. Working through the exercises will enhance familiarity with the programs and answer many questions that may arise during a PHABSIM analysis.

Changes Between PHABSIM Version 2 and PHABSIM for Windows

The first obvious change between PHABSIM Version 2 (DOS) and PHABSIM for Windows is use of the Windows graphical user interface and development of the necessary interface programs. The graphical user interface program now includes considerably more code than the analytic al core programs. Additional benefits of developing an extensive interface program include the following: file management is largely done by program; users no longer need to keep track of file names and the risk of removing a file needed at a later step has been essentially eliminated and each study site is kept in a separate, user-specified, project directory, reducing the risk of confusing project files.

In developing this version of PHABSIM, certain decisions were made regarding the structure of PHABSIM data and analyses. All cell definitions now match the data gathering approach taught in the IF305 field techniques course. The cell definition distinctions HABTAE and HABTAV have disappeared and all HABTAV options are now included in HABTAE. Thus, there is no HABTAV program. For consistency, HABTAM cell definitions also match those used in HABTAE. The 100 cell per cross section limit has been eliminated so an unlimited number of cells may be defined for each cross section.

Another difference is the consolidation of AVDEPTH and AVPERM into one program. In doing so, the options and outputs of both programs have been retained.

With these changes have come some differences in computed results. The core analytical programs were translated into C++ from Fortran. Different compilers have different methods of creating machine language so there can be small differences in results of numerical calculations. This is largely due to a combination of order of the calculation, round-off error, method of optimization used within the compiler, etc. While in most situations the differences between the DOS PHABSIM Version 2 and PHABSIM for Windows are very small, there are situations where these differences can accumulate.

The following is an example of possible calculation discrepancies that may occur between the DOS PHABSIM and Windows PHABSIM. Both the Windows and old DOS versions were run for the same study site. The results for a specific cell in the study site at the same discharge and one selected life stage are shown in Table 1.

For illustration, the Weighted Usable Area (WUA) calculation had equal velocity Suitability Index (SI) and channel index SI values (1.0 and 0.91 respectively.) For the species/life stage in question, the depth suitability curve had a steep slope at this point (depth of 0.8 = SI of 0.06 and depth of 0.85 = SI of 0.15). The steep slope of the suitability curve gave a large difference in suitability for a small difference in calculated depth. Thus, noticeable differences in the final computed WUA value between DOS PHABSIM Version 2 and PHABSIM for Windows are likely in situations where the SI criteria are very sensitive to changes in the parameter(s) (depth in this case) for that cell.

Thus, for a relatively small difference of 0.014 in WSL, we show a large difference in WUA for the cell. The WSL model is performing as expected and is within reasonable calibration error for the data set. The differences in water surface elevation have been determined to be due to compiler differences as all calibration parameters were set to the same values in both versions and the internal calculations were traced to ensure they were being accurately performed.

It should be noted that over an entire cross section or over a study site, few cells show these dramatic differences and the resulting calculated WUA differences are usually less than 1 to 2%. Although no study site WUA difference greater than 10% was found during testing, larger differences could occur if a study encounters a situation where numerous cells have differences similar to that illustrated above.

Windows		DOS	Difference	% difference
Cell bed elevation	91.65	91.65	0	0.00
Water surface elevation	92.456	92.47	0.014	0.02
Depth	0.806	0.82	0.014	1.71
Depth Suitability Index	0.0708	0.096	0.025	26.25
Combined Suitability Index	0.0644	0.087	0.023	26.25
Weighted Usable Area	8.698	11.79	3.096	26.25
Acknowledgements				**i**
PREFACE				**ii**

Table 1. Example of propagating differences between PHABSIM for Windows and DOS PHABSIM.

Conventions Used in This Document

IOC References to Old PHABSIM

PHABSIM Version 2 (DOS) (Milhous et al., 1989) used lines of numerical switches to control program options. These were referred to as IOC (originally input/output control) lines. Users became familiar with selecting program options by remembering items like "IOC 5 set to 2 and IOC 8 set to 1". While these options are now described in the PHABSIM for Windows interface using text phrases, the old IOC numbers are also displayed with the text to aid experienced users in migrating to PHABSIM for Windows.

Menu Notation

The PHABSIM for Windows software is menu driven through a graphical user interface and the familiar Windows point and click sequence to operate program menus and options. An abbreviated notation convention is used throughout this document to instruct readers in how to make option selections without filling a large amount of space on the page with screen images for each action to be performed.

The following example illustrates how to assign the calibration data sets to each of the desired simulation flows when using the STGQ model. The first item is part of the main menu list that is always displayed at the top of the main PHABSIM window. Subsequent items are submenu items or choices that users will see on the screen as they work across the line. The "/" character is a delimiter to separate higher-level menu items from lower level items. Menu navigation notation is always displayed in **bold** type.

Example notation for using PHABSIM for Windows menus:

> "To assign calibration sets to specific simulation discharges, go to **/Models/WSL/STGQ Options/Assign Cal Sets** and click the check boxes for the appropriate discharge/cal set combinations in the table shown".

To follow this example, the user would click on the main menu item **Models** followed by clicking in order the **WSL** item in a drop down menu, the **STGQ Options** tab, and the **Assign Cal Sets** button to arrive at the data entry table. This notation is further illustrated in Chapter 1.

Table of Contents

Windows		DOS	Difference	% differenc
Cell bed elevation	91.65	91.65	0	0.00
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Acknowledgements **i**
PREFACE **ii**
A Brief History of PHABSIM
Use of this Document
Changes Between PHABSIM Version 2 and PHABSIM for Windows
Conventions Used in this Document
Chapter 1, Introduction to the Physical Habitat Simulation System **1**
Objectives
Associated Laboratory Exercises
An Overview of IFIM
The Purpose of PHABSIM
The Structure of PHABSIM
Application of PHABSIM
Scoping
Selection of Target Species and Suitability Curves
Selection of Target Species
Types of Suitability Curves
Transferability of Suitability Curves
Segmenting the Study Area and Study Site Location
Critical Reach
Mesohabitat Study Site Selection
Cross Section Selection and Field Data Collection
Cross Section Selection
Field Data Collection
Hydraulic Modeling
Water Surface Elevation Modeling
Velocity Modeling
Habitat Modeling
The Average Parameter Model
Distributed Parameter Models
Effective Habitat Analysis in PHABSIM
Interpreting PHABSIM and Completing the IFIM Process
Use of the PHABSIM for Windows Menu System
PHABSIM for Windows File Structure
Analysis Limits in PHABSIM for Windows
Summary of Chapter 1
Chapter 2, Hydraulic Modeling in PHABSIM **25**
Objectives
Laboratories
Introduction
Terms and Definitions of Open-Channel Flow
Equations Used for the Description of Open-Channel Flow
Continuity and Mass Balance

Union Analysis
Competition Analysis
Stream Flow Variation Analysis

Manning's Equation Energy Balance and the Bernoulli Equation Applied Modeling of Water Surface Elevations in PHABSIM Modeling of the Stage-Discharge Relationship by Regression Determining the Stage of Zero Flow
Stage-Discharge Analysis using Regression in PHABSIM – The STGQ
Model Running the STGQ Model A Practical Guide to Modeling Stage-Discharge Relationships Using the Regression Approache
Modeling the Stage-Discharge Relationship Using Manning's Equation – The MANSQ Model Running the MANSQ Model MANSQ Options A Practical Guide to Calibrating MANSQ
Modeling the Stage-Discharge Relationship Using A Step-backwater Approach – WSP General Theory of the WSP Model A Conceptual Overview of WSP Calibration Calibration of WSP to Additional Longitudinal Profiles using Roughness Modifiers (RMODs) Adjusting n Values for Individual Transects Determining Initial Water Surface Elevations for Calibrated WSP Models A Step-by-Step WSP Calibration Strategy Hydraulic Controls Divided Flow Running the WSP Model
Modeling of Velocities in PHABSIM
Calibration and Simulation of Velocities VELSIM with No Measured Velocities VELSIM with a Single Velocity Data Set VELSIM with Multiple Velocity Data VELSIM Computational Procedures and Mass Balance Significance of Initial Slopes and Manning's n Values in VELSIM
Nose Velocities Control of VELSIM Calibration and Simulation Options Evaluating Quality of the Hydraulic Modeling Evaluation of Water Surface Modeling Predicted versus Observed Water Surface Elevations at Calibration Flows Longitudinal Profiles of the Water Surface Elevations Valid Ranges of Simulated Discharges
Evaluation of Velocity Modeling

Chapter 3, Habitat Suitability Criteria
Objectives

Laboratories
Introduction
Format
HSC Categories
Criteria Verification
Discussion Items
Organization of Habitat Suitability Criteria in PHABSIM
Accessing Habitat Suitability Criteria in PHABSIM for Windows
Summary of Chapter 3

Chapter 4, Habitat Modeling
Objectives
Laboratories
Introduction
Habitat Model Computational Cells
Deriving Habitat Computational Cell Areas and Volumes
Representative Reaches
Habitat Mapping and the Idealized River Reach Approach
Integrating Habitat Suitability Criteria Curves and Computational Cell Attributes
Basic Assumptions of Habitat Modeling
Habitat Modeling Options in PHABSIM
The Average Parameter Model AVDEPTH/AVPERM
Running AVDEPTH/AVPERM
The HABTAE Program
Setting HABTAE Options
Description of Habitat Calculation Options
ZHAQF Options
Using Bends
Using Minimum Contiguous Width
Use of a Zero Channel Index Value
Near Shore Habitats
Weighted Usable Area Calculations and Independent Cross Sections
The Form of the Habitat Calculation
Velocity Limits and Eddies
Minimum Effective Composite Suitability
Nose Depth: Empirical Calculation of a Velocity at a Given Depth
Replacements for Velocity
Habitat Calculations Conditioned on Adjacent Velocities
Selecting the Form of the Adjacent Velocity Calculation
Adjacent Velocity Calculation Example
Evaluating HABTAE Results
Running HABTAE
Lateral Migration Analysis using the HABTAM Program
Setting HABTAM Options
Running HABTAM
Effective Habitat Analysis using the HABEF Program

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Acknowledgements **i**
PREFACE **ii**
A Brief History of PHABSIM
Use of this Document
Changes Between PHABSIM Version 2 and PHABSIM for Windows
Conventions Used in this Document
Chapter 1, Introduction to the Physical Habitat Simulation System **1**
Objectives
Associated Laboratory Exercises
An Overview of IFIM
The Purpose of PHABSIM
The Structure of PHABSIM
Application of PHABSIM
Scoping
Selection of Target Species and Suitability Curves
Selection of Target Species
Types of Suitability Curves
Transferability of Suitability Curves
Segmenting the Study Area and Study Site Location
Critical Reach
Mesohabitat Study Site Selection
Cross Section Selection and Field Data Collection
Cross Section Selection
Field Data Collection
Hydraulic Modeling
Water Surface Elevation Modeling
Velocity Modeling
Habitat Modeling
The Average Parameter Model
Distributed Parameter Models
Effective Habitat Analysis in PHABSIM
Interpreting PHABSIM and Completing the IFIM Process
Use of the PHABSIM for Windows Menu System
PHABSIM for Windows File Structure
Analysis Limits in PHABSIM for Windows
Summary of Chapter 1
Chapter 2, Hydraulic Modeling in PHABSIM **25**
Objectives
Laboratories
Introduction
Terms and Definitions of Open-Channel Flow
Equations Used for the Description of Open-Channel Flow
Continuity and Mass Balance

Union Analysis
Competition Analysis

Chapter 1. Introduction to the Physical Habitat Simulation System (PHABSIM)

Objectives

This chapter provides a broad overview of the components of the Physical Habitat Simulation System (PHABSIM). The chapter begins with a summary of the Instream Flow Incremental Methodology (IFIM) to ensure readers are exposed to PHABSIM use in the broader context of IFIM. Readers already familiar with PHABSIM can move directly to Chapter 2.

Associated Laboratory Exercise

Laboratory 1 introduces the structure and use of the PHABSIM for Windows software system and Laboratory 2 covers initial data entry steps required for a PHABSIM analysis.

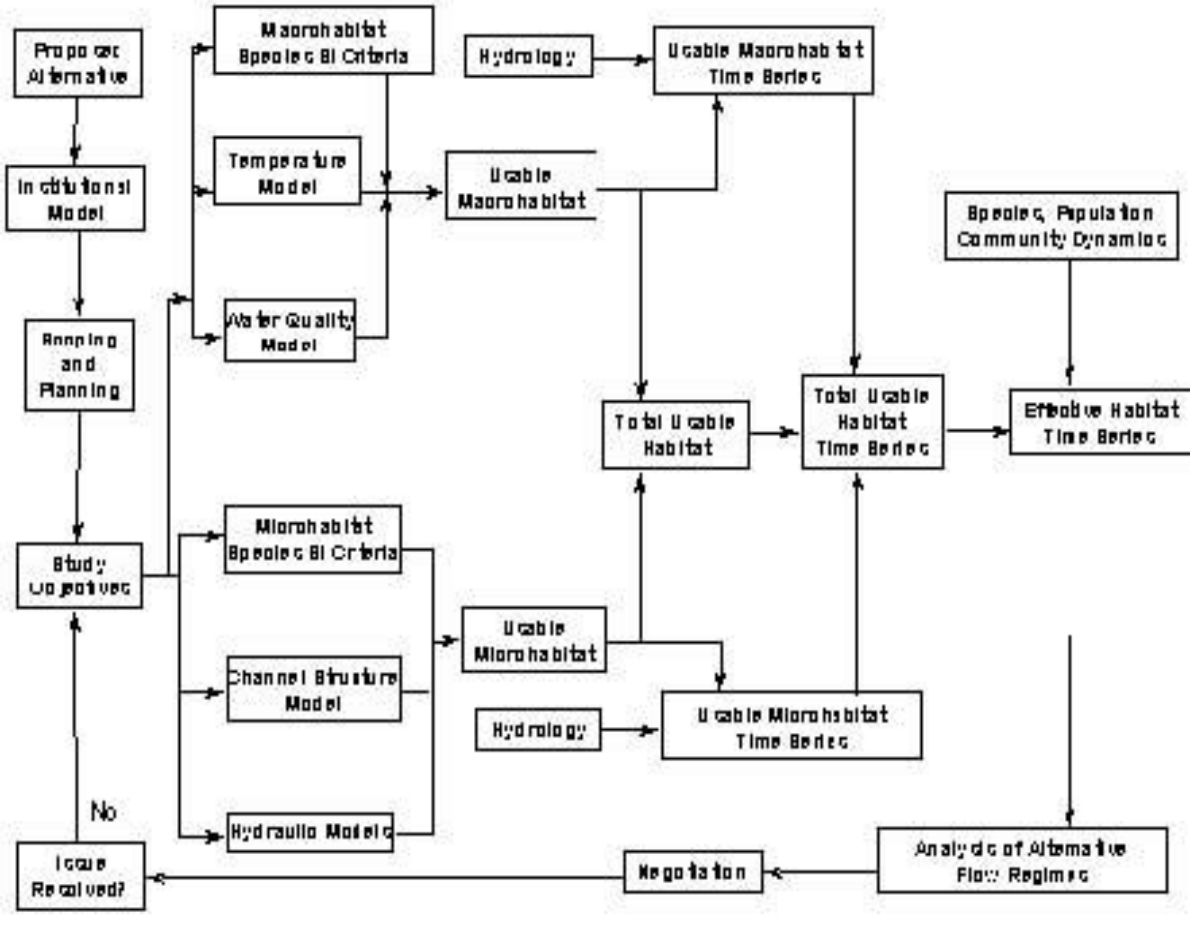
An Overview of IFIM

PHABSIM is part of a broad conceptual and analytical framework for addressing stream flow management issues called the Instream Flow Incremental Methodology (IFIM) (Stalnaker et al., 1995) (Figure 1-1). IFIM provides a problem-solving outline for water resource issues in streams and rivers. IFIM and PHABSIM were developed as aids to instream flow decision making. Thus, the structure addresses the decision making environment as well as the techniques for quantifying incremental differences in instream habitat that result from proposed alternative instream flow regimes. Figure 1-1 shows the major components and model linkages of IFIM and where elements of PHABSIM fit into this framework. Integration of PHABS IM with other modeling and analysis efforts is strongly encouraged under the IFIM framework.

> "IFIM is based on the analysis of habitat for stream-dwelling organisms under alternative management treatments. One could logically question why habitat was chosen as the decision variable in IFIM when there are so many other factors (such as stream productivity or fishing mortality) that can potentially influence fish populations. The simplest reason for basing the analysis on habitat is that IFIM was designed to quantify environmental impacts, and impacts to habitat are the most direct and quantifiable." (Stalnaker et al., 1995, p. 16).

The four major ecological components of a stream system that determine productivity for aquatic animals are:
(1) flow regime; (2) physical habitat structure (e.g., channel form and substrate distribution); (3) water quality (including temperature); and (4) energy inputs from the watershed (nutrients and organic matter) (Karr and Dudley, 1981). The complex interaction of these components determines primary production, secondary production, and ultimately the status of fish populations in the stream. In riverine systems, the amount and quality of suitable habitat can be highly variable within and among years. Observed populations and biomass of fish and invertebrates can be expected to be a function of the four components operating on a variety of temporal and spatial scales. Habitat-induced population limitations are related to the amount and quality of habitat available to fish and invertebrate populations at critical stages in their life history. Long-term habitat reductions, such as reduced flows, may be important in determining population and production levels.

Figure 1-1. Major components of IFIM.



IFIM was designed to address these four ecological components in the context of management decisions concerning instream flow. As such, IFIM also includes mechanisms for analyzing the institutional aspects of water resource issues (i.e., the Institutional Model in Figure 1-1), study scoping and planning process, along with techniques for negotiation and resolution.

Two of the most important aspects of any PHABSIM study are that it is set in the IFIM framework and that it is adequately planned. When the problem scoping phase of an IFIM study indicates that the water management issue is an incremental rather than a standard setting issue, PHABSIM can provide the microhabitat component of the analysis (Stalnaker et al., 1995, Chapter 2). The IFIM study may also incorporate models and/or expert knowledge to assess water quality, water temperature, geomorphology, or other characteristic features of the stream and its current and proposed flow regimes that could influence habitat or populations of aquatic organisms within the stream corridor. In any IFIM application, care should be taken to ensure that the factors that control the instream habitat have been fully considered prior to the use of PHABSIM. For example, it would not make sense to only apply PHABSIM to a stream where the sole limit to habitat is water quality. An IFIM study in such a situation may be appropriately limited to only water quality induced limits to habitat quality and quantity. That is,
an IFIM study may be appropriately conducted without use of PHABSIM if physical habitat is determined not to be a major limiting variable. A complete treatment of IFIM is beyond the scope of this document. Users of PHABSIM are strongly encouraged to read *"Stream Habitat Analysis Using the Instream Flow Incremental Methodology"* (Bovee et al. 1998) and "*A Primer for the IFIM"* (Stalnaker et al., 1995) and to conduct PHABSIM analyses within the framework of an IFIM application.

The Purpose of PHABSIM

PHABSIM predicts physical microhabitat changes associated with flow alterations such as a reduction of stream flow from 125 cfs to 100 cfs in June. It provides a variety of simulation tools, which characterize the physical microhabitat structure of a stream and describe the flow-dependent characteristics of physical habitat in light of selected biological responses of target species and life stages. When interpreting PHABSIM results, an assumption is normally made that flow-dependent physical microhabitats are useful in determining carrying capacity and therefore are related to the instream flow needs or impacts of flow variations on fish or other aquatic organisms in streams.

The relationship of physical habitat to fish (or any other aquatic organism) production assumes the production of benefits for fish is limited by the availability of physical habitat. This assumption is not always true. Production may be limited by water quality (i.e., acid rain in the Canadian Shield region), by the activities of man (i.e., land use activities or over-harvesting of some species), or by events and conditions occurring at a temporal and spatial scale beyond the scope of the model application. In essentially all situations, physical habitat is a necessary, but not sufficient, condition for production and survival of aquatic organisms. Thus, PHABSIM results may best be viewed as an indicator of population *potential* in systems where the habitat conditions described in PHABSIM are major population constraints. The IFIM process (see Figure 1-1) contains a critical problem-scoping phase where the analyst(s) must evaluate the plausible limiting environmental variables before embarking on an instream flow needs study. The likely relationship of microhabitat to organism abundance needs to be determined on a case-bycase basis through localized studies or analyst consensus attained within the IFIM process.

To understand PHABSIM one must understand how the general term "habitat" is used. *Macrohabitat* refers to a longitudinal portion of stream within which physical and/or chemical conditions influence the suitability of an entire stream segment for an aquatic organism. *Mesohabitat* is a discrete area of stream defined by the channel geometry with similar physical characteristics, e.g., slope, width, depth, and substrate. Such channel geomorphic units (Hawkins, et. al. 1993) are commonly named pool, run, riffle, etc. *Microhabitat* refers to the small, localized areas within a larger scale mesohabitat unit used by an aquatic organism for specific behaviors (e.g., spawning). Microhabitat is typically described by a combination of hydraulic and/or physical variables such as, depth, velocity, substrate, and cover at a spatial scale of near zero to a few meters. Finally, *total habitat* is an aggregation of available wetted area conditioned by microhabitat and macrohabitat suitability. It is summed for all stream segments, i.e., total habitat is the area of a stream with suitable macro and microhabitat. The microhabitat measures in PHABSIM must be integrated to mesohabitat and total habitat spatial scales and evaluated over the appropriate spatial scale. The PHABSIM software does not directly provide this integration facility. Such integration is easily accomplished using spreadsheets and other commonly available commercial software.

PHABSIM estimates changes in physical microhabitat as a function of flow, but does not directly address other elements of stream systems such as water quality and energy inputs. However, as will be discussed in later sections of this manual, inclusion of other components of interest such as changes in channel configuration can often be accommodated. PHABSIM describes flow-dependent changes in physical components of the system and translates them into an estimate of the quality and quantity of microhabitat for aquatic organisms. Incremental changes in stream flow are used to produce relationships between simulated depth and velocity, measured channel index (e.g., substrate and cover), and microhabitat for target species and life stages. Similar relationships can be produced for broader mesohabitat conditions such as low or high gradient riffles, adequate density of woody debris, pools greater than a specified depth, etc. that can be related to communities as well as individual species of aquatic organisms.

The most commonly used output from PHABSIM is Weighted Usable Area (WUA). This habitat measure is a combination of physical microhabitat quantity and quality. WUA is expressed in units of microhabitat area per unitized distance along a stream (e.g., square feet per 1000 feet of stream or m^2 per 1,000 m). In IFIM, microhabitat values derived from PHABSIM serve as input to an assessment of alternative stream flow management proposals leading to negotiation of flow regimes. These values may also be used in establishment of mitigation targets and for spatial niche analysis.

PHABSIM is intended for use in those situations where stream flow is one a limiting factor controlling aquatic resources and field conditions are compatible with the underlying theories and assumptions of the various habitat and hydraulic models. In practice, if the assumptions of the various hydraulic and habitat models are reasonably met, PHABSIM can be coupled with habitat time series analysis to incorporate the temporal component of habitat variability (see the IFIM general layout in Figure 1-1) to address a variety of applications which include but are not limited to:

- Quantification of instream flow requirements
  - Area wide planning
  - Reservation or licensing of water rights

- Negotiation of water delivery schedules
  - Minimum release schedules
  - Hourly, seasonal and yearly flow regimes (normal and dry year conditions)

- Impact analysis
  - Stream flow depletion
  - Stream flow augmentation
  - Channel alterations

Note that these outcomes follow from integrating PHABSIM analytical results with alternative discharge time series to arrive at habitat time series. PHABSIM alone does not address the issues of time varying habitat requirements to maintain species life cycles.

The Structure of PHABSIM

The focus of this document is on the PHABSIM software, although some discussions on study scoping, study site selection, habitat mapping mesohabitat classification, cross section placement, and impact assessment are provided for completeness. Figure 1-2 provides a schematic "road map" to the basic modeling elements of PHABSIM. It also presents the flow of information between the various modeling components. The reader is strongly encouraged to refer to *"Stream Habitat Analysis Using the Instream Flow Incremental Methodology"* (Bovee, et al. 1998) for guidance in using PHABSIM as part of an IFIM study.

Figure 1-2 illustrates several key features representing both the conceptual and practical processes for modeling instream habitat in PHABSIM. First, a new project is defined and either an old (DOS) format data file is imported or raw field data is entered using the PHABSIM for Windows data entry interface. Once the data have been entered and checked, the analyst then proceeds with the calibration and simulation of water surface elevations using any (or a combination) of the three available hydraulic simulation models: STGQ, MANSQ, and/or WSP. Upon completion of the water surface elevation modeling, the analyst then proceeds to calibration and simulation of velocities within the VELSIM program. The selection or development and entry of appropriate target species and life stage habitat suitability criteria (HSC) curve data can be done in parallel as indicated in Figure 1-2. Finally, the user will select the appropriate habitat model(s) and set the required or desired modeling options and generate the habitat versus discharge results which are indicated by the box labeled habitat-flow relationship at the lower right of Figure 1-2. At this point, the microhabitat analyses are completed and these results can be integrated with macrohabitat results or utilized directly in the IFIM assessment framework as illustrated in Figure 1-1.

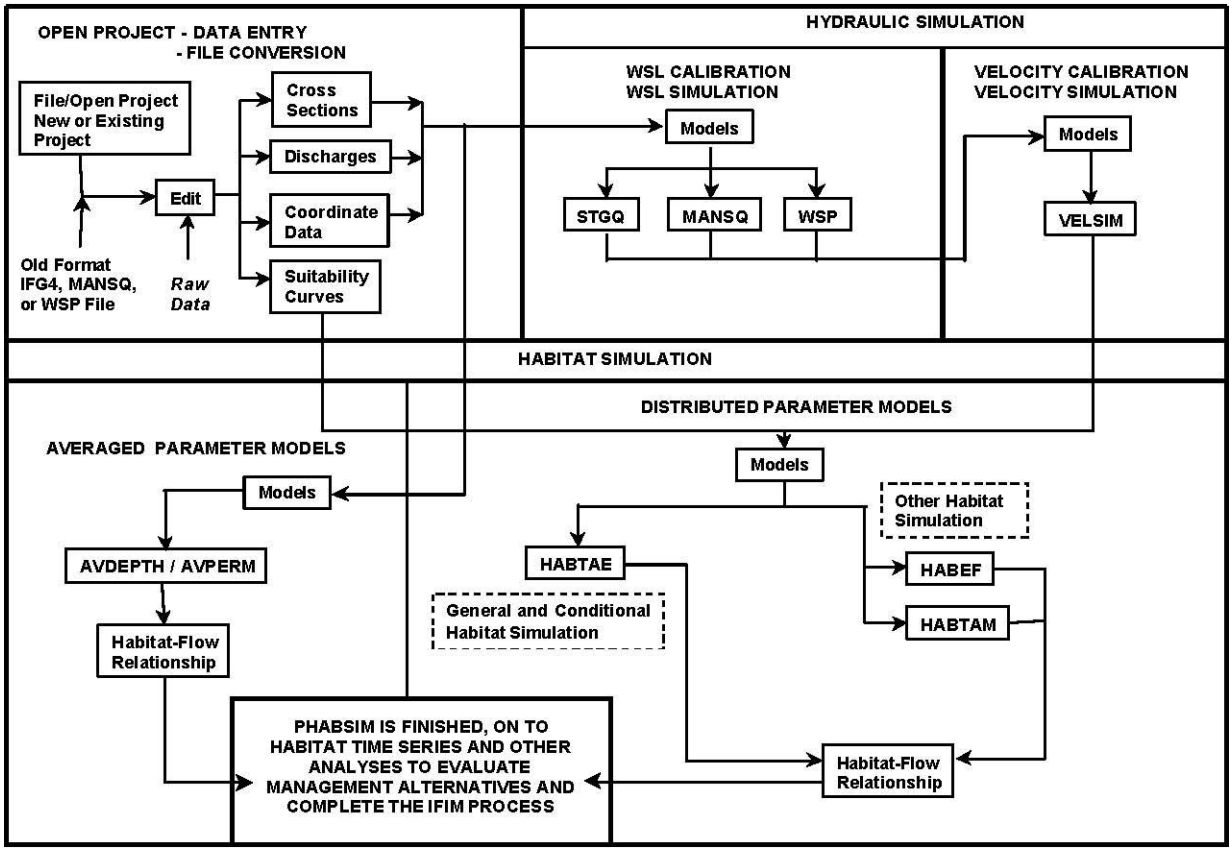


Figure 1-2. PHABSIM for Windows flowchart.

Application of PHABSIM

Once PHABSIM has been determined to be an appropriate analysis tool in the scoping and tool selection stages of IFIM, the general approach to its application can be broken down into nine conceptual steps. These provide an initial outline for the application of the model and a guide to some of the issues involved. Individual studies may deviate from these steps and in all cases users should carefully consider, justify, and document decisions made to structure the analysis for a particular application.

The nine steps (see Bovee, et al., 1998, and Stalnaker et al., 1995) involved in application of PHABSIM within the IFIM context include:

1. Scoping: identification of habitat information needs and study objectives, selection of methods, IFIM Phase II (if PHABSIM is a selected method, proceed to steps 2 – 9 below)
2. Selection of target species or guild, selection or development appropriate micro and or macrohabitat suitability criteria, IFIM Phase II
3. Study area segmentation and study site selection, IFIM Phase III
4. Cross section placement and field data collection, IFIM Phase III
5. Hydraulic modeling, IFIM Phase III
6. Habitat modeling, IFIM Phase III
7. Derivation of total habitat time series, micro and macrohabitat, IFIM Phase III
8. Determination of habitat bottlenecks, IFIM Phase III
9. Evaluation of management alternatives and problem resolution, IFIM Phase IV

Although the remaining chapters of this manual will primarily focus on the technical aspects of the hydraulic and habitat modeling, and to a lesser degree on HSC and assessment frameworks, each of these conceptual steps is briefly described below. Reference materials on study scoping, field data collection techniques, and general approaches on impact assessment frameworks can be found in Bovee, et al. (1998) and *Data Collection Procedures for the Physical Habitat Simulation System (*Bovee, 2000).

Scoping

This section gives a very brief outline of the project scoping process. The reader is encouraged to carefully read Bovee, et al. (1998) prior to engaging in an IFIM or PHABSIM study.

Project scoping should follow a pragmatic approach based on the importance of the issues to be addressed. Project records should include supporting evidence for each of the choices made. Project scoping should address the following questions:

1. **Why?** A statement of study objectives. The outputs, expectations, and requirements of the project should be stated in as much detail as practicable and, where possible, agreed before starting. The "why" is important for determining whether a PHABSIM study is appropriate to the problem.

2. **Where?** Identification of the impacted area or areas to be studied. A decision on the best approach to study site selection must be made, such as whether a critical or representative reach or stratified random sampling based on habitat mapping (mesohabitat classification) is more appropriate (or even a combination of the methods). How should the available mesohabitats be classified? How should mesohabitat study sites be selected? A further consideration is physical access and the location of gauging stations that can provide suitable hydrological data.
3. **Skills?** Identification of skills required and selection of personnel. PHABSIM applications generally require input from a multidisciplinary team, including expertise in aquatic biology, hydrology, hydraulic and habitat modeling, interpretation of PHABSIM outputs, and possibly in negotiation.
4. **Limiting factors?** Use of PHABSIM for a study and interpretation of WUA results will be different if physical habitat is one of the factors limiting target species populations than if it is not limiting. Characterization of macrohabitat issues (e.g., water quality and temperature) and consideration of other factors such as exploitation and stocking, food availability and competition, channel dynamics and sediment transport may be necessary to link

changes in habitat with production of target organisms. Such linkages may be best addressed with other models, or predictive techniques such as multivariate regression analysis or regression quantiles (Cook, et al., 2000). Habitat for food organisms may be modeled using habitat suitability criteria for selected invertebrate species.

5. **Which organisms?** Selection of target species and life stages. It is seldom possible to evaluate the effects of changes in physical habitat on all species or even life stages in a stream. During the scoping process, an indicator species or species which may be the most sensitive to habitat change, which characterizes changes in habitat for an assemblage of other species, or represents a major management interest of the participants in the instream flow assessment may be selected. The management issue driving the study, combined with advice from fisheries and conservation personnel, will determine if the study is to concentrate on a broad range of species, or a small number of specific species or life stages. One method used to select species is to rank them, according to various criteria, including their importance, vulnerability, and extent of available information. Users should locate any existing sources of habitat suitability criteria information; assess their "transferability" (see below); and identify possible strategies for HSC curve development, if existing information is not available or is not sufficiently comprehensive. The importance of characterizing fish species by size/age class cannot be underestimated. Size will have a significant impact on what conditions constitute habitat. The characterization to be used must be compatible with available suitability data.

6. **When?** The temporal aspects of the study must be considered. This includes the timing of field data collection (e.g., when can high/low flows be considered? Is annually variable vegetation growth an issue?). Users are encouraged to construct species periodicity charts (which target species/life stages are important and when?) and determine the availability of suitable hydrological time series data (there is likely to be a requirement for flow data both with and without the artificial influence being investigated).

7. **Who?** The responsible parties must be identified and a clear commitment by those individuals and agencies to carry out the study stated in writing as part of the study plan.

Selection of Target Species and Suitability Curves

Use of PHABSIM involves both the selection of target species as well as the development and/or selection of habitat suitability criteria curves for use in the habitat models. This document does not deal with development of HSC curves. A vital part of a PHABSIM study is defining what conditions provide favorable habitat for the target species being considered. Microhabitat in PHABSIM is defined by water depth, velocity, and channel index. Channel index represents substrate, cover, or other similar immobile variable(s) important in defining the physical habitat requirements of the target species. Habitat suitability criteria (HSC) have been referred to as suitability indices, suitability criteria, preference indices, preference curves, and suitability curves in previous IFIM-related publications and in the general literature. These terms are not entirely synonymous, so the reader is cautioned to check the definitions used in each publication. An example of a set of HSC is provided in Figure 1-3.

It is important that consideration be given to the selection of habitat suitability criteria as early in the scoping process as possible for the following reasons:

1. The scoping process attaches an importance to HSC, which is otherwise easy to overlook. Their simple nature when presented graphically belies the effort behind their development, and interpretation. To simply adopt whatever curves are available after hydraulic modeling is complete may greatly hinder meaningful interpretation of habitat model outputs. Consensus about the HSC among project proponents, regulatory agencies, and other stakeholders early in the project planning process is often essential to successful completion of a PHABSIM study.

2. From the beginning of the analysis the scoping process determines the form and coding of the channel index data to be collected and indicates the areas in the stream that analysts should take care not to overlook.

3. If no acceptable habitat data exist, it may be necessary to initiate a data collection program which can require a long time period, even more so than the site data collection and hydraulic modeling phases of the analysis.

4. PHABSIM results are very sensitive to HSC.

A PHABSIM analysis report should either justify transferring habitat suitability criteria developed elsewhere to the study stream, refer to development of HSC curves specifically for the study in question, or document the agreements by which consensus on HSC curves for the study was attained.

Selection of Target Species

A fundamental step during the initiation of a PHABSIM study is the identification and selection of target species and life stages. Valuable data may be obtained from fisheries collection records, stocking records, and management agencies to determine the historical and existing structure of the fish community. In some stream systems, species and/or life stages (such as migrating salmonids) may only be present in the system for a short period. Historical records of fish numbers can be used in determining whether or not management decisions are to focus only on what is present now or on potential restoration and recovery efforts.

Once the initial list of candidate species and life stages has been assembled, data should be organized into a species and life stage periodicity chart which highlights the seasonal (e.g., at least as small as monthly divisions) use of the study area(s) by different life stages of the target organisms. Next, the availability of existing HSC should be determined and decisions made as to whether to proceed with collection of site specific habitat suitability data, collection of transferability testing data, and/or HSC reviews by species experts, from which a final set of curves can be determined. It may be possible to consider some species or life stages without developing locally derived HSC by using literature values. However, in applied PHABSIM studies, not all the target species or life stages have HSC available even from the broader literature sources. When development of site specific HSC is not an option, users may take a guilding approach to represent components of the fish community by mesohabitat use. Here again, literature values or expert consensus may be needed to define community-based HSC.

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Windows		DOS	Difference	% difference
Cell bed elevation	91.65	91.65	0	0.00
Water surface elevation	92.456	92.47	0.014	0.02
Depth	0.806	0.82	0.014	1.71
Depth Suitability Index	0.0708	0.096	0.025	26.25
Combined Suitability Index	0.0644	0.087	0.023	26.25
Weighted Usable Area	8.698	11.79	3.096	26.25

Acknowledgements **i**
PREFACE **ii**
A Brief History of PHABSIM
Use of this Document
Changes Between PHABSIM Version 2 and PHABSIM for Windows
Conventions Used in this Document

In general, suitability curves have been classified according to the following categories (Bovee et al., 1998,

Transferability of Suitability Curves

Regardless of how the data are collected, suitability curves will demonstrate some specificity to the stream(s) in which they were developed. With limited resource availability and the high cost associated with development of stream-specific suitability curves, use of HSC from other streams is common. Thus, checking for the appropriateness of the transfer is important. Avoiding development of study-specific HSC leads to considerable cost savings. The investigator must apply professional knowledge and judgment to evaluate if the source curves are meaningful for the current application and transferable. In the IFIM context, it is essential for all parties to agree on the HSC to be used for the study and to agree on their transferability. Thomas and Bovee (1993) and Groshen and Orth (1994) provide methods for quantitatively testing HSC transferability. Manly (1993) provides general guidance on modeling habitat selection by various animals.

For further discussion of habitat suitability criteria curves, see Bovee (1996), Bovee et al. (1998), and Chapter 3.

Segmenting the Study Area and Study Site Selection

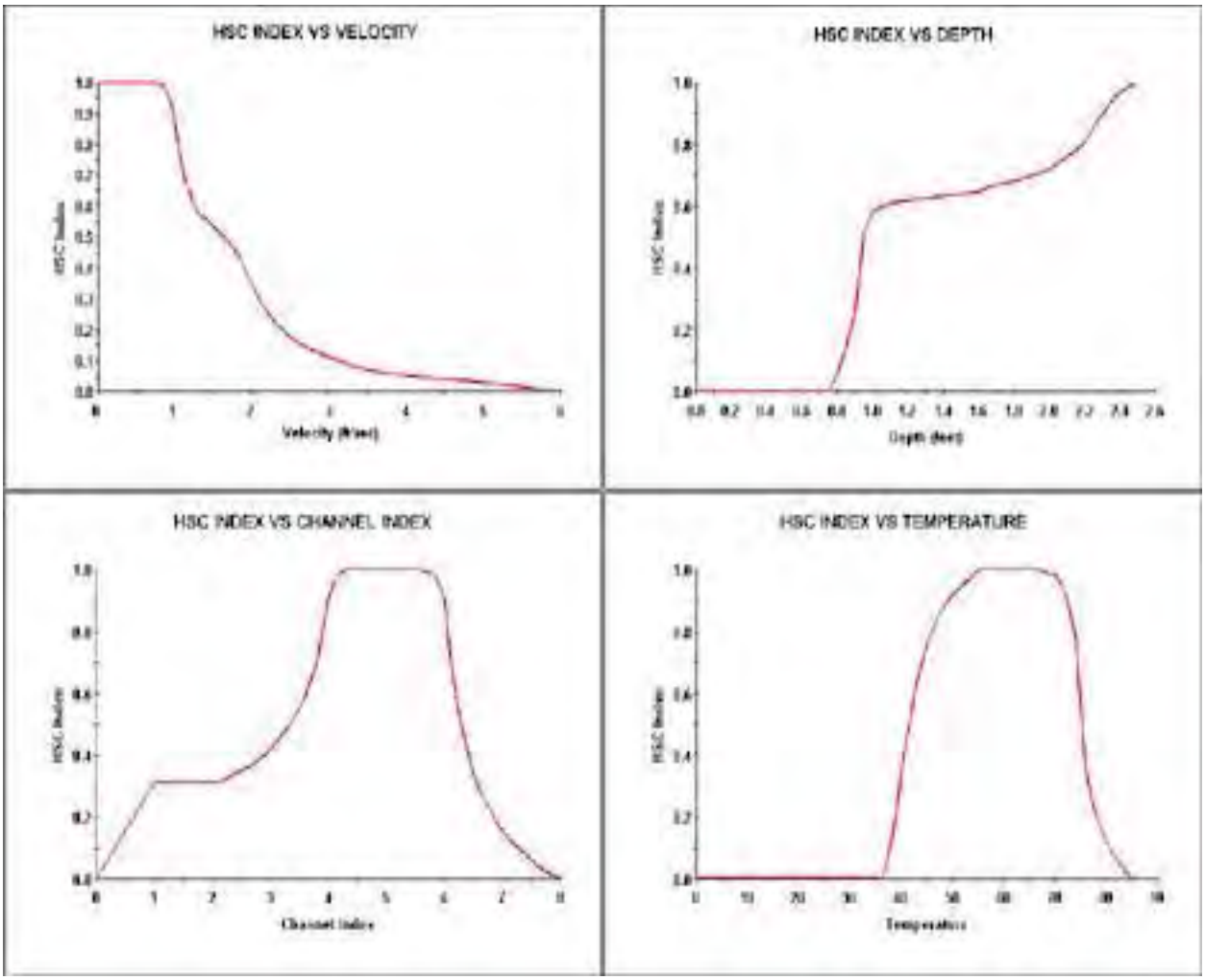
Three approaches are commonly used to sample microhabitat: a critical reach study site, a representative reach study site, or a collection of mesohabitat type study sites. (Bovee et al. 1998) All three require that the stream be segmented using a five-step process. These steps are as follows:

1. Identify the study area boundaries; that is, the reach of stream that is or will be impacted by an altered flow regime.
2. Identify the study area boundaries; that is, the reach of stream that is or will be impacted by an altered flow regime.
3. Segment the study area into hydrologic segments that is reaches of stream that have a homogeneous hydrograph.
4. Segment the hydrologic segments into sub-segments based on geomorphologic factors that influence habitat suitability. For example, within a hydrologic segment there are two reaches that have distinctly different slopes but similar hydrographs. One reach has a mean slope of 1.5 feet per mile while the other is 2.8 feet per mile. Since this factor controls water velocity and sediment (substrate), variables used to describe microhabitat, the hydrologic

segment should be further divided into two sub-segments.

5. Identify the type of study site(s) that will be sampled: critical reach study site, a representative reach study site, or mesohabitat type study sites. Once this decision is made then specific study sites are selected using a stratified random or stratified systematic sampling scheme. If the mesohabitat types approach is used then a mesohabitat type classification must be developed and proportions inventoried within each segment or sub-segment.
6. Place cross sections within each study site using a stratified random or stratified systematic sampling scheme plus place cross sections on all hydraulic controls within or on any hydraulic control having an influence on any portion of the study area.

Figure 1-3. An example of Habitat Suitability Criteria for Adult Brown Trout (one life stage of one species).


HSC INDEX VS VELOCITY
HSC INDEX VS DEPTH
HSC INDEX VS CHANNEL INDEX
HSC INDEX VS TEMPERATURE

The approach used depends on individual study objectives and may involve a combination of the above procedures. The procedure characterizes the study area microhabitat(s) important to the selected target species/life stages affected by the water resource issue in question. When initiating a study, the length of the study area, hydrologic segment(s), and sub-segment(s) over which the assessment is required should be quantified. The more homogeneous the stream segment or sub-segment is in terms of its hydrological and geomorphic characteristics, the more accurate the extrapolation from study site simulations to the entire study area will be.

Critical Reach

This approach uses a specific reach (or reaches) of the stream that is most sensitive to changes in flow, and/or is critical to the success of a particular species' life stage. If, for example, it is believed that the availability of spawning habitat is a limiting factor to recruitment of a particular fish species, then the selection of a study site(s) within the known spawning area may be an appropriate part of a study designed to specify a flow regime optimal for recruitment of the species.

A critical reach may be selected on the basis of basic criteria such as:

1. The reach may be highly affected by, or particularly sensitive to changes in stream flow. For example, the most sensitive reaches with respect to discharge may be elevated portions of the channel, such as riffles and gravel bars. Alternatively, the artificial influence being investigated may only have an impact over a confined area but that area may be highly important with respect to the target species/life stage being considered.

2. The critical reach may act as a biological control limiting a particular life stage of the target species. For example, if the availability of spawning habitat is known to be limiting trout populations, then the only known spawning area within an extensive section of river (e.g., a convex gravel bar) could be an appropriate choice for a critical reach. Or a low flow passage block that limits access to spawning areas could be the critical reach in an investigation.

The assumed role of a particular mesohabitat type as the limiting factor to success of the species/life stage should be verified by sampling whenever possible. For a single species, different mesohabitat types may be limiting to different life stages at different times of the year, and if the study addresses more than one target species, different mesohabitat types may be limiting to populations of the different species. In either case, it is important that the study site(s) represent(s) the full range of mesohabitat types present in the study area. This situation typically involves the use of a representative reach or mesohabitat classification. Some study designs may employ a stratified random sampling approach or a combination of all of the above, which usually involves using a "habitat mapping" strategy for weighting the data in PHABSIM.

Mesohabitat Study Site Selection

One general approach to selecting study sites using a mesohabitat classification is as follows:

1. Within the whole study area in question, hydrologic segments and, if appropriate, sub-segments are identified (e.g., defined by geomorphology or human influences such as channelization, dams, or diversions). This may include portions of a river where the stream hydrology is significantly different such as above or below a tributary inflow or below a water diversion.
2. A classification scheme is developed for delineation of specific mesohabitat types in the stream. These mesohabitat types correspond to channel geomorphic units such as deep glide, shallow glide, pool, riffle, and cascade. This may be accomplished using the skills of people familiar with the stream and the target species in question, as well as those trained in the use of PHABSIM. This may also be approached using any number of different habitat classification schemes published in the open literature or adopted by resource management agencies involved with the study. In addition to identifying different geomorphological features, (e.g., pools and riffles) the distribution of areas having cover (e.g., overhead cover, undercut banks, or floating aquatic plants) and areas thought to be of special ecological importance (e.g., backwater refuges) should be identified where appropriate. The flows under which the mesohabitat classification fieldwork should be carried out must also be considered.
3. The mesohabitat classification itself is then carried out. PHABSIM study sites are established at the selected locations and surveyed according to the techniques described in Bovee (2000). The data are entered into PHABSIM

for Windows using a weighting scheme that causes the resulting habitat simulations to allocate the desired proportions of each habitat type in the final PHABSIM results. (See Chapter 4 for details on this “habitat mapping” procedure.)

Simply stated, the mesohabitat classification procedure involves a classification of mesohabitat types by inventorying (typing and measuring the length of) within each hydrologic segment and sub-segments in the stream. Then specific locations for PHABSIM study sites and cross sections are chosen to characterize these habitats. It may be possible to represent the entire study area with one representative reach. In most circumstances, such as in streams containing complex and variable habitat types, numerous study sites will be necessary. One common approach is to delineate the number and linear distribution of each mesohabitat type within each hydrologic segment and sub-segment using a predefined channel geomorphic unit classification scheme based on actual physical measurements. The investigator can then select cross sections within each of the mesohabitat types within a representative reach(s) within the study area, or a stratified random selection procedure or a combination of methods. The final weights given to each cross section during habitat modeling within PHABSIM are derived from the total mesohabitat classification results. In some studies, only mesohabitat types that are represented by some minimum amount (e.g., at least 5 to10% of the total area) are included, unless a rarer habitat type is considered critical to the life history needs of the target species. The inclusion or exclusion of mesohabitat types based on the percentage composition or critical nature should be clearly identified during the study scoping process.

Another more detailed approach to mesohabitat classification involves the delineation of study sites of generally similar physical microhabitat identified through a survey which takes spot measurements of habitat variables such as stream width, maximum velocity, depth, substrate, and cover, along with a quantitative discrimination of these habitat variables. Analysis of the distribution of these habitat variables can enable a detailed discrimination of related habitat variables. For example, it may highlight distinctive areas within deep glides or shallow pools. Based on these analyses, specific locations for cross sections can then be accomplished as outlined above.

Still another variation on this basic theme for mesohabitat classification involves the random selection of a starting point within a specific hydrologic segment or sub-segment where mesohabitat classification is conducted over a longitudinal distance equivalent to approximately 20-30 channel widths. Based on the habitat types encountered, each type is assigned as a stratum and the specific habitat unit within a stratum is randomly selected. The location of cross sections in the selected habitat unit is then determined using a random selection process for the location within the specific habitat unit.

No single preferred method exists for selection of study sites or specific cross section locations. The specific approach taken should be determined during project scoping. It is strongly suggested that representatives of all parties in an instream flow issue participate in the cross section selection process.

Cross Section Selection and Field Data Collection

The relationship between cross section placement, number of cross sections, and the subsequent field data collection of the hydraulic properties of the stream are critically important to the successful application and interpretation of PHABSIM.

Cross Section Selection

The number and location of PHABSIM study cross sections is based on the habitat types identified by one of the above mapping strategies. If the distribution of habitats within the stream permits, a series of hydraulically linked cross sections should be chosen to facilitate the collection of field data and increase the flexibility in hydraulic and habitat modeling. The total number of cross sections will depend on habitat diversity, the extent or spatial domain of the study, and resources available. The number of cross sections within each study site will generally be small, but where resources permit, cross sections should be selected to provide replicate samples of habitat types to incorporate the inherent variability within a specific habitat type in a more robust manner.

In addition to the placement of cross sections in target mesohabitat types, it is frequently necessary to place an additional cross section at all hydraulic controls within or influencing each individual mesohabitat type. If a representative reach approach is being used, all hydraulic controls within a study site should be sampled, or if cross sections are clustered into groups, then the hydraulic control at the downstream end of each cluster should be included. Placing of cross sections at the hydraulic controls enables the user to consider the full range of hydraulic models in PHABSIM, including the step-backwater based WSP model. These additional cross sections can be ignored during habitat modeling and therefore will not necessarily contribute to the physical habitat calculations.

A variation on basic mesohabitat classification at a single flow involves mapping the changing proportions of the habitats (as mapped above) at different flows. This information can then be utilized to change the weighting of individual habitat type WUA versus discharge relationships as a function of flows to produce a composite WUA for the range of flows simulated in the study. For example, a stream may contain 30% riffle habitat at low flows, but only 10% at high flows. The particular utility of this type of approach has its own inherent bias. For example, a cross section located in a pool at one discharge may be subsequently classified as a run habitat at an alternative flow.

Field Data Collection

PHABSIM data collection generally requires the following steps to be completed and reported.

1. Units of measurement must be chosen (metric or U.S. customary fps).

2. The selection of target discharges (usually three or more) where field data are required, as well as the selection of the best time to get high, medium, or low flow measurements. Data may be required from more than three flows in order to model the physical habitat correctly. For example, where the bed morphology is complex or where there is seasonal weed growth.

3. Survey headpins are driven into the bank at each cross section. These should be located to provide a stable horizontal and vertical datum and should be securely placed a reasonable distance away from the water to avoid disturbance during high flow events.
4. For each set of linked cross sections, a closed-loop survey through all headpins showing elevations and distances is required.
5. A topographic survey of channel morphology (bed elevation) at each cross section (selected above), relative to the fixed cross section headpin. The investigator should ensure an adequate number of observations to describe the channel cross section and remember that each survey point will be used as a location for hydraulic measurement when covered by water.

6. A record of channel index parameters (substrate, and cover) at each of the points where bed elevation was taken. PHABSIM considers substrate and / or cover to be unchanging throughout the flow range, though the user may evaluate habitat for changing channel index conditions by creating more than one set of study project files.

7. Establish a temporary staff gage to check fluctuations in the water surface elevations during each discharge measurement.

8. Mean column velocities are measured at each survey point across each cross section. A full set of measurements should taken at several well spaced discharges. This is not essential but it is desirable since it allows the user maximum flexibility in velocity simulation and allows a more comprehensive assessment of simulation errors. Mean column velocity is measured at 0.6 of the depth up to depths of 2.5 ft. In depths greater than 2.0-2.5 feet, an average of readings at 0.2 and 0.8 of the depth is recommended if time and resources allow. See USGS stream gaging guidelines in Rantz and others (1982).

9. At each flow, wading rod depths should be noted at each wetted point where flow measurements are made.

10. At each flow, a survey of water surface levels at each cross section, relative to the cross section headpin. Repeated water surface elevation readings on the left, center and right of the channel provide best accuracy. This provides some data redundancy (wading rod depths are also taken) and provides an essential check on the survey techniques.

11. Any flow changes during fieldwork periods must be noted. A fixed staff gage located at a good cross section for measuring discharge should be read frequently to detect changes in discharge.

12. Field notes describing the stream and in particular every cross section. It is important always to collect as much information as possible.

13. Installation of a data logger for water surface level in lieu of a staff gage at a convenient point (the most downstream cross section or the best cross section for measuring discharge) can provide valuable additional information.

MESC recommends that at least three complete sets of water surface levels and at least a single velocity data set be collected to ensure maximum flexibility in the hydraulic model calibrations. However, in most channels, additional velocity sets at alternative flows are highly advisable, since a single velocity data set is unlikely to reflect the velocity distributions across all flow ranges. Additional water surface and velocity sets are particularly needed in complex channels where it may be necessary to measure several cross sections to capture multiple channels and other features. Available resources may limit time spent on data collection, so it is important to plan in advance on the number of data collection trips and the target discharge ranges necessary to meet data quality

objectives for the hydraulic and habitat modeling for a particular study. For example, in relatively uniform channels, one or two velocity data sets may be adequate. In general, the more data (and more redundant data) one can collect, the greater the anticipated accuracy and reliability of the study. For a more complete description of field data collection considerations and techniques, see Bovee (2000).

Hydraulic Modeling

The techniques used to simulate hydraulic conditions in a stream can have a significant impact on the habitat versus discharge relationship determined in the habitat-modeling portion of PHABSIM. The correct choice of hydraulic models as well as proper calibration often represents the most difficult step in the process of analyzing instream flows.

The hydraulic simulation programs in PHABSIM assume that the shape of the channel does not substantially change with discharge over the range of flows being simulated. In practice, small changes in the bed topography will often occur between field data collection efforts at the high and low flows. If these differences are small, then they are ignored in the analyses. However, if significant changes in bed topography do occur between data collection field trips, these data should be treated as independent estimates of the hydraulic properties within the channel and used as independent data sets (evaluated as different project files) in the hydraulic model calibrations and subsequent habitat simulations.

The simulated hydraulic characteristics of the stream are the water surface elevations (i.e., depth) and velocities, in that order. Water depths are calculated in the habitat programs from water surface elevations simulated in the hydraulic programs. The water surface elevations are assumed to be the same across a single cross section (although depth varies since it is calculated by subtracting the bed elevation from the water surface level). In contrast, velocity varies from cell to cell across any cross section.

The approaches available for calculation of water surface elevations are: (1) stage-discharge relationships, (2) Manning's equation, and (3) the step backwater method. The absolute minimum data set used in the application of PHABSIM requires at least one set of water surface elevations. In standard practice, at least three sets of water surface elevations are targeted for collection along with at least one and preferably additional sets of velocity measurements.

Water Surface Elevation Modeling

The first step in hydraulic modeling within PHABSIM is the calibration and simulation of water surface elevations. Depending on the nature of the field data available, the following programs and approaches can be utilized:

Windows		DOS	Difference	% difference
Cell bed elevation	91.65	91.65	0	0.00
Water surface elevation	92.456	92.47	0.014	0.02
Depth	0.806	0.82	0.014	1.71
Depth Suitability Index	0.0708	0.096	0.025	26.25
Combined Suitability Index	0.0644	0.087	0.023	26.25
Weighted Usable Area	8.698	11.79	3.096	26.25

Acknowledgements **i**
PREFACE **ii**
A Brief History of PHABSIM
Use of this Document
Changes Between PHABSIM Version 2 and PHABSIM for Windows
Conventions Used in this Document
Chapter 1, Introduction to the Physical Habitat Simulation System **1**
Objectives
Associated Laboratory Exercises

all cross sections being analyzed in a given model run be related to each other in terms of survey controls and sequence upstream. That is, each cross section's hydraulic characteristics in terms of bed geometry and water surface elevations are measured from a common datum. The model is initially calibrated to a measured longitudinal profile of water surface elevations by adjusting Manning's roughness, first for the entire study site and then at each cross section. Manning's roughness is then adjusted for subsequent measured longitudinal water surface profiles at other discharges by setting the roughness modifiers used within the model. This approach requires all hydraulic controls within the modeled study site are represented by cross sections.

In addition to these three water surface elevation models, PHABSIM can utilize water surface elevations derived at each cross section from external sources. This approach is discussed in the chapter on hydraulic modeling.

Velocity Modeling

In PHABSIM for Windows, the **VELSIM** program is the principal tool used to simulate the velocity distributions within a cross section over the required range of discharges (i.e., the mean column velocity in each wetted cell in a study cross section at each simulation discharge). The technique relies on an empirical set of velocity observations (i.e., measured velocities) that act as a template to distribute velocities across a channel by solving for the „n' in Manning's equation (in this context „n' acts as a roughness distribution factor across the channel). The channel is divided into cells and the velocity calculated for each of these cells. The usual practice is to use one set of velocities as a template for simulating velocities for a particular range of discharges. When more than one set of empirical velocity measurements is available, a commensurate number of flow ranges can be simulated with different velocity templates. The program can be used when no velocity measurements are available. In this situation, velocity will be distributed across the cross section as a function of flow depth.

For further discussion of hydraulic modeling, see Chapter 2.

Habitat Modeling

Habitat modeling transforms information on channel structure, modeled water surface levels and velocities into an index of the quantity and quality of available habitat using the HSC as the transfer function. This index of habitat is referred to as Weighted Usable Area (WUA) and is computed for each cell across each cross section at each modeled flow. The cell values are then summed to produce a composite or study site level WUA for a given discharge, for each separate species or life stage. This enables a relationship to be built up between a range of discharges and aggregate habitat availability for the whole study site. The options used in habitat modeling can affect the predicted habitat area relationship and magnitudes to some extent. Thus, the modeler should select the options in a reasoned manner, and should be consistent when modeling habitat at different sites if the results are to be comparable.

The two general types of habitat modeling options available in PHABSIM are based on either average conditions in an entire stream channel (i.e., the average parameter model) or on the explicit distribution of velocity, depth, and channel index across an entire cross section(s) (i.e., distributed parameter models). Each of these approaches is supported by a set of analysis tools that are described below in general terms and in more detail in Chapter 4. An additional group of effective habitat models deals with the value of distributed habitat under certain changes in flow.

The Average Parameter Model

The average parameter model, **AVDEPTH /AVPERM**, calculates a variety of hydraulic characteristics for each cross section in addition to a study site average view. These include wetted width, wetted perimeter, and wetted surface area, cross sectional area, mean channel velocity, and average depths. They can also be utilized to determine the width of a stream with water that is over some arbitrary depth(s) specified by the user. These programs provide a wealth of information at a cross section or a study site level aggregate and should be examined in most applications.

Distributed Parameter Models

This second habitat modeling category is based on the flow-dependent attributes of depth and velocity at each measured vertical, which are integrated with biological criteria in the form of HSC curves. The primary program using distribution parameters is the **HABTAE** model. In earlier versions of PHABSIM, there were two other habitat models, HABTAT and HABTAV. The functions of these two programs have been combined in the revised **HABTAE** program in PHABSIM for Windows. Options within **HABTAE** allow the user to select habitat calculation assuming the condition within a cell establishes the worth of the habitat in the cell or assuming the condition in a cell plus the velocity in adjacent cells or at another location nearby establishes the worth of the habitat in the cell. The **HABTAE** program also allows habitat to be determined in terms of volume (instead of the surface area), and provides a method for determining the habitat conditions at each cross section.

Effective Habitat Analysis in PHABSIM

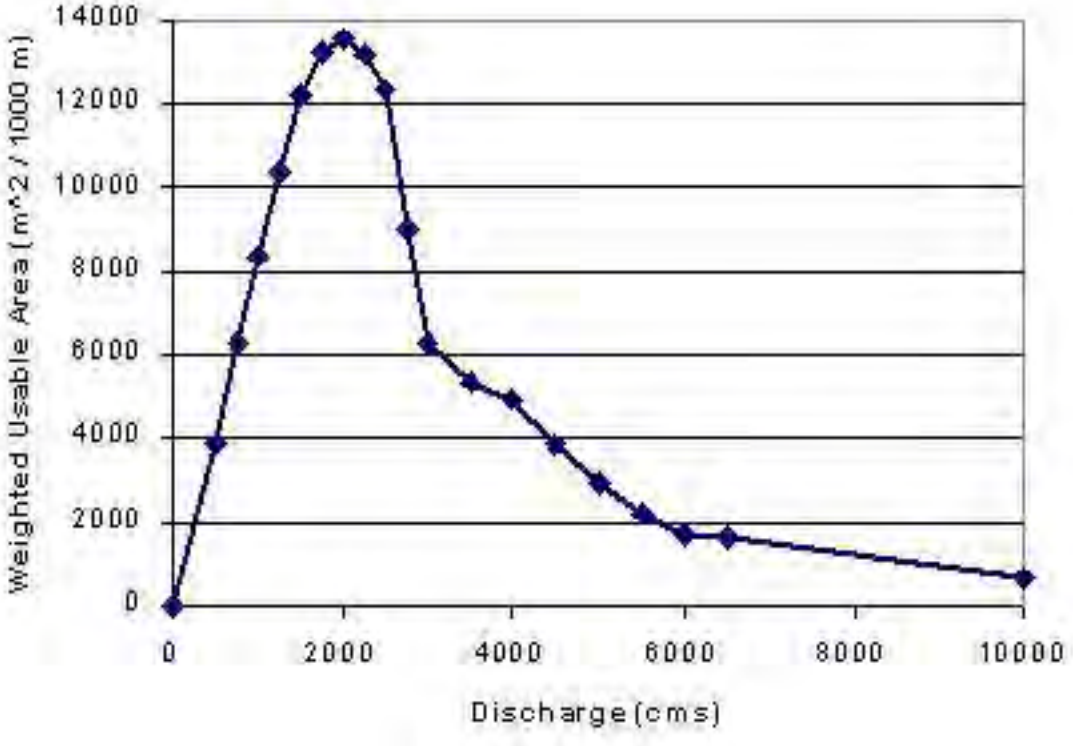
In addition to the two general categories noted above, a third class of habitat modeling involves the determination or evaluation of effective habitat. There are two programs available for effective habitat analysis in PHABSIM. The first is the **HABEF** program, which is used to determine availability of physical habitat considering two flows; in other words, the HABitat that remains EFfective when two flows are of importance. This situation often arises, for example, in the evaluation of reducing flows during the spawning period and subsequent incubation period or in hydro-peaking operations that have a daily minimum and maximum flow. In the case of spawning and incubation analyses, the spawning area at a cross section is not „effective' unless the incubation period flow regime maintains the habitat in a suitable condition for the eggs to hatch.

The second effective habitat model is the **HABTAM** program in which the species can move from cell to cell over a range of starting and ending discharges. In this model, effective habitat is defined as the habitat that remains usable when the species is forced to move due to flow fluctuations. The computational aspects of each of these habitat modeling options are discussed in detail in Chapter 4.

Interpreting PHABSIM and Completing the IFIM Process

The end product of the habitat modeling in PHABSIM is the production of habitat versus discharge functions for each target species and life stage (Figure 1-4). These relationships represent the starting point for assessment of alternative flow regimes or impacts of a proposed project. In many instances additional analyses of such factors as channel and riparian maintenance flows, and/or water quality and temperature modeling will be needed to assess alternate flow regimes.

IFIM provides an assessment framework for use in the interpretation of PHABSIM results. In IFIM, stakeholders are encouraged to reach consensus on evaluation of these results in the context of the water resource decision at hand. Fortunately, there are a number of analytical approaches that can aid the investigator and water resource manager in this decision process. From a physical habitat modeling perspective, the most common (and recommended) approach is to conduct time series analysis based on the existing or anticipated flow regime(s) for the project. Habitat time series illustrate the dynamics of the temporal habitat change for a particular species and life stage during each season or critical time period under historical, existing, and proposed project flow scenarios. This aspect is one of the critical distinctions between an application of PHABSIM (which produces a habitat-flow relation) and a true IFIM study (which produces numerous alternative habitat time series). Some examples of



using PHABSIM within an IFIM study are treated in Chapter 5.

Figure 1-4. Example of a habitat-discharge relationship for a single life stage.

Habitat time series analysis quantifies project impacts or benefits in terms of habitat gains or losses when comparing flow scenarios to the selected project base line conditions. These analyses can also be used to generate habitat duration curves on a seasonal basis or compute habitat conditions that are continually below some prescribed threshold. It is a matter of professional judgement as to what adverse impact or benefit is represented by any quantitative change in habitat area or as a percentage change from baseline scenarios. Often the kind of water resource issue and the importance of the target species to the resource manager, dictate the level of impacts or benefits that are considered acceptable. In addition, establishing an instream flow regime will often require the integration of water quality or temperature during critical periods. It is also common to use alternative techniques such as channel maintenance flow computations during the peak runoff periods to select an appropriate flow regime rather than rely solely on the PHABSIM model outputs.

There are several approaches to habitat modeling available in PHABSIM. See Chapter 4 for treatment of each of the habitat models and their numerous options for generating and aggregating habitat values.

This concludes the overview of the background and general concepts in PHABSIM. This chapter concludes with an introduction to the PHABSIM for Windows software.

Using the PHABSIM for Windows Menu System

The general steps for using the interface consist of clicking on the appropriate menu, tab, or button items to enter data, select options, run programs, or view output. In this manual each of those steps is presented in text in the following format:

Main Menu/Next Menu/Next Menu or Tab: Instructions for what you should do.

For example to run the STGQ model and generate simulated water surface elevations, click on **Models**, then **WSL**, followed by **Method** and the **STGQ** radio button. Then either click the cells in the data entry table where you wish to enter stage or click the **Set All** button to the right. That sequence of operations is noted in the documentation as:

/Models/WSL/Method/STGQ: Select **Set All** or click the cells for the cross section and discharge for which you wish to run the STGQ model.

The actions are:

Move mouse to **Models** item in the main menu, click. Move mouse to **WSL** drop down menu item, click. Move mouse to **Method** tab (if not already showing), click. Move mouse to radio button (round button) for the model you wish to use (in this case **STGQ**), click. A black dot should appear in the middle of the round button. Move mouse to the individual cells for cross section and discharge where you wish to use STGQ and click each cell or clic k the **Set All** button.

The notation **../Method/WSP** is used in some places to abbreviate long entries such as **Models/WSL/ Method/STGQ** when moving within the same set of tabs.

The following figures illustrate these operations.
Figure 1-5. Selecting the Models Menu Item. Move the cursor over the word Models and click. A drop down menu with the model categories will appear.

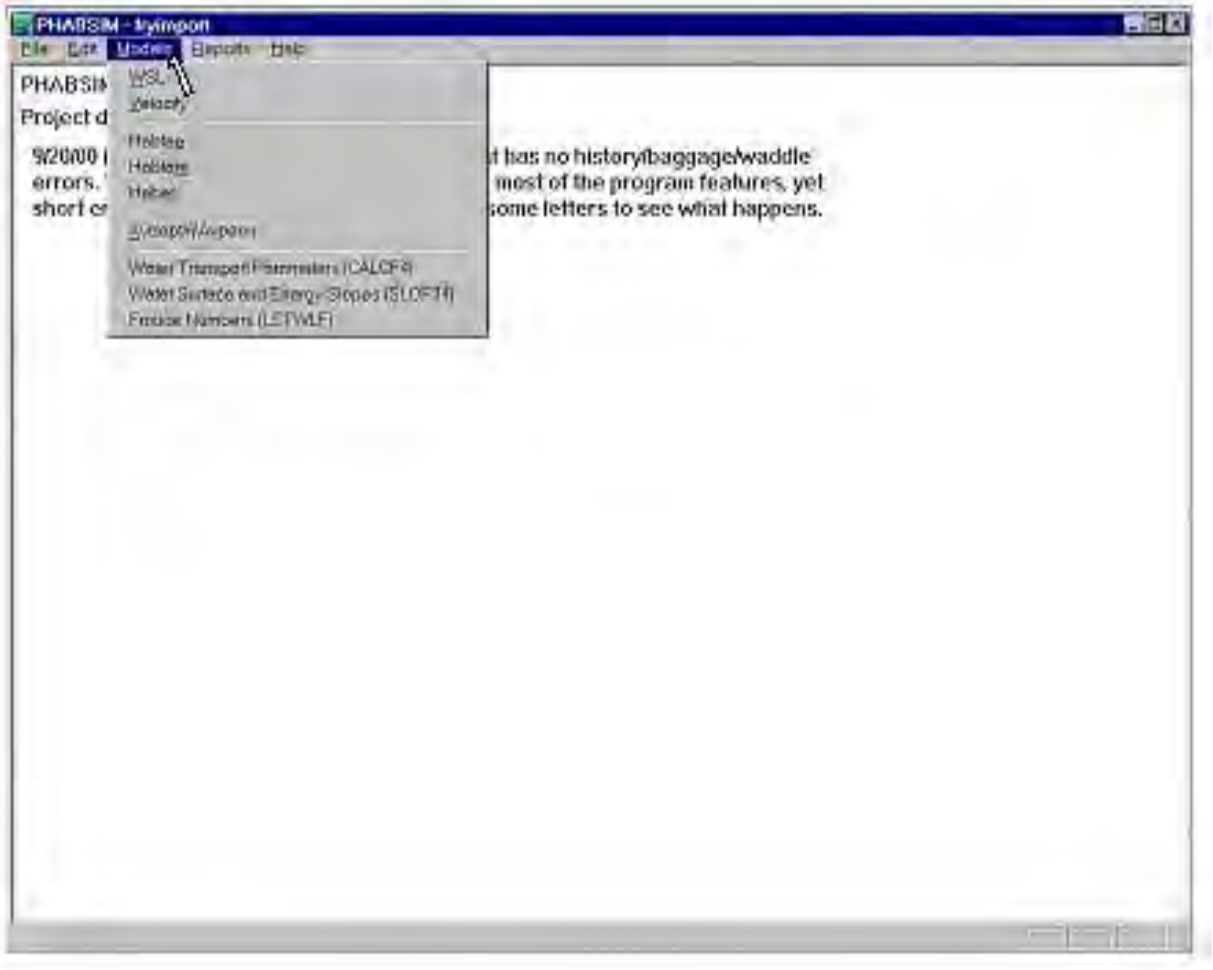


Figure 1-6. Selecting the WSL Menu Item. Move the cursor over the WSL item on the drop down menu and click.

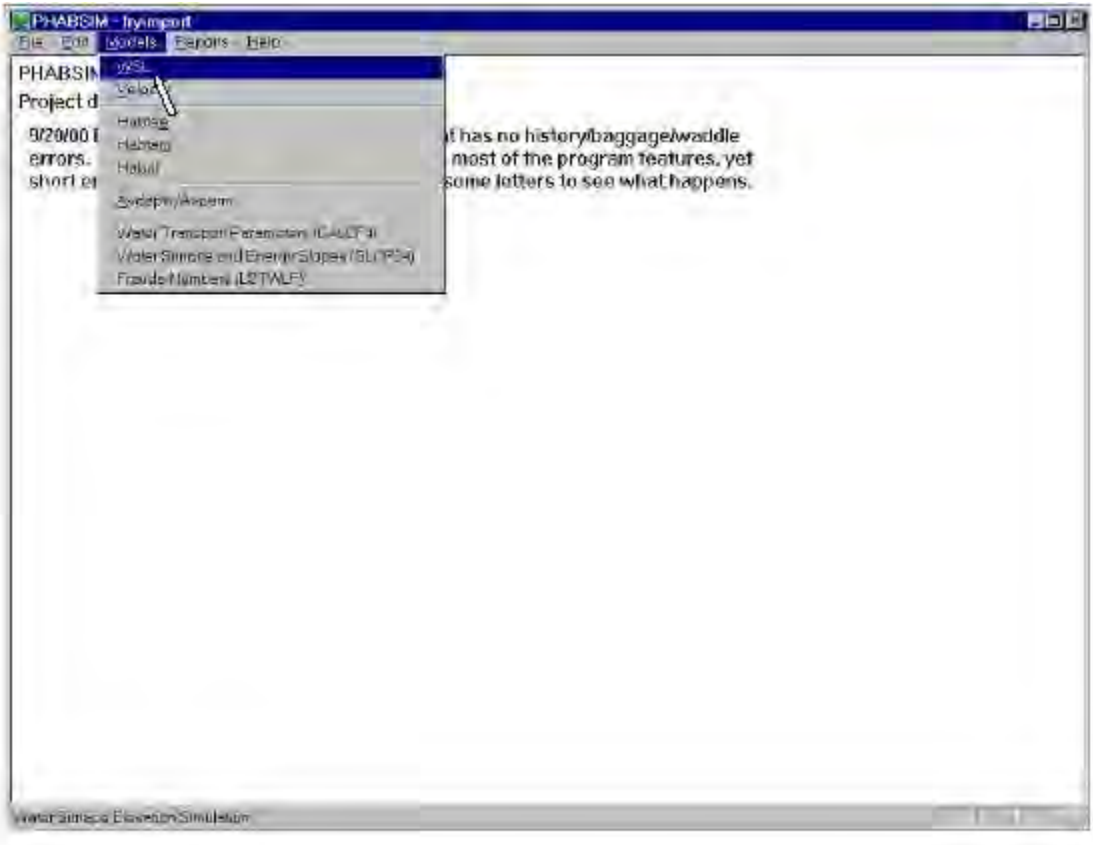


Figure 1-6. Selecting the WSL Menu Item. Move the cursor over the WSL item on the drop down menu and click

Figure 1-7. Selecting the STGQ Radio Button followed by Set All, Result of the Set All Operation is shown.

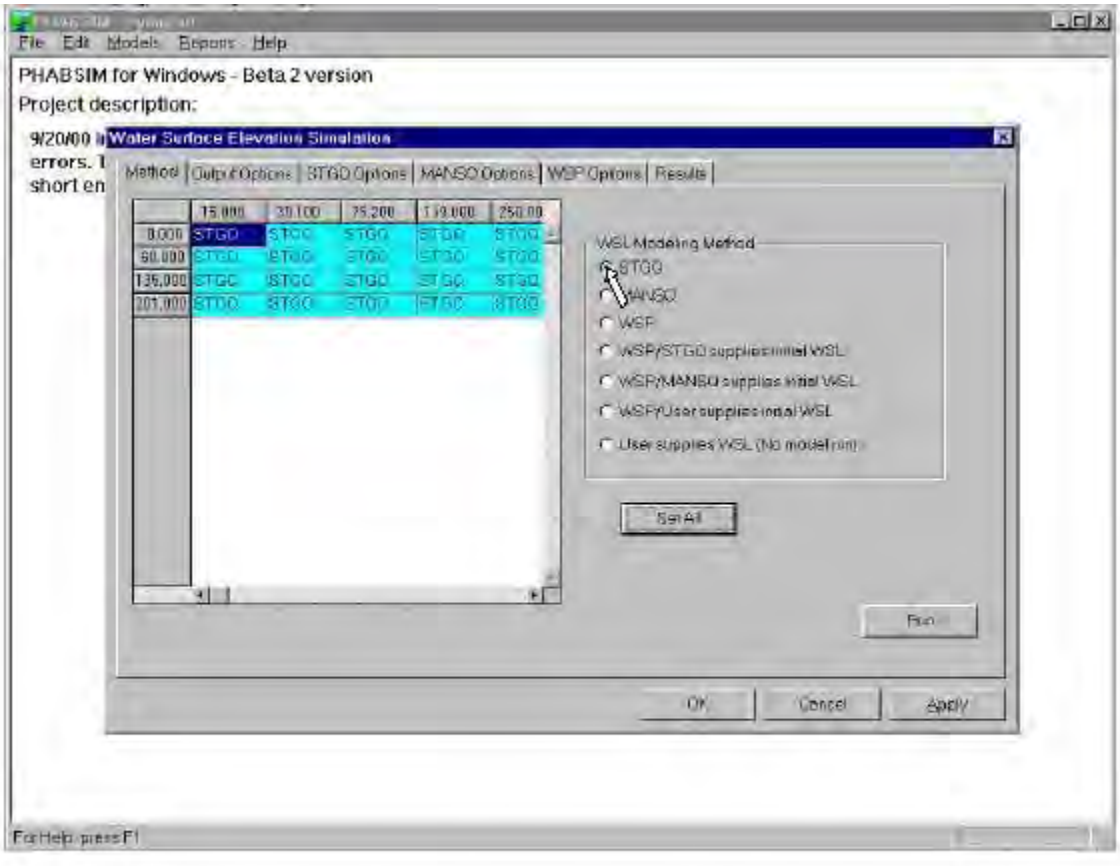


Figure 1-7. Selecting the STGQ Radio Button followed by Set All, Result of the Set All Operation is shown.

This notation is used throughout this manual in lieu of repeating this sequence of figures for each operation to be performed. If the operations are not clear, click the first two or three items in the sequence and read the screen that appears. The next item in the command list will be shown on that screen.

PHABSIM for Windows File Structure

PHABSIM for Windows uses a file structure designed to allow maximum flexibility in the analysis and reduce the amount of file management demanded of the user. To accomplish this, each study site is defined as a "project". When creating a new project, the software will create a folder with the project name. Within the folder there will be several files with the project name and an extension. Most of the files are in a binary format and cannot be read without running PHABSIM for Windows. Table 1-1 contains a general description of the project files.

Table 1-1. Project files.

<project>.phb - general project information binary <project>.pxs - cross section data binary <project>.ppt - point data -binary <project>.pxp - cross section point index -binary <project>.pcl - calibration set data -binary <project>.pcv - suitability curve data -binary <project>.opt - project options -binary <project>.history - project history file -text <project>.hyd - hydraulics output -binary <project>.zout# - accumulating ZOUT files -text <project>.zvaff - velocity adjustment factors -binary <project>.zhaqf - ZHAQF habitat-flow relation output -binary <project>.11111e - HABTAE output for curve 11111 -binary <project>.11111m - HABTAM output for curve 11111 -binary <project>_options.txt - dump of the options -text. <filename> - communication files have no extension binary <filename>.bin - binary internal communication files binary

Notes:

- The history file grows as analysis progresses. It is a text file that may be viewed with a text editor to see what steps have been taken in the analysis. This is especially useful when preparing testimony or when preparing reports where the analytical choices must be explained.
- A separate ZOUT file is created for each program run in the PHABSIM suite. ZOUT files contain analysis results and error messages. *The user is recommended to search the latest ZOUT file with a text editor after each model run for error messages*. The number of ZOUT files will grow as the analysis progresses. One may delete ZOUT files as results are stored in the project database. However, if files are deleted, the numbering sequence will start over with 1 or the next number above the lowest existing ZOUT. If you delete ZOUT10 through 17, ZOUT10 will be the next one created.
- A separate numbered result file is created for each species/life stage in a habitat simulation. The number is the habitat suitability criteria curve number for the particular species/life stage. These are binary files that contain the habitat-flow relation resulting from running HABTAE or HABTAM. The files are used at later stages of the analysis process and are the source of display of habitat results.
- The project_options.txt file is created when the user instructs the interface to record options in **/Reports/Record Options**.
- The project.hyd file contains cell-by-cell depth and velocity information.
- The project.ZHAQF file may be produced by HABTAE or HABTAM.
- Cell-by-cell habitat results will be produced for each selected species/life stage. Those results will be contained in files named project.xxxxxxe, where the x's represent the HSC number. The extension will have an "e" or "m" matching the HABTAE or HABTAM program that produced the file.
- The internal communication files should be retained with the project as they can be useful when asking for assistance if the program fails.

Analysis Limits in PHABSIM for Windows

PHABSIM for Windows contains few limits on the number of items that may be analyzed in one project. There is no limit on the number of cross sections that may be included in a project, although there is a practical limit of about 50 cross sections due to the difficulty of tracking all of the habitat issues that may be addressed. A second practical limit applies when using the step-backwater hydraulic model; numerous pool riffle sequences may prove difficult to calibrate unless cross section placement fully satisfies all of the assumptions of the model. Finally, smaller projects generally run faster and are easier to manage.

The number of cells on a cross section is not limited. This is in contrast to PHABSIM Version 2 for DOS, which had a 100 point limit per cross section. Also, the number of digits in x, y, and z position values is not limited by hollerith field lengths as in the previous version.

A limit of 30 discharges per habitat simulation has been retained in PHABSIM for Windows. Both programming costs and run time considerations contributed to this decision. In the event you need to simulate more than 30 discharges, we suggest you make a copy of the project and split the discharge range between two otherwise identical projects.

Summary of Chapter 1

This chapter introduced PHABSIM as a component of the Instream Flow Incremental Methodology. A general outline of its use within the IFIM framework was given. Several activities such as study site selection, field data collection, and habitat suitability curve development were briefly described. Those activities are outside the scope of the PHABSIM software and are not further elaborated in this manual. The remaining chapters deal with the structure and use of the PHABSIM for Windows software. They are presented in the order of a typical PHABSIM analysis beginning with hydraulic analysis in Chapter 2.

Chapter 2. Hydraulic Modeling in PHABSIM

Objectives

This chapter introduces the basic concepts of hydraulic simulation in PHABSIM followed by a detailed explanation of the specific calibration and simulation options for each hydraulic model within PHABSIM. Calibration and simulation of water surface elevations are treated first followed by calibration and simulation of velocities. Specific steps in use of the software for each stage of hydraulic simulation are presented. The chapter concludes with a general discussion of how to evaluate hydraulic modeling results.

Laboratories

The associated laboratories for this material are contained in Laboratory Exercises 3-7. They introduce the three principal water surface modeling options within PHABSIM, as well as the general approaches to velocity simulations. Laboratory 3 introduces the stage-discharge modeling of water surface elevations using STGQ, Laboratory 4 covers the use of the MANSQ model for this purpose, while Laboratory 5 introduces the use of the step-backwater model (WSP). Finally, Laboratory 6 covers the use of the VELSIM model for velocity simulations.

Introduction

Flow in an open channel is a three-dimensional process. It includes response to change in the channel shape, secondary currents, and it varies continuously across and along the axis of the stream. Models of varying complexity capture the overall streamflow process to different degrees. In PHABSIM, the Water Surface Profile model (WSP) uses the step-backwater method to obtain a one-dimensional representation of flow. The STGQ and MANSQ models use empirical means to obtain similar transect-based representations of flow. The hydraulic models in PHABSIM operate with assumptions of a fixed bed profile and a sloped water surface that is level across each cross section. There are many empirical relations used to simplify flow representations so they can be represented on transects, rather than continuously. Thus, flow representations within PHABSIM are discretized as cells located across transects. The influence of the assumptions and one-dimensional form of PHABSIM models will become more apparent as the reader progresses through this chapter.

Hydraulic modeling within PHABSIM characterizes the physical attributes within the stream (i.e., depth, velocity, and channel index) over a desired range of discharges. This characterization could be accomplished by direct empirical measurements taken at small increments of discharge covering the range of discharges of interest for a habitat study. However, time, safety and funding constraints typically prevent this empirical approach. Fortunately, it is possible to sample the stream's hydraulic properties at a few target discharges and then rely on these data to calibrate one or more hydraulic model(s) and use the model(s) to predict the stream hydraulic attributes over the full range of discharges of interest in the study. The success or failure of this effort is dependent on the quantity and quality of the field data, the complexity of the physical nature of the stream, and ultimately the ability of the hydraulic models to reflect the physical processes in the stream.

The material in this chapter represents concepts and application strategies of elements contained in the hydraulic simulation portion of the information flow within the PHABSIM system as indicated by the area labeled hydraulic simulation in Figure 1-2. The chapter concludes with a section on evaluating hydraulic model results.

Terms and Definitions for Open-channel Flow

Prior to presentation of these specific modeling approaches within PHABSIM, a brief introduction to the vocabulary and physical setting of open channel flows is necessary. A more technical and detailed treatment of the hydraulics of open channel flow can be found in any number of general texts on hydraulics such as Henderson (1966). Those readers who are interested in a more rigorous treatment of hydraulics should consult that or similar works.

The following terms and their definitions are important since they constitute the vocabulary of hydraulic analysis terminology within PHABSIM related to the analysis of open-channel flow and in particular to the use of hydraulic modeling options for the specific models within PHABSIM. The relationships between these terms and physical properties within a river channel or cross section(s) are illustrated in accompanying figures where possible. Figure 2-1 provides an idealized representation of a stream reach showing the location of several cross sections (transects), a hydraulic control, and a lateral view of a typical cross section profile.

Cross Section: A two-dimensional (width and depth) section derived from measurement of lateral distance and stream bed elevation across a stream channel that is perpendicular to direction of the flow and is synonymous to a transect. These are indicated in plan view by T_1, T_2, etc, in Figure 2-1 and in lateral view for T_3.

Reach Length: Reach length is the distance that the current cross section is located from the previous cross section and, therefore, by convention is measured in an upstream direction. The downstream-most cross section has a reach length of zero and as illustrated in Figure 2-1, the reach length for T_2 is 35 feet, while the reach length for T_3 is 42 feet. In practice, both the left bank and right bank distances between adjacent transect head pins are measured and typic ally the average distance is used as the reach length for hydraulic modeling. In hydraulic modeling within PHABSIM, the actual reach length is only important when using the WSP hydraulic model since WSP uses this distance to dissipate the energy between adjacent cross sections. Since the STGQ and MANSQ models analyze each cross section independently, reach lengths play no role in these hydraulic models. The use of reach lengths and reach length weighting factors (upstream weighting factors) is critical in habitat modeling since these factors are used to derive the longitudinal dimension of the habitat cells and thus contribute to determining habitat area. Reach lengths are discussed in more detail in the section on habitat modeling.

Backwater: An area of stream where the water surface elevation is controlled by a hydraulic control. An example of a typical backwater area is a pool upstream of a riffle. Backwaters also occur in secondary (or side) channels where water "backs up" from the main channel, though flow through the side channel is cut off at some point upstream.

Hydraulic Control: A section of the channel which "controls" the water surface elevation of the stream in an upstream direction under sub-critical flow conditions or in a downstream direction under super critical conditions. Hydraulic controls are most often associated with a shallow and raised section of stream or a steep section of the stream such as a riffle as illustrated in Figure 2-1. Hydraulic controls typically have a higher bed elevation than the backwater areas upstream. Hydraulic controls can also occur at major channel constrictions.

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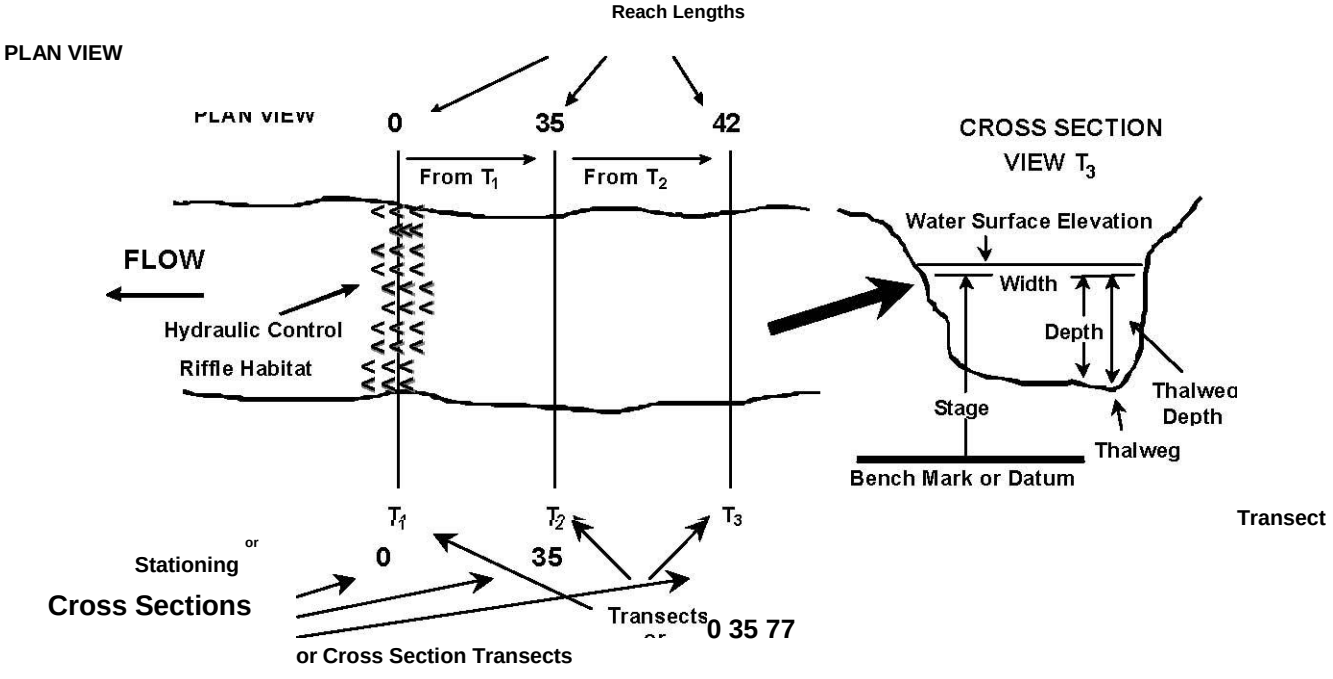


Figure 2-1. Schematic of a PHABSIM representative reach and a typical transect.

Hydraulic Control: A section of the channel which "controls" the water surface elevation of the stream in an upstream direction under sub-critical flow conditions or in a downstream direction under super critical conditions. Hydraulic controls are most often associated with a shallow and raised section of stream or a steep section of the stream such as a riffle as illustrated in Figure 2-1. Hydraulic controls typically have a higher bed elevation than the backwater areas upstream. Hydraulic controls can also occur at major channel constrictions.

Water Surface Elevation (WSL): The height of the water surface at a cross section as measured (or predicted). The WSL can also be determined from the streambed elevation plus water depth. The WSL is also called the water surface level.

Stage: The elevation, or vertical distance of the water surface above some datum (i.e., height relative to the established bench mark used during surveying of the stream geometries or as predicted from the hydraulic models in PHABSIM. Stage is equivalent to WSL.

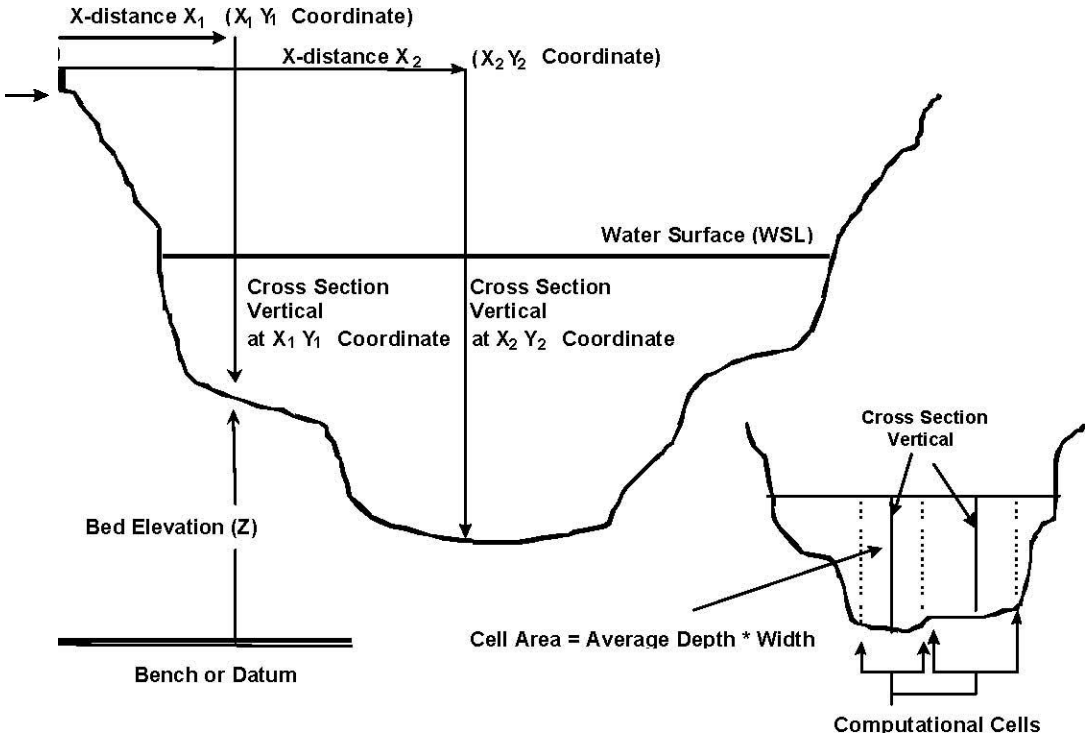
Depth: The vertical distance from a point on the streambed to the water surface. Depth is either measured or computed for each vertical.

Hydraulic Depth: Equivalent to the mean depth at a cross section; hydraulic depth is derived by dividing the cross sectional area of the flow by the width of the water surface.

Thalweg Depth: The vertical distance from the lowest point of a channel section (the thalweg) to the water surface. It is equivalent to the maximum depth of a cross section.

Width: The distance across a channel at the water surface, measured normal (i.e., perpendicular) to the flow.

Figure 2-2 provides a representation of a cross section view of a cross section (or transect) which relates the following hydraulic field data measurements to their equivalent terms as used by the various hydraulic (and

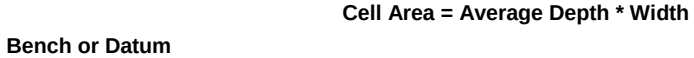


habitat) models.

0

X-distance X2 (X_2 Y_2 Coordinate)

Head Pin



Bench or Datum

Figure 2-2. Schematic view of a Cross Section showing hydraulic measurement and modeling terms.

X-distance (X): Lateral distance measured from either the left or right bank head pin across the stream perpendicular to the axis of stream flow. X-distance must always increase when moving across the transect for use in the PHABSIM hydraulic models. The X-distance (X) in combination with the bed elevation (Y) represents the coordinate points or verticals that define the cross section geometry in PHABSIM.

Bed Elevation (Z): Height of the stream bed measured from some established bench mark or elevation reference point for the transect or cross section. Bed elevations are measured at each X-distance along the cross section. The bed elevation (Z), in combination with the X-distance (X) represents the coordinate points or verticals that define the cross section geometry in PHABSIM.

X,Y,Z-coordinate: The X-distance as measured from a head pin to a particular vertical along a cross section. The Y distance is the accumulated distance upstream from the first transect in a study site. Identifying transects by their Y distance is also called "stationing" (see Figure 2-1). The Z-distance is the elevation of the stream bed at the X,Y-coordinate above the datum.

Cross Section Vertical: An imaginary line perpendicular to the water surface at each X-distance where the bed elevation, depth, velocity, and channel index (see chapters 3, 4 and glossary) values are recorded and used to represent the hydraulic properties for the cross section.

Computational Cell (hydraulic programs): The area of the cross section defined by one-half the distance to each adjacent cross section vertical such that the cross section vertical resides at the approximate center of the "cell". Computational cells are used by the hydraulic simulation programs for computing the water's edge based on the simulated water surface elevation, the predictions of velocities and individual cell discharges.

Habitat Cell (habitat programs): The area of the cross section lying between adjacent cross section verticals. Habitat cells have the average of the depth predicted at the bounding verticals and the average of the velocity at those verticals. The length of a habitat cell is determined from reach length and transect weighting factors.

Cell Discharge (q): Discharge computed within each computational cell based on the cell area and mean column velocity.

Cell Area (a): Computational cell area derived from the average difference between bed elevation and water surface elevations at the cell boundaries and the width of the computational cell.

Figure 2-3 shows an idealized representation of a cross section which defines the relationship between the following terms and definitions.

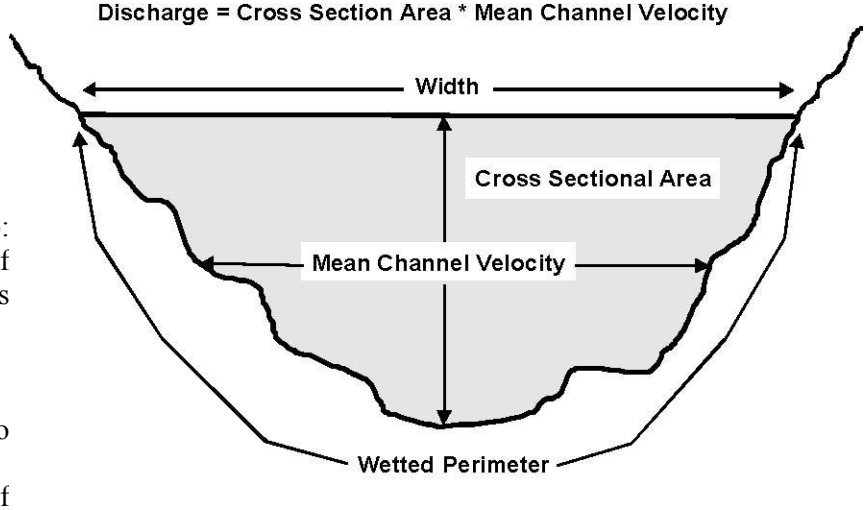


Figure 2-3. Cross section hydraulic terminology.

Cross-sectional Area (A): The area of the cross section containing water, normal to the direction of flow. It is also called the conveyance area. Cross sectional area is derived from the product of the average depth of flow times the width of flow.

Wetted Perimeter (P): The distance along the bottom and sides of a channel cross section in contact with water at a specific discharge and is roughly equal to the stream width plus 2 times the mean depth (hydraulic depth).

Hydraulic Radius (R): The ratio of the cross sectional area to wetted perimeter, R = A/P. For wide shallow channels, R approximates the hydraulic depth. Also called characteristic length (L).

Mean Channel Velocity (V): The mean rate of water movement or travel past a given location. It should not be confused with discharge. Mean channel velocity at a cross section can be computed by dividing the discharge by the cross sectional area.

Mean Column Velocity (v_i): At a vertical i, mean column velocity is usually measured at 60% of water depth (measured down from the water surface) if the depth is less than 2.5 feet. When depths exceed 2.5 feet, measurements are made at 20% and 80% of the water depth and the two values are averaged to obtain the mean column velocity.

Discharge (Q): The rate of flow, or volume of water flowing past a given place (i.e., a cross section) within a given period of time, traditionally expressed as cubic feet per second (cfs).

Figure 2-4 illustrates the relationship between important hydraulic parameters and definitions applied between adjacent cross sections. These items define the principal factors and terms used by the WSP model to compute

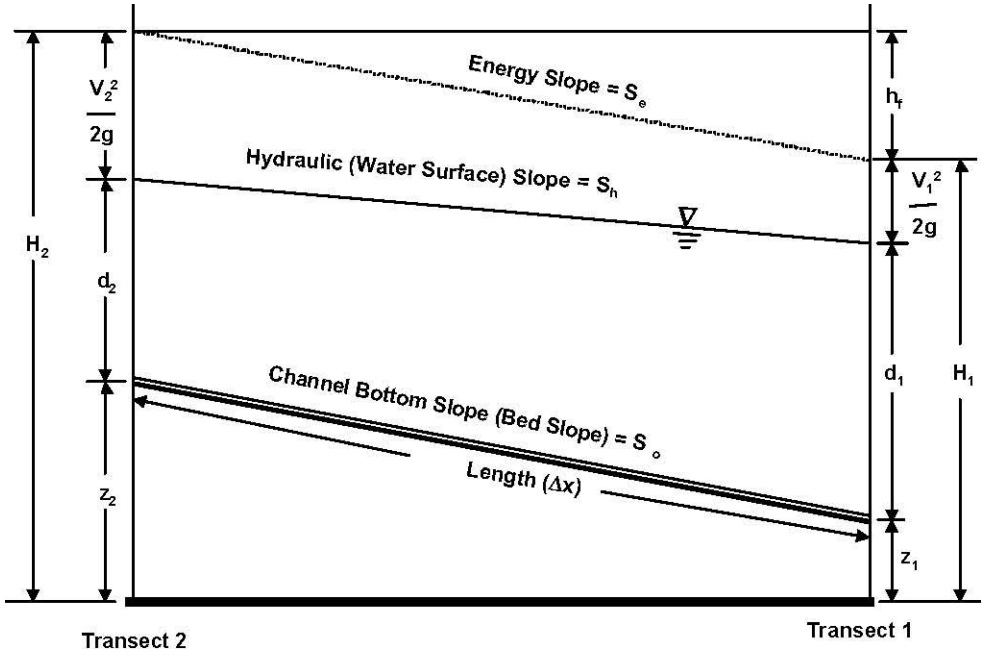


Figure 2-4. Energy relationships between transects.

Transect 1Transect 2

water surface elevations.

Upstream Transect Downstream Transect

Hydraulic Slope (S_h): The change in elevation of water surface between two cross sections, divided by the distance (reach length) between cross sections.

Bottom Slope (S_o): The change in average elevations of the bed between two cross sections, divided by the length.

Energy Slope (S_e): Change in total energy (potential and kinetic) available, divided by the length.

Velocity Head: The square of the velocity divided by 2 times the acceleration due to gravity. Velocity head is computed at adjacent cross sections in order to estimate the energy slope between the adjacent cross sections. This is the kinetic energy term in the energy balance equation.

Longitudinal Profile : A plot of the water surface elevations at each cross section within a reach versus the cumulative reach length distances for the cross sections. It typically includes the thalweg elevations. Longitudinal profiles can be represented by either calibration data, simulated values, or both. These plots are used in hydraulic simulations to verify that water is running downhill over the range of discharges modeled. A typical example of a longitudinal water surface elevation plot is illustrated in Figure 2-5.

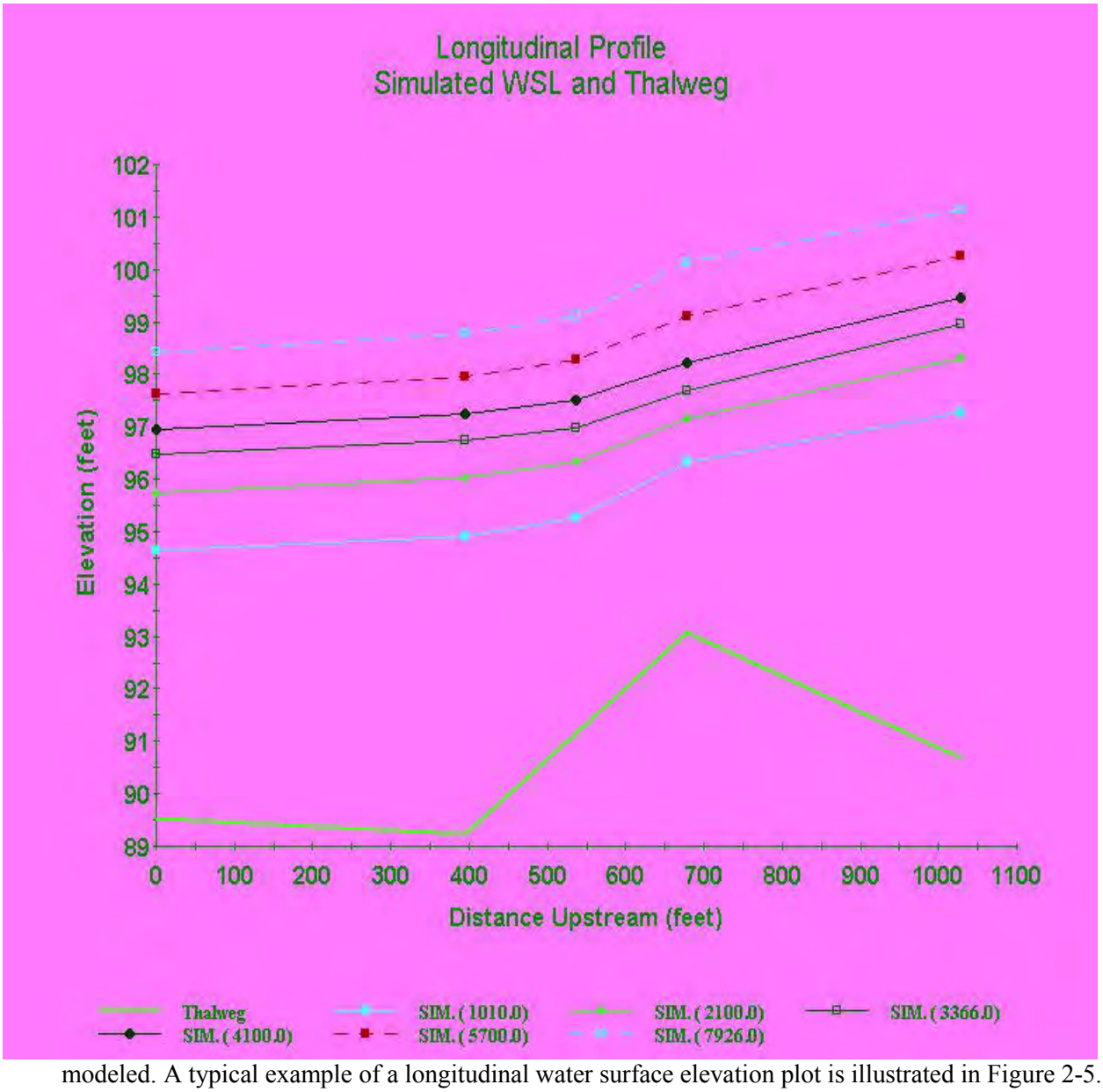


Figure 2-5. Simulated longitudinal water surface profiles.

The following terms are provided for completeness. They are treated in more detail in the specific sections on hydraulic models which follow. Additional terms and definitions related to hydraulic modeling can be found in Appendix 1.

Velocity Adjustment Factor (VAF): The ratio of discharge for which velocities are being simulated to the sum of simulated cell velocities times cell areas. VAF's are used to adjust simulated velocities to maintain mass balance for the simulated discharge. Interpretation of the VAF-discharge relation is discussed below in the section dealing with calibration and simulation of velocities.

Conveyance Factor (CFAC): The conveyance factor describes the ability of a cross section or cross section cell to transport (convey) water downstream. The standard conveyance factor formula for U.S. conventional units is: CFAC = (1.49 * Area * $R^{2/3}$)/n, where R is the hydraulic radius and "n" is Manning's n value. For metric units the 1.49 becomes 1.00. Since the conveyance factor at a cross section generally follows a power law relationship to discharge CFAC = aQ^{b}, the exponent can be determined from multiple discharge measurements at a cross section and used as a good initial estimate for the calibration parameter ß in the MANSQ model as discussed below. Also called Water Transport Parameter (WTP) in the CALCF4 program output file.

Thalweg Slope : The change in elevation of the bed, measured at the point of maximum depth (i.e. thalweg depth) divided by the distance between cross sections. In PHABSIM, the thalweg slope may also be referred to as bed slope as shown in Figure 2-4.

Roughness (n): A coefficient indicating the resistance to flow or energy loss caused by the combined effects of particle size, vegetative friction, and channel features. In PHABSIM, this is most often expressed with the use of "Manning's n" values.

Stage of Zero Flow (SZF): The water surface elevation when water would stop flowing by a particular cross section. The stage of zero flow when measured in the field is usually the lowest ground elevation at a cross section when the cross section is at a hydraulic control. However, for some river features such as pools, the SZF is the lowest point of the streambed at the downstream hydraulic control for the pool. Because hydraulic controls can "migrate" with variation in discharge, measurement of SZF is difficult and is best done when flow is extremely low and water is not turbid. The determination of the proper SZF is discussed in more detail in the section dealing with modeling of water surface elevations using the STGQ program.

Equations Used For The Description and Analysis of Open-Channel Flow

Several fundamental equations and relationships are important to understand, since they constitute the computational basis for the various hydraulic models used within PHABSIM. A fundamental tenant of open channel flow is that continuity and mass balance of discharge must be maintained between adjacent cross sections for proper application of the hydraulic models. In addition, the overall energy balance due to friction losses between two adjacent cross sections must also be maintained. This is addressed in the hydraulic models within PHABSIM through the application of Manning's equation, which describes open channel flow in terms of measured cross section properties and relationships between the discharge, water surface elevation, velocity, and resistance to flow and the Bernoulli equation which evaluates longitudinal energy dissipation.

Continuity and Mass Balance

The water surface elevation in a stream defines the cross-sectional area of flow if the bed geometry is known. If mean cross section (channel) velocity is also known, discharge can be calculated using the equation of continuity (see Figure 2-3):

$$Q = AV \quad (2\text{-}1)$$

where: Q = discharge (cubic feet per second, cubic meters per second)

V = average velocity of flow through the cross section (feet/second, meters/second)
A = cross section area of flow (square feet, square meters)

In practical applications, if no inflows or outflows occur within the study site and the water surface elevations do not change during the period of field data collection, the estimated or user-computed discharge for individual cross sections should yield estimates of the discharge that are alike for similar habitat types. Hydraulic data collection for a PHABSIM study is usually undertaken in habitat types important to fish and, therefore, some channel types that are not ideal for estimating discharge will be sampled. It is not uncommon that riffle habitats have discharges that are 10–20% higher than the discharge estimated in runs, which are more ideal in terms of estimating the "true" discharge. Conversely, discharge estimates in pools can typically be 10–20% lower than runs. When selecting the best estimate of discharge, users are encouraged to consider cross section conditions as a major determinant of the user-supplied "best estimate" discharge. For example, an average of the discharge measurements obtained from three run cross sections in a study site may be superior to an average of the flow measured at all cross sections.

Manning's Equation

One of the most widely applied equations used to describe flow in open channels is referred to as Manning's equation (p. 96 in Henderson, 1966). The equation represents an alternative formulation of Equation 2-1 in which site specific channel characteristics are incorporated in order to describe the resistance of flow within the channel given the roughness of bed material, energy slope, and channel geometry. For U.S. conventional units Manning's equation is:

$$V = \frac{1.486}{n} R^{2/3} S_e^{1/2} \quad (2\text{-}2)$$

where: V = mean channel velocity (feet/second, meters/second)
1.486 = U.S. conventional unit correction (cube root of 3.28 feet/meter), or a value of 1.0 for metric units R = hydraulic radius, in feet (meters) S_e = slope of the energy grade line N = coefficient of roughness, referred to as Manning's n

This equation, in several different formulations, is used within PHABSIM in the MANSQ and WSP models for the simulation of water surface elevations and in the VELSIM program for the simulation of velocities.

Energy Balance and the Bernoulli Equation

In Manning's equation, the slope required as input is the slope of the energy grade line. This slope is defined as the difference in total energy at two (or more) channel sections, divided by the distance between them (refer to Figure 2-4). The total energy at a channel section is found with the open-channel form of the Bernoulli equation:

$$H = z + d + \frac{V^2}{2g} \quad (2\text{-}3)$$

where: H = total energy head, in feet (meters)
z = elevation of the bed, in feet (meters)
d = average depth for section, in feet (meters)
V = average velocity in feet/second (meters/second)
G = acceleration of gravity, 32.2 ft/sec^2 (9.8 m/sec^2)

For practical purposes, Figure 2-4 shows that the term z + d equals the water surface elevation (WSL) for a given cross section, therefore, the slope of the energy grade line can be determined by:

$$S_e = \frac{H_2 - H_1}{?x} \quad (2\text{-}4)$$

If the assumption is made that flow in the channel is uniform, then bed slope, hydraulic slope, and energy slope are considered equal, $S_o = S_h = S_e$. Therefore, this equation represents the Energy Balance between two adjacent cross sections of the stream. The Bernoulli equation in conjunction with mass balance of the discharge and Manning's equation form the computational core to the WSP program as described later in this chapter.

Applied Modeling of Water Surface Elevations in PHABSIM

Determining the relationship between the water surface (stage) and the discharge is the first step in the hydraulic calibration and simulation phases of PHABSIM (Figure 1-2). The stage is used to derive depth distributions for each cross section by subtraction of bed elevations across the channel from the stage. It is also used to identify the location of the free surface to establish boundaries (i.e., wetted cell locations) for some of the equations that describe velocity distributions. If stage and bed elevation are known, depth may be determined at any location on the cross section. Stage varies with discharge, so it is important to derive a reliable relationship between stage and discharge for the study site or hydraulic simulation results will be in error.

There are three approaches for predicting stage-discharge relationships in PHABSIM. The approaches described in this section include: (1) linear regression techniques based on multiple measurements from the field (the STGQ model); (2) use of Manning's equation (the MANSQ model); and (3) calculation of water surface profiles using standard step-backwater computations (the WSP model).

In the PHABSIM for Windows interface, all three models are accessed under the **/Models/WSL** menu. To provide maximum flexibility in modeling water surface elevations, the interface allows the user to select different models for different discharges at individual transects. Thus, it is possible to mix modeling approaches (including supplying water surface elevations from an outside source) for individual transects in a project and across the full range of discharges. The selected WSL calculation method is entered in the table displayed in the **/Models/WSL/Method** tab. Other tabs provide for selection of options within each model and are discussed below and in the laboratories.

NOTE: Graphs may be viewed on screen from several tabs within the WSL modeling section. In the options tabs, the graphics aid in checking the appropriateness of input to the particular WSL model to be run. The **Cross Section** and **Longitudinal** buttons in the **/Models/WSL/Results** tab allow the user to view the results of WSL modeling. These plots are useful in calibration and quality control of the WSL simulation process.

Modeling the Stage-Discharge Relationship by Regression

One method of obtaining a relationship between stage and discharge is to measure the discharge at several stages and develop an empirical regression equation relating stage to discharge. In practice, typically three (MESC recommends three [3] or more) measurements of the stage and discharge are obtained at each cross section over as wide a flow range as practical or as necessary to meet the study objectives.

In a large number of channels, stage-discharge data of this nature has been found to be adequately approximated by the following equation:

$$(WSL - SZF) = a\,Q^{b} \quad (2\text{-}5)$$

where: Q = discharge
WSL = stage or water surface elevation
SZF = stage of zero flow
a = constant derived from measured values of discharge and stage
b = constant derived from measured values of discharge and stage

Note that we have included the SZF in Equation 2-5 since the stage-discharge relationship at a channel cross section is a function of the SZF at that specific location, as discussed below under the STGQ model. The SZF is used within the STGQ model and one option in MANSQ. It should be included whenever using alternative stage-discharge regressions. Equation 2-5 can be transformed to a linear relationship between stage and discharge by taking the log of the equation which yields:

$$\log(WSL - SZF) = \log(a) + b * \log(Q) \quad (2\text{-}6)$$

A simple linear regression can then be performed between the log of the discharge and the log of the water surface elevation (minus stage of zero flow) to determine the constants. The resulting regression equation is then used to predict stage over a desired range of discharges. An example of a measured stage-discharge relationship with the resulting regression equation derived from these data is given in Figure 2-6.

In some channels however, where complex geometry may result in a significant change in cross section area over a wide range in discharge as illustrated in Figure 2-7, or where a backwater effect from a downstream hydraulic control may occur, the stage-discharge relationship may not be log-linear as illustrated in Figure 2-8. In these instances, the user should take care to review the stage-discharge relation developed by the models in PHABSIM to ensure that the most accurate evaluation of the stage-discharge relationship is achieved. If the STGQ model is allowed to proceed normally, a single regression line will be derived from all of the data in the log-log domain as shown in Figure 2-9. In these instances, the analyst may choose to partition the data into multiple, piece-wise linear data sets and develop corresponding regression equations for specific ranges of discharges which are to be simulated as illustrated in Figure 2-10. In PHABSIM for Windows this can be accomplished by creating separate copies of the project for each regression range or by running STGQ for pairs of calibration flows and reentering the data in the methods table as fixed water surface elevations. Such two point lines have zero degrees of freedom and should be used for extrapolation with caution.

In addition, stage values may be generated entirely outside of PHABSIM and entered in the **/Models/WSL/Methods** table in lieu of running any of the PHABSIM models. Stage values entered in the **../Methods** table must be converted to normal domain; that is, one must exponentiate to remove the log conversion.

Yellowstone R. near Fairview

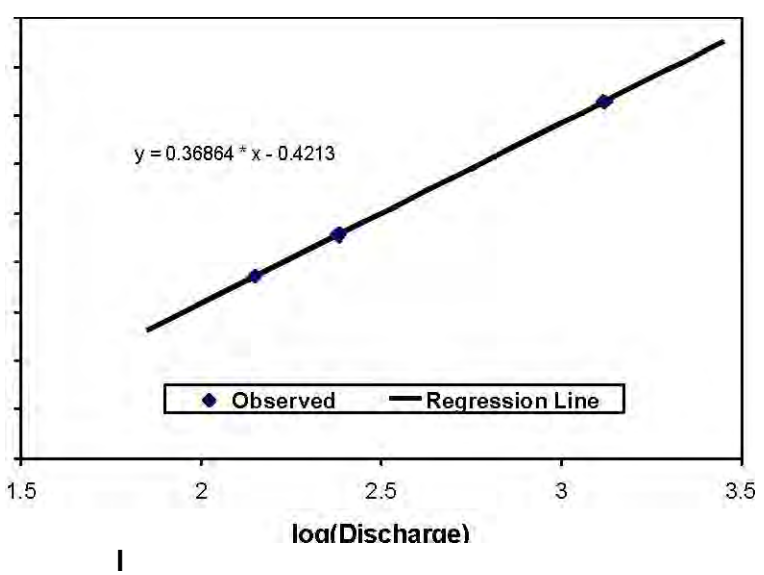
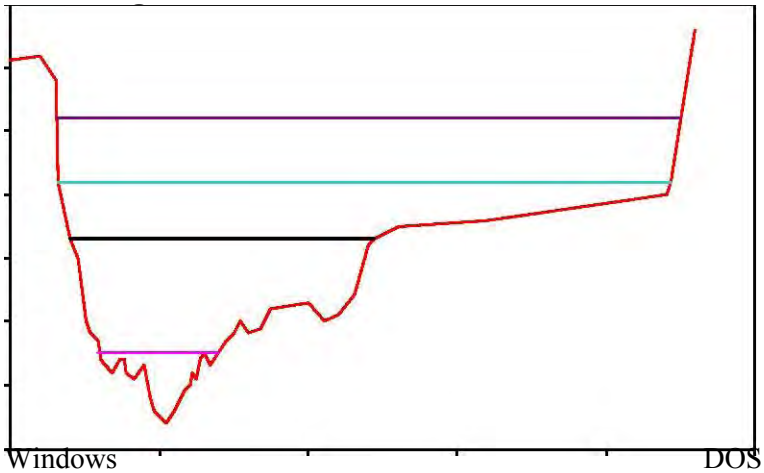


Figure 2-6. Example of a stage-discharge relationship based on three observed discharges.

Cross Section



Windows		DOS
Cell bed elevation	91.65	91.65
Water surface elevation	92.456	92.47
Depth	0.806	0.82

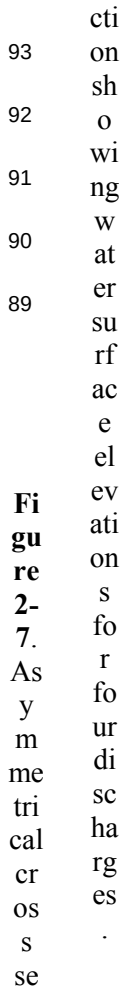


Figure 2-7. Asymmetrical cross section showing water surface elevations for four discharges.

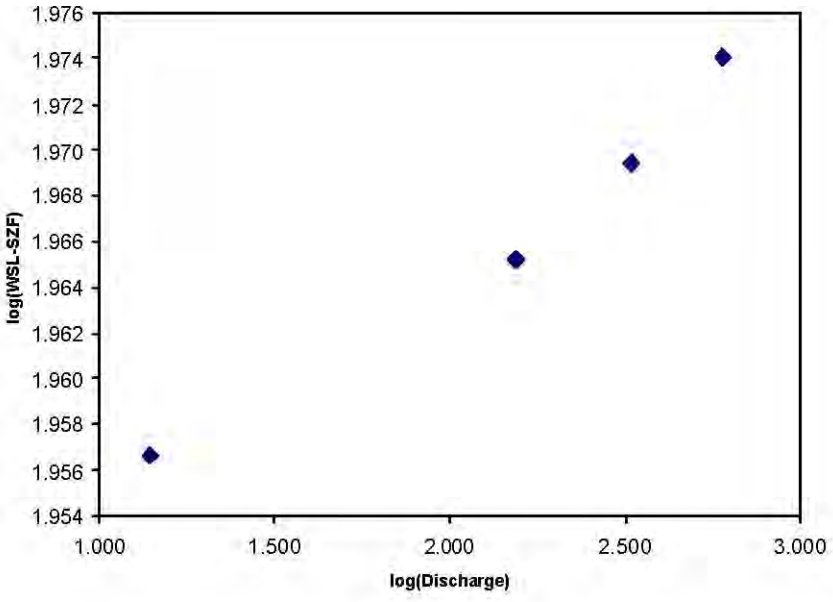


Figure 2-8. Log-log plot of stage-discharge for asymmetrical cross section above.1.000 1.500 2.000 2.500 3.000 **log(Discharge)**

Stage-discharge Relationship

Stage-discharge Relationship

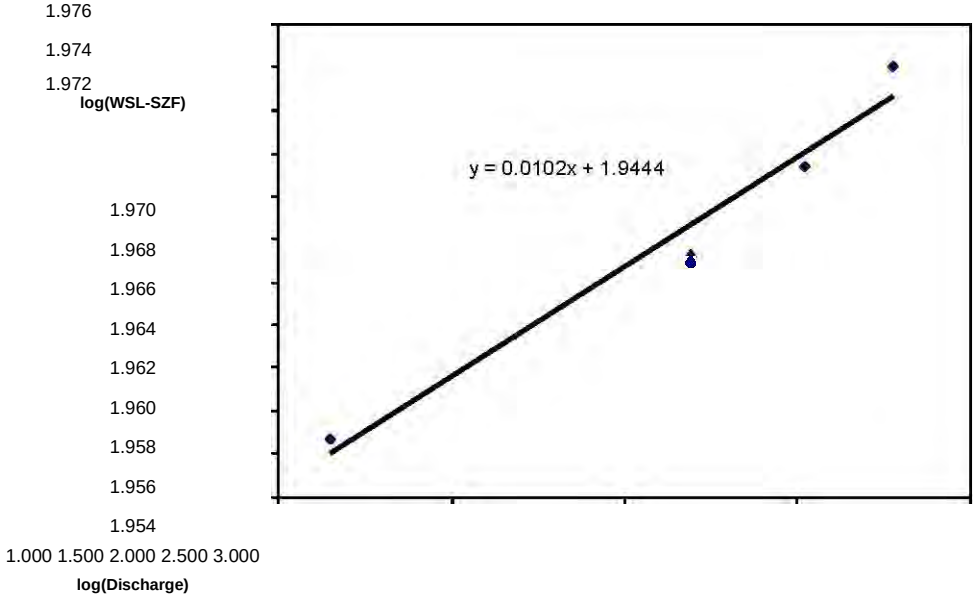


Figure 2-9. Default linear fit to non-linear stage-discharge data.

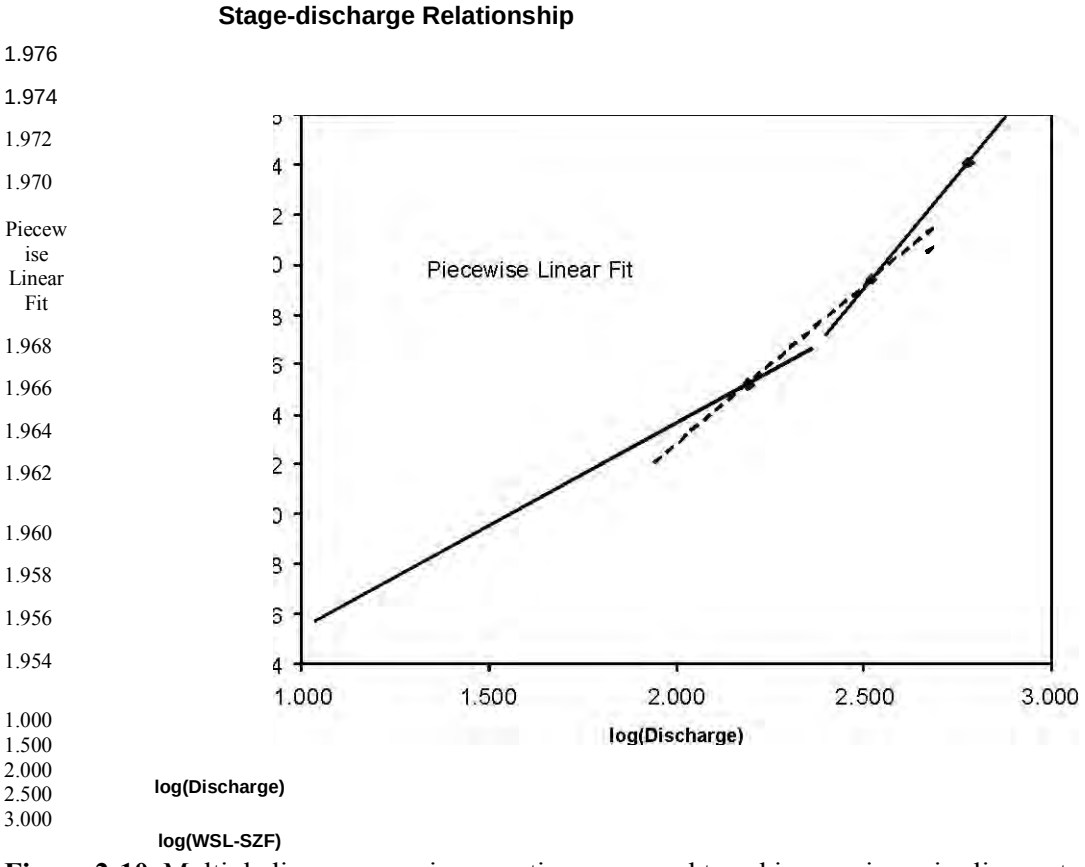


Figure 2-10. Multiple linear regression equations arranged to achieve a piecewise linear stage-discharge relation.

Alternatively, the user may also elect to fit a non-linear equation to the observed data for the purposes of modeling the relationship between stage and discharge as illustrated in Figure 2-11. It is advisable to use four or more points to allow for at least one degree of freedom in the regression. Non-linear fitting functions are available in various spreadsheet and statistical programs. The results may be inserted into PHABSIM as fixed WSL values in the methods table.

Regardless of whether the observed data is fit using a log-linear, piece-wise log-linear, or non-linear regression approach, the extrapolation of the regression equation to lower and higher discharge ranges than what was measured should be examined critically for reasonableness as discussed below. Upper and lower limits of extrapolated discharges are, to some degree, a matter of professional judgement and the specific analytical needs of a particular study. In general, the further away from the observed conditions, the greater the potential error between the actual stage and the stage predicted by extrapolation. The reasonable range of extrapolation varies among study sites so caution in extrapolation is advised.

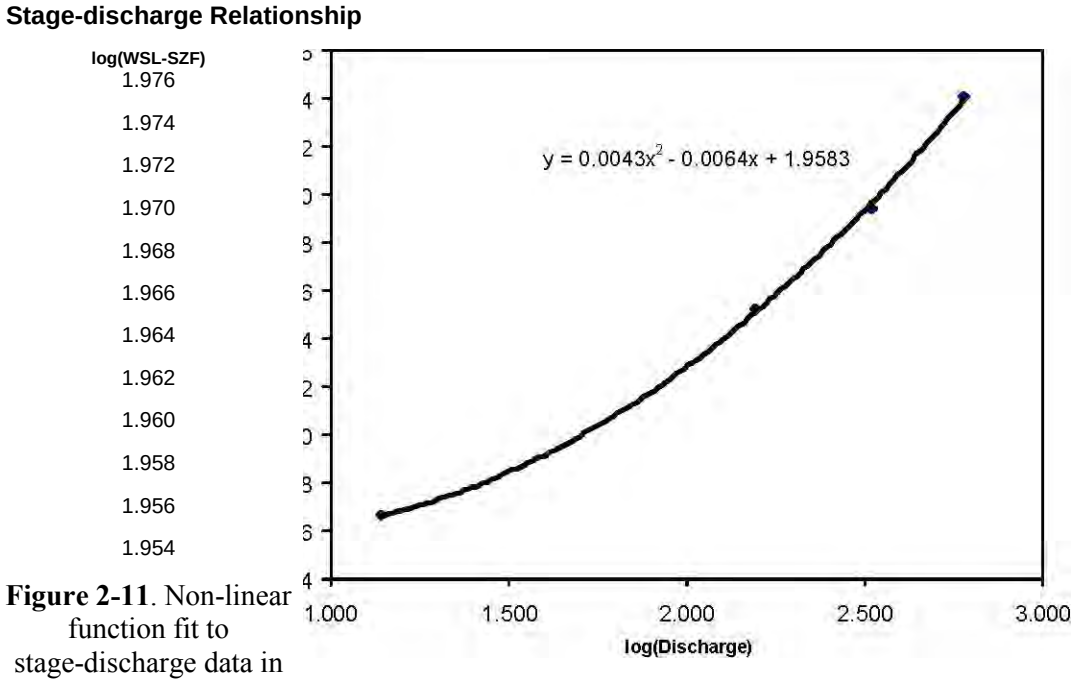


Figure 2-11. Non-linear function fit to stage-discharge data in logarithmic domain.

When using the regression approach, one should recognize that the regression equation developed for a specific cross section is independent of all other cross sections within a study site. Therefore, care should be exercised that internal consistency is maintained in the longitudinal profiles of the water surface elevations between adjacent cross sections within a specific study reach. For example, the results presented in Figure 2-12 show that the independent analysis of several cross sections using a log-linear regression approach (i.e., STGQ) results in the analysis predicting "water flowing uphill" for several discharges. Although the individual R^2 values of each regression were high (e.g., ≥ 0.95), longitudinal profile plots provide a simple diagnostic of model results that indicate an alternative modeling approach is required if the study requires simulating a range of discharges where water appears to flow uphill. Errors in water surface prediction will affect both the predicted depth and velocity values for this transect. Diagnostic evaluation of water surface modeling is discussed later in this chapter.

Determining the Stage of Zero Flow

Since the STGQ, and MANSQ models make use of the stage of zero flow (SZF) for computational purposes (see Equation 2-5 above and the MANSQ discussion below), it is important to understand how to obtain the proper SZF. The SZF is important since it is used directly in regression analysis of the stage-discharge equations in STGQ and in one simulation option within MANSQ. An error in estimating the SZF can alter hydraulic simulation results. The easiest way to determine the SZF is to plot the thalweg elevations at each cross section moving in an upstream direction as shown in the example provided in Figure 2-13.

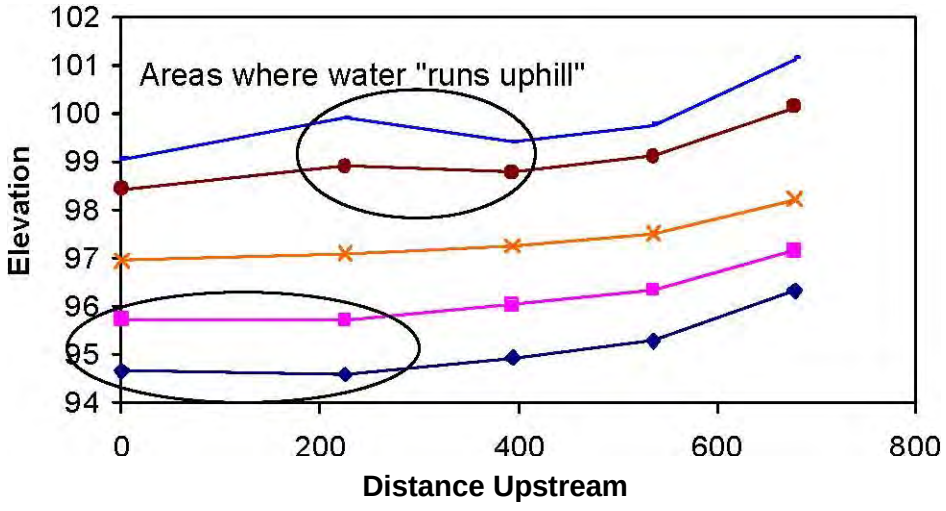


Figure 2-12. Independent stage-discharge analysis can result in a simulated adverse water surface profile.

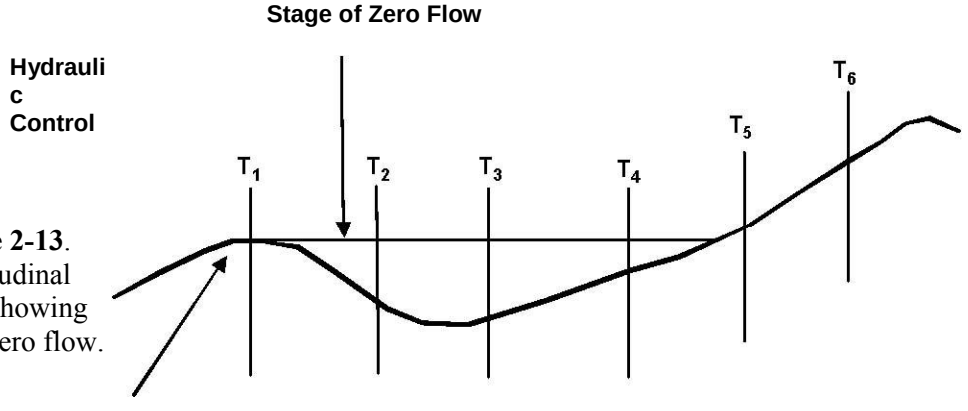


Figure 2-13. Longitudinal profile showing stage of zero flow.

As can be seen, the SZF at cross section T_1 corresponds to the thalweg depth at this cross section and will control the surface of the stream when the water level drops to this point. At that level, flow will cease, hence the concept of the stage at which zero flow will occur. It should also be apparent that this same SZF should be used at cross sections T_2 through T_4 since the elevation of the SZF at T_1 will control the water surface at these next two upstream cross sections. The individual thalweg depths should be used as the SZF at transects T_5 and T_6.

Stage-Discharge Analysis using Regression in PHABSIM – the STGQ Model

The STGQ hydraulic simulation model predicts water surface elevation as a function of discharge. Given stage-discharge data, STGQ will automatically conduct the log-linear regression on the calibration data sets and determine the water surface elevations for all flows contained on the **/Edit/Discharges** table. When using the stage-discharge relationship, each cross section is treated independently of all others in the data set. This approach has the advantage that habitat areas from several locations in the stream (habitat mapping strategy) can be analyzed simultaneously. The principle disadvantage is that not all cross sections are well-suited for stage-discharge regression and the phenomenon of simulated adverse water surface gradients (see Figure 2-12) can occur. The STGQ program simulates water surface elevations using the stage-discharge relationship information supplied in the **/Edit/Cross Sections/ Calibration Data** tab in PHABSIM for Windows.

Running the STGQ Model

Once the STGQ model has been selected for a combination of cross sections and discharges in the **/Models/WSL/Method** table, the user selects options to be run for the study site in the **/Models/WSL/STGQ Options** tab. These selections are made by clicking on the model type, eg. **STGQ** and then clicking each of the transect/discharge boxes in the table to which that model is to be applied. The boxes will then contain the term "STGQ".

Remember to review the output file **ZOUT** for error messages and inconsistencies in the data. (It will be the latest sequentially numbered ZOUT file in the directory where the project resides.) Error messages in the form of notes or other statements that do not appear on the screen or cause the program to abort may be written to the ZOUT file. Output from the STGQ model is variable depending on the selected simulation options. Examination of STGQ output is covered in the laboratory exercises.

STGQ Options

The user has the ability to select a variety of simulation and reporting options during the execution of the STGQ model. The associated laboratory exercises will address the use of the most commonly used options and, therefore, a detailed discussion of each option will not be presented here. Table 2-1 lists each of the options within STGQ and provides a concise description of the function for each option.

A Practical Guide to Modeling Stage-Discharge Relationships Using the Regression Approach

In most applications, the analyst will need to determine the "best estimate" of the discharge at a given calibration flow. Typically, the discharge calculated from observed velocity distributions may vary considerably between all measured cross sections. For example, it is not uncommon for the discharges computed within a single study reach in which the stage remains stable during field measurements to vary by as much as 25%. This is due to measurements being taken in pools, riffles, runs, etc. Generally, pools and riffles are poor areas for discharge estimation but are typically measured since they often represent critical habitat types necessary for evaluation as part of the instream flow investigations. Field crews should indicate during data collection which cross section(s) are best for estimation of the actual flow for a particular calibration set. The best discharge measuring sections are used to estimate the discharge for use in the regression analysis for all cross sections within the reach. The difference between the measured right and left bank water surface elevations can vary considerably with differences of 0.1 to 0.5 feet occurring in highly turbulent conditions. The analyst should select the average of the left and right bank, only the left or only the right, or other water surface elevation at each cross section in the regression equations based on the conditions reported in the field notes.

Table 2-1. Options in the STGQ program.

Option description	Action when set to indicated value
Prints the numerical details of the computed velocities and water surface elevations for each simulated discharge to ZOUT.	
Displays a table where the user assigns a CAL set to each discharge for each cross section.	
Discharge (IOC 5) (click cell, click down Selects whether the best estimate of the discharge arrow to change from Best Estimate of Q to or the discharge measured at this transect is used Xsec (transect) Q) in stage-discharge calculations. If no transect Q is supplied, defaults to best estimate.	
WSL (Click cell, click down arrow to change to Selects which of the WSL values supplied in Left, Right, Average or User supplied WSL) **/Edit/Cross Sections/Calibration Data** is used in WSL simulation.	
Selects if the stage of zero flow is used in the WSL simulation. Default is yes (checked).	
Output Options (applies to all WSL Simulation Models)	
Selects which discharges are simulated in the current run. Default is all (all boxes checked).	

The analyst also has the option of using the actual calculated discharges at each cross section in the regression equations rather than the best estimate for the reach. The analyst may also elect to vary the water surface elevations at a cross section within the range of measured differences between the left and right bank in attempts to get a better log-linear regression fit to the data. Using discharges other than the best estimated discharge or water surface elevations different than the average should be carefully considered; but, this choice does not imply errors in modeling as long as a rational basis for the use of alternative data is clearly articulated and justified in the study report.

In some instances, the flow rate will change during the course of field data collection at a study reach either within the day or between successive days for a variety or reasons. This is most often noted by changes in the stage readings of the water surface elevation during field data collection or during data processing where calculated discharges show a consistent increase or decrease between successive measurements. A typical approach with data sets having these characteristics is to derive best estimates of the discharge for groups of cross sections, which represent consistent field measurements under similar flow conditions.

For example, the first three cross sections measured during the first field day may have a best estimate of discharge equal to 100 cfs at the low calibration set while cross sections 4 through 7, collected the next day, may have a best estimate of the discharge of 120 cfs. Because the STGQ program treats each cross section as an independent data set, it has the ability to accommodate different discharges between cross sections for a given calibration set. In those instances in which the discharge changes during the collection of data at a single cross section, it is best to stop data collection until the flow stabilizes. However, if this is not an option, or this was determined in the office during review of data collection efforts, advanced modeling approaches beyond the scope of this chapter need to undertaken. In those instances, the analyst should contact an experienced hydraulic engineer for technical assistance.

In summary, the following step-wise procedure can be followed for conducting stage-discharge modeling using the regression approach to estimate water surface elevations in PHABSIM.

1. Decide whether to use the best estimate of the discharge for each calibration set for all cross sections and whether to use the average of the right and left bank water surface elevations measured at each calibration flow. Be sure to check if the discharge remained constant during field collection efforts or whether different best estimates of the discharge need to be provided for different groups of cross sections. Finally, determine the appropriate stage of zero flow (SZF) for each of the cross sections.

2. Plot the log of the discharge versus the log of the WSL-SZF (**/Models/WSL/STGQ options/Stage Discharge Graph**) and examine the relationship for linearity or piece-wise linearity before proceeding. If the relationship at a cross section is not log-linear, consider an alternative modeling approach such as MANSQ or WSP or proceed with a non-linear analysis of the data (outside of PHABSIM for Windows) to predict the water surface elevations.

3. Ensure that all measured calibration data sets use the appropriate discharge and water surface elevations at each cross section and each calibration flow. Check that all such data are in the project file (See **/Edit/Cross Sections/Calibration Data**). When using a piece-wise linear approach, assign the Cal sets for a single "piece" and remove check marks from the rest to select the range of discharges you wish to simulate (**/Models/WSL/Output options**).

4. Run the STGQ model (Click **Run** under the **../WSL/Method** tab) and examine the longitudinal profiles (**Longitudinal** profile plot in the **../Results** tab) of the water surface elevations for all spatially linked cross sections to determine the quality of the model results.

5. If the longitudinal profiles look reasonable for all simulated discharges, proceed to the velocity calibration and simulation step of PHABSIM. If not, examine alternative WSL modeling approaches using MANSQ and/or WSP.

Review the output file ZOUTnn for error messages and inconsistencies in your data. Error messages in the form of notes or other statements that do not appear on the screen or cause the program to abort may be written to the output file. Output from the STGQ model includes a listing of the calibration data used in the stage-discharge regression, and the regression equation with diagnostic statistics for each cross section.

Modeling the Stage-Discharge Relationship Using Manning's Equation – The MANSQ Model

The MANSQ model can be used to determine the stage-discharge relationship for individual cross sections. The uniform flow assumption allows use of measured hydraulic slope instead of energy slope, since, by definition, they are equal if flow is uniform. In addition, this approach assumes that flow variations caused by changes in channel configuration are negligible (i.e., minimal backwater effects). Generally, the more uniform the channel, the more reliable the results using this approach, thus it is more reliable in run sections. The application of the MANSQ model in pools can sometimes be problematic since pools are generally created by backwater effects of a downstream hydraulic control. As was the case in using the STGQ model, the MANSQ model also assumes that each cross section is independent of all other cross sections during calibration and simulations. Therefore, as indicated for the STGQ program, the longitudinal profile of the simulated water surface elevations should always be checked to ensure water is flowing down hill between spatially linked cross sections in a study reach.

The MANSQ model uses Manning's equation in the form:

$$\neg 1.49 \rangle \qquad S^{1/2} R^{2/3}$$

$$Q = * * A * \qquad \text{(2-7)}$$

$$\square$$

$$\equiv n \Downarrow$$

and simplifies it to:

$$Q = KA_R^{2/3} \qquad \text{(2-8)}$$

The value of K is determined from one set of measured discharge and water surface elevation pairs and measured channel geometry at a cross section. The program then uses additional calibration data sets (i.e., discharges and water surface elevations) to solve one of the following three equations selected by the user:

$$\} \; {}_{Q} \} \; {}^{\beta} K = K_o \; {}^{\}\}} \qquad \text{(2-9)}$$

$$Q$$

$$\leq o \geq \qquad \left| \; \Big/ 1 \cdot \log(2.42 \qquad \left| \; {}_{\}} \right. \right.$$

$$\} \; R \; \}^{\beta} \qquad \text{(2-11)}$$

$$K = K_o \qquad \}\} \; \text{(2-10)} \leq R_o \geq$$

$$^{5/3}$$

$$^{\}} R_o \} \; {}^{\}\}} \} \; R \; \}\} \; \} \; R_o \}\}\}$$

$$K = K_o \; {}^{\}} \} \; * \; {}^{\}} \log {}^{\}} 2.42 \}$$

$$R \geq {}^{\}} \leq D50 \; {}_{\geq}$$

$$\leq D50 \; \text{ł}_{\geq} \geq \leq \leq \leq {}^{\geq}$$

where: subscript o refers to calibration values,
exponent β represents a coefficient supplied by the user for each transect, and
D50 is the median particle size on the stream bed.

Selection of the ratio of discharges, the ratio of the hydraulic radius, or the empirical relation between hydraulic radii and median particle size is a choice made by the investigator. There is no strong evidence to suggest the discharge ratio is generally superior to the hydraulic radius ratio. Functionally, given multiple sets of discharge-water surface elevation data at a cross section, the user employs a trial and error procedure for selecting a value of β that minimizes the error between observed and predicted water surface elevations at the calibration discharges, regardless of which equation formulation is used. Due to the ease of switching between the first two

options, a trial-and-error approach may be used.

The third approach requires a sediment study to determine the median bed material size. This option cannot be used unless such a study has been conducted. When selecting the third option, the D50 value is entered in place of β (in the **/Models/WSL/MANSQ Options** tab). In all cases, the investigator should be able to justify the final calibrations by demonstrating minimum error between predicted and observed WSL at the calibration discharges.

The MANSQ β coefficients will typically be different for each cross section within a study reach. The range of the differences will depend on the variation in complexity of the channel at different cross sections. The range of β in typical applications is approximately 0.0 to 0.6; β cannot be less than 0. If calibrated β values fall outside this range, the results should be examined carefully, but such results do not necessarily imply that the data has errors or that hydraulic calibration is faulty. The investigator should examine the errors between predicted and observed water surface elevations in light of variations in cross section geometry and the observed ranges in discharge and water surface elevations. An average of several data sets evaluated at MESC yielded a β value of 0.22 for gravel bed channels. This may be a good starting estimate of β in the calibration process.

As previously noted, MANSQ treats each cross section independently. Therefore, once all cross sections have been suitably calibrated and the full range of desired discharges have been simulated, the longitudinal profiles of the water surface elevations should be checked for internal consistency (i.e., water flows downhill).

Running the MANSQ Model

Once the MANSQ model has been selected for a combination of cross sections and discharges in the **/Models/WSL/Method** table, the user selects options to be run for the study site in the **/Models/WSL/MANSQ Options** tab. You may find that by selecting only the desired calibration flows in the table in the **/Models/WSL/Output Options** tab during the calibration phase, calibration of the model is somewhat easier due to reduced amounts of output to evaluate. However, the user should ensure that after successful calibration of the model all flows of interest have been selected in **../Output Options** prior to performing the final WSL production run.

Remember to review the output file (latest ZOUTnn file) for error messages and inconsistencies in the data. Error messages in the form of notes or other statements may be written to the output file that did not appear on the screen or cause the program to abort. Examination of MANSQ output is deferred to the Laboratory exercises.

MANSQ Options

The user has the ability to select a variety of computational and reporting levels for the MANSQ program. The associated laboratory exercises will treat the use of the most commonly used options and therefore a detailed discussion of each option will not be presented here. Table 2-2 lists each of the options within MANSQ and provides a concise description of the function for each option.

Table 2-2. Options in the MANSQ program.

Windows		DOS	Difference	% difference
Cell bed elevation	91.65	91.65	0	0.00
Water surface elevation	92.456	92.47	0.014	0.02
Depth	0.806	0.82	0.014	1.71
Depth Suitability Index	0.0708	0.096	0.025	26.25
Combined Suitability Index	0.0644	0.087	0.023	26.25
Weighted Usable Area	8.698	11.79	3.096	26.25

Acknowledgements **i**
PREFACE **ii**
A Brief History of PHABSIM
Use of this Document
Changes Between PHABSIM Version 2 and PHABSIM for Windows
Conventions Used in this Document
Chapter 1, Introduction to the Physical Habitat Simulation System **1**
Objectives
Associated Laboratory Exercises
An Overview of IFIM
The Purpose of PHABSIM
The Structure of PHABSIM
Application of PHABSIM
Scoping
Selection of Target Species and Suitability Curves
Selection of Target Species
Types of Suitability Curves
Transferability of Suitability Curves
Segmenting the Study Area and Study Site Location
Critical Reach
Mesohabitat Study Site Selection
Cross Section Selection and Field Data Collection
Cross Section Selection
Field Data Collection
Hydraulic Modeling
Water Surface Elevation Modeling
Velocity Modeling
Habitat Modeling
The Average Parameter Model

Option description	Action when set to indicated value

Output Options (Applies to All WSL Simulation Models)

Use (check boxes for each discharge)	Selects which discharges are simulated in the current run. Default is all (all boxes checked).

A Practical Guide to Calibrating MANSQ

The calibration of the MANSQ program involves a trial-and-error procedure to pick a β value that minimizes the error between predicted and observed water surface elevations at each transect. This can be summarized in the following steps:

1. Run **/Models/Water Transport Parameters (CALCF4)** by selecting that menu item. Use Notepad or Wordpad to view the **table.calcf4** file and search for the text string „WTP' at each cross section. This is the conveyance factor. Locate the regression equation between discharge and the channel conveyance factor or water transport parameter (WTP) term for each cross section. The exponent (B) in the WTP regression equation is an excellent initial estimate for the β coefficient for each transect in the MANSQ program. Alternatively, just make a guess (i.e., 0.22) and proceed.
2. Select MANSQ options in the **/Models/WSL/MANSQ Options** tab. Then take care to select which calibration flow you intend to use as the initial calibration flow since this will represent a "fixed" calibration set for the program. The calibration sets are numbered in order of ascending discharge magnitude. Then select only the CAL set flows shown in **..WSL/Output options** , that is remove the checks from all but the calibration flows. Enter your best estimate for β at each cross section either derived from the WTP regression exponent term or your initial guess. Click **Run**.

3. Go to the **..WSL**/**Method** tab and select MANSQ for all transects.). Set the β coefficient at each transect (in the **../MANSQ Options** tab, change beta values in the table). Run the MANSQ program (../**Method** tab, click the run button). Compare the predicted versus observed WSL at each transect for all the calibration flows by moving to the **../Results** tab and noting WSL values in the table compared to observed values. The **Longitudinal** graph button in the **../Results** tab allows comparison of the observed and predicted WSL profile. Note that at the selected calibration flow the program will always return the given water surface elevation since this is an initial condition for determination of the K value at that discharge (see equations above). Change the β coefficient at each transect (**../MANSQ** tab, change beta values in the table) and repeat this process until the error between predicted and observed water surface elevations is minimized at all calibration flows. Remember each cross section is treated independently, so once one is calibrated, you can ignore it during the remaining calibrations of the other cross sections.

4. Once an adequate calibration is achieved, add all the flows of interest by checking the boxes in **../Output Options** and make the production run using MANSQ.

5. Check the predicted longitudinal profiles of the water surface elevations to ensure water flows downhill at all discharges.

As discussed in modeling water surface elevations with STGQ, the analyst can use the MANSQ program when discharges change between data collection efforts and/or cross sections. The calibration flows at each cross section or groups of cross sections are simply those used in the calibration process. Users may select different calibration flows for each cross section in the table in the **../MANSQ Options** tab. Similarly, the analyst can elect to use the computed discharge at each cross section rather than the best estimate of the discharge for the reach. Again, as long as a rational justification can be put forward and defended, these choices are a matter of professional judgement.

The reader is also encouraged to revisit the discussion in the section titled **"**A Practical Guide to Modeling Stage-Discharge Relationships Using Regression Approaches**"** provided above since many of the same situations will be encountered when applying the MANSQ model.

Modeling The Stage-Discharge Relationship Using A Step-backwater Approach – WSP

General Theory of the WSP Model

The WSP model is a water surface profile program that is used to predict how the longitudinal profile of the water surface elevation changes over a range of simulated discharges. Specific hydraulic relationships between the physical channel and discharge must be met to evaluate these changes in reference to a particular stream reach being modeled. These relationships are defined using concepts of mass balance (continuity) and energy balance. Several basic assumptions apply. These include assuming steady flow conditions existing during the period of field measurements and assuming boundary conditions remain basically rigid (i.e. the channel geometry does not change substantially over the range of measured data sets).

The following example illustrates the step-backwater computational process and introduces the relevant equations. In the example, two cross sections will be described which were illustrated in Figure 2-13. When more than two cross sections are involved, the process is repeated step-wise upstream; hence, the term step-backwater. The flow balance is calculated using the continuity equation:

$$Q_2 = Q_1 + ?Q \quad (2\text{-}12)$$

where: $Q_{1,2}$ = flow at each cross section as specified by the user)Q = specified change in flow (usually zero) between sections

The velocity is then calculated using the following equation:

$$V_i = \frac{Q_i}{A_i} \quad (2\text{-}13)$$

where: V_i = velocity at a cross section *i* A_i = area of cross section *i* Q_i = flow through cross section *i*

The energy balance is then calculated using:

$$H_2 = H_1 +)H \quad (2\text{-}14)$$

where: $H_{1,2}$ = total energy at each cross section ΔH = total energy losses as water moves downstream

The total energy of the stream at a given cross-section is derived from the Bernoulli equation Chow (1959).

$$H = z + d + \frac{v^2}{2g} \quad (2\text{-}15)$$

where: z = elevation of channel bottom d = depth of water

$v^2/2g$ = energy component due to flow velocity (called velocity head) v = mean column velocity of water g = gravitational constant

The Bernoulli equation written in terms of two adjacent cross sections in the stream is therefore (see Figure 2-4):

$$z_1 + d_1 + \frac{v_1^2}{2g} = z_2 + d_2 + \frac{v_2^2}{2g} - \text{losses} \quad (2\text{-}16)$$

This equation accounts for the net effects of energy loss between two adjacent locations within the stream reach. Effects due to changes in bed elevation changes, depth, and velocity are accounted for by losses accumulated between cross sections and are accounted for within the WSP program.

An additional equation is used to relate energy and flow values so that the computational procedure can cross check between the flow and energy balances. Using the user-supplied data for discharge (Q) and roughness (Manning's n), and the calculated values for area (A) and hydraulic radius (R) from the measured data at each cross section, Manning's equation is used to define the energy slope S_{ei} at each location by:

$$S_{ei} = \left(\frac{Q_i n_i}{1.49 R_i^{2/3} A_i} \right)^2 \quad (2\text{-}17)$$

where: Q_i = discharge (cfs, cms)
n_i = roughness coefficient
A_i = cross-section area (ft^2, m^2)
R_i = hydraulic radius (ft,m), e.g., area divided by wetted perimeter
S_{ei} = energy slope (subscripts refer to any cross section i)

Manning's equation is empirical, and the roughness coefficient "n" is used to quantitatively express the degree of resistance to flow in the channel. The value of Manning's "n" is an indication of the roughness of the sides, bottom, and other irregularities of the channel profile. The value is used to indicate the net effect of all factors which resist the movement of water moving downstream through the channel. Typical values of Manning's roughness coefficient n in a natural river channel are given in Table 2-3 (derived from Henderson [1966]).

Windows		DOS	Difference	% difference
Cell bed elevation	91.65	91.65	0	0.00
Water surface elevation	92.456	92.47	0.014	0.02
Depth	0.806	0.82	0.014	1.71
Depth Suitability Index	0.0708	0.096	0.025	26.25
Combined Suitability Index	0.0644	0.087	0.023	26.25
Weighted Usable Area	8.698	11.79	3.096	26.25

Table 2-3. Typical Manning's n values associated with channel types or conditions.

In the most general sense, the roughness or resistance to flow within a channel decreases with increasing discharge as illustrated in Figure 2-14. As can be seen the magnitude of Manning's n estimated for use in the model will be a function of the calibration discharge and will typically vary with simulated discharges according the general relationship shown in Figure 2-14.

This discharge-dependent change in roughness is accounted for in the WSP model by allowing the user to empirically determine this functional relationship and thus vary the Manning's n with discharge within the model

as described below. Under practical working conditions, Manning's n values may fall outside reported handbook ranges. This parameter in the model is attempting to integrate all kinds of resistance to flow that include "errors" in approximations such as fixed expansion and contraction coefficients, etc. Also, many of the cited handbook values are more indicative of high flow conditions. In addition, the presence of aquatic vegetation, for example, will result in much higher Manning's values than would be obtained at the same cross section in the absence of vegetation. The overriding principal in the application of the WSP model and, in particular, deriving Manning's n values is whether or not the model adequately predicts the observed water surface elevations.

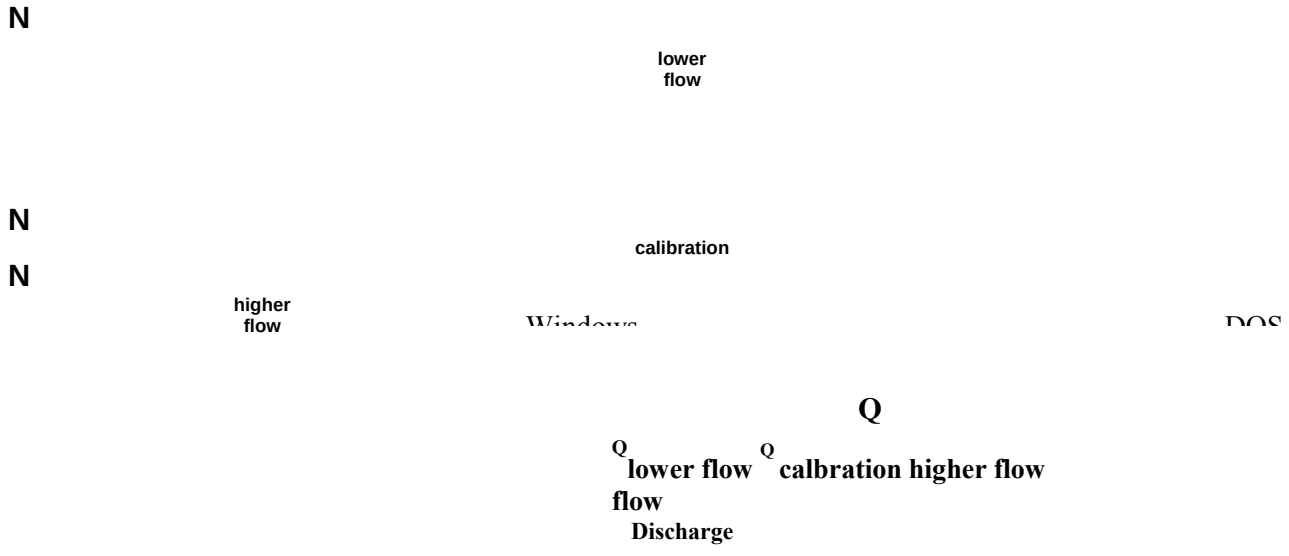


Figure 2-14. Change in roughness magnitude with discharge. Computational Process of the Step-Backwater Approach to Water Surface Modeling The basic step-backwater approach to compute water surface profiles proceeds as follows:

1. Starting at the farthest downstream cross section, a water surface elevation (WSL_1) is taken from user-supplied values or calculated from the user-supplied energy slope using Manning's equation.
2. The energy slope for cross section 1 (S_{e1}) may be calculated from Manning's equation if water surface elevations are supplied or may be used directly if energy slopes are supplied. (Values of A, R, and V are determined from channel geometry, WSL, and flow.)
3. The water surface elevation at the next cross section (WSL_2) is estimated by projecting S_{e1} upstream over the distance (L) between the two cross sections.
4. The energy slope at cross section 2 (S_{e2}) is calculated using Manning's equations and an average slope for the section is determined from:

$$S_e = \text{function } (S_{e1}, S_{e2}) \quad (2\text{-}18)$$

$$Q_2 = Q_1 \quad (2\text{-}19)$$

5. Flow and energy balances at the two cross sections are performed using:

$$H_2 = H_1 + S_{eL} + (\text{other losses}) \quad (2\text{-}20)$$

where: $Q_1 = Q_2$ = steady flow at both cross sections H_1, H_2 = total energy at both cross sections S_{eL} = energy losses over the distance L

Other losses associated with effects such as expansion and eddy losses are calculated within the program.

6. The water surface elevation at the second cross section is calculated by removing the velocity head from the total energy head yielding:

$$WSL_2 = H_2 - \frac{V_2^2}{2g} \quad (2\text{-}21)$$

1. The WSL_2 values from steps 3 and 6 are compared and a numerical technique is used to adjust the estimated WSL_2 values.
2. Steps 3 through 8 are repeated until there is close agreement between estimated and calculated water surface elevations.
3. The entire process is repeated for cross sections 2 and 3, 3 and 4, and so on until all cross section are processed.

Users should note that the computed water surface elevations may not agree with those measured in the field even though internal agreement may be obtained within the WSP model. In this situation, the value of Manning's n is changed by the user and the program is rerun until the energy-balanced water surface elevations calibrate with observed water surface elevations at the single calibration flow. After this initial calibration is achieved, the additional calibration data sets are used to empirically derive the relationship between roughness and discharge illustrated in Figure 2-15 for use in the model as described in the following sections.

WSP Options

The user has the ability to select a variety of computational and reporting levels during the execution of the WSP program. The associated laboratory exercises will treat the use of the most commonly used options in WSP and therefore, a detailed discussion of each option will not be presented here. Table 2-4 lists the options within WSP and provides a concise description of the function for each option. Although various hydraulic options were provided in the original WSP program, most of them have a limited applicability to PHABSIM studies. Thus, the options available in PHABSIM for Windows are limited to those relevant to habitat studies. For a detailed explanation of these options, the reader should consult a "Guide to the Application of the Water Surface Profile Computer Program" (U.S. Bureau of Reclamation, 1968).

Table 2-4. Options in the WSP program.

Option description	Action when set to indicated value
Use Critical Discharge Constraint (check box)	Forces water surface elevation to be at critical flow elevation if supercritical flow is detected. (Strongly recommend checking this box for most applications.)
Override Error Processing (check box)	Overrides certain error processing by overriding the limit on the allowable change in energy loss between two sections. WSP will not calculate the upstream water surface elevation if the change in elevation is too large and will not proceed further. Sometimes it is useful to review the results with a large change in water surface elevation between two cross sections to find the cross section(s) where the problem occurs. Suggest production runs should be made with this option off as the underlying problem should be dealt with first.
Write cell details (check box)	Writes cell calculation details to ZOUT.
Set "n" values (table)	N values are entered for each cross section and the entries revised to achieve calibration.
OD" (table)	Transect roughness modifiers are supplied to adjust n as a function of discharge.

Output Options (this Applies to all WSL Simulation Models)

Use (check boxes for each discharge)	Selects which discharges are simulated in the current run. Default is all (all boxes checked).

A Conceptual Overview of WSP Calibration

Calibrating the Longitudinal Water Surface Profile

We begin by recalling that WSP assumes the cross sections are connected and contiguous within a study site. Then, from an applied perspective, the first calibration step in WSP involves the estimation of an appropriate Manning's n value for the entire study site (that is, the same n is supplied for each cross section) which minimizes the error between observed and predicted water surface elevations at the selected discharge. In other words, the user selects a Manning's n value for all cross sections which allows the WSP model to approximate the observed longitudinal profile of the water surface elevation at all cross sections at this initial (or base) calibration discharge. Normally an increase in the roughness coefficients increases the predicted water surface elevation and a decrease in Manning's n usually reduces the predicted water surface elevation. The first phase of calibration consists of setting n for all cross sections, running WSP, evaluating the results, and adjusting n until suitable agreement between observed and simulated water surface elevation is achieved.

Note that the water surface elevation (or slope) at the downstream-most cross section is a given input to the model and as such, is not part of the actual calibration of WSP for the first cross section. If the user has not measured the starting water surface elevations for all flows of interest and for which the WSP program will be used, then either the STGQ or MANSQ model (or other suitable approach) must be used to generate the starting water surface elevations at the down stream cross section.

One can provide an initial estimate of the Manning's n value using handbook values based on the observed channel configuration and substrate characteristics (e.g., see Table 2-3, or [Chow, 1959]), however, the following technique provides a means of adjusting Manning's n that empirically reflects the dynamics of the resistance to flow based on field measurements.

Begin by using the observed WSL and an initial estimate (obtained from handbooks or by professional judgement) for the Manning's n value for the study site (a global value for all cross sections) and run the WSP model. Examine the output and record the average value of the computed slope obtained over the entire study site (see Equations 2-16 and 2-17, above).

Treating the initial estimate of Manning's n and computed slope from WSP as "trial" values, along with the actual average measured slope for the study obtained from field measurements, the following equation will yield an adjusted estimate of Manning's n for the study site.

$$n_{needed} = n_{trial} * \frac{S_{computed}^{1/2}}{S_{measured}^{1/2}} \quad (2\text{-}22)$$

This value can be substituted for the initial trial Manning's n value for <u>all</u> cross sections. The WSP model can then be re-run to evaluate the overall fit of the simulated water surface profile. The user should not expect that the n selected will result in a "perfect" match of all observed WSL's at all cross sections. When an apparent best fit has been obtained, proceed to "Calibration of WSP to Additional Longitudinal Profiles", below.

Calibration of WSP to Additional Longitudinal Profiles using Roughness Modifiers (RMODs)

In this calibration step, the relationship between discharge and roughness observed in open channels illustrated in Figure 2-15 is derived empirically. Since the roughness varies as a function of discharge, some means must be used to take into account the changes in roughness with discharge. Therefore, the Manning's n values obtained in the first step of the calibration must be modified appropriately in order to reproduce the observed longitudinal water surface profile at other calibration discharges. The objective is to select roughness modifiers so the new roughness (i.e., computed Manning's n values used during program execution) minimizes the error between observed and predicted longitudinal profiles of the water surface elevations at the remaining calibration flows.

To accomplish this step of the calibration, the remaining calibration discharges and starting water surface elevations (or slopes) at the downstream-most cross section are provided to WSP using the table in the **/Models/WSL/Method** tab. The user then uses a trial and error procedure to select appropriate roughness modifiers for each new calibration flow which minimize the error between predicted and observed water surface elevations for all cross sections at each of the new calibration flows. Note that the RMOD value for the initial (or base) calibration discharge used during the first step for calibration of Manning's n is 1.0 and should remain so for all simulations. The "base" condition represents our starting point for adjusting n as a function of discharge so it should be multiplied by 1.0 to preserve the starting point. Once the appropriate roughness modifiers associated with the other calibration discharges have been obtained, experience has shown that the roughness modifiers vary approximately with discharge as shown in Figure 2-15, which can be represented by a power law equation:

$$RMOD = a\ Q^{b} \quad (2\text{-}23)$$

The coefficient and exponent can be empirically determined from a linear regression between the logarithm of the RMODs and the logarithms of their associated calibration discharges. This regression equation is then used to derive the appropriate RMODs at all flows of interest to be simulated with the WSP model and entered along with the starting water surface elevations (or slopes) at the downstream cross section. A linear regression for RMOD values can easily be performed in a spreadsheet and is not included in PHABSIM for Windows.

The user should not expect that the RMODs will result in a "perfect" match of all observed WSLs at all cross sections for the remaining calibration discharges. The final selection of a particular RMOD value for a given calibration flow will be based on an attempt to minimize the error between predicted and observed WSLs between all cross sections at a particular calibration flow. Often, for example, one will accept a larger error at some cross sections to preserve a better fit over the entire study site and range of observed discharges. This will require the analyst to exercise some degree of judgement which must have a rational basis in light of the conditions at the study site and the needs of the particular study.

PHABSIM for Windows provides effective graphical tools for n calibration. Viewing longitudinal profile graphs in the **/Models/WSL/Results** tab can give a quick visual comparison of calculated and observed water surface values at each transect. Adjustments to n and RMOD values can be made and the WSP model re-run rather quickly, so a trial-and-error procedure for n and RMOD calibration is both feasible and timely.

Adjusting n Values for Individual Transects

It is tempting to adjust n values to obtain an exact match between measured and simulated water surface elevations at your selected "base" calibration discharge. While visually appealing, such a practice can: (a) maximize the impact of any measurement errors, and (b) result in a poor fit to measured water surface profiles at other measured discharges. If there is a poor fit at the other measured discharges, the analyst cannot be confident about the quality of the simulated water surface profiles obtained using widely varying Manning's n values. In short, if n must vary over a wide range to obtain an exact match to the measured water surface profile at the calibration discharge, something is very wrong. *Such a practice is strongly discouraged.*

Instead, using different n values among cross sections at a study site should be based on some assessment of changes in the physical conditions among the cross sections. Such changes typically include variation in the bed material (where n represents bed particle roughness, e.g., friction) or in the channel configuration or bed form (where n also incorporates form roughness).

Because Manning's equation does not differentiate between the types of roughness described by n, the user must supply (and defend) the rationale for varying n among cross sections. The initial "global" n approach captures the overall resistance to flow of the channel within the study site. Then, local variations in n may be considered where there is some physical justification. For example, if there is an area with large numbers of colluvial boulders in the stream, the boulder field would be expected to have a higher-than-site-average flow resistance. Other areas would be likely to have resistance below the average. Similarly, changing from a rectangular cross section in a riffle to a parabolic cross section in a pool may justify small local adjustments to n by trial and error. In general, adjustment of n values for individual cross sections more than approximately 10% ~15% of the global value for the study site needs to be justified by specific evidence about large changes in bed material or channel configuration. Whenever making local n adjustments keep two criteria in mind: (1) there must be some physical basis and (2) the adjustment is intended to obtain a better match between predicted and observed water surface profiles. If an adjustment made to obtain a better water surface elevation match is contrary to the apparent physical processes in the channel, it cannot be defended.

Note that the Manning's n value at a downstream cross section can have an "impact" on the magnitudes of the Manning's n values at the remaining cross sections. During the calibration procedure, care must be taken to avoid a see-saw effect in selected n values.

Determining Initial Water Surface Elevations for Calibrated WSP Models

The final required step for using the calibrated WSP model for WSL simulation is to define the starting water surface elevations at the downstream cross section for all unmeasured flows. The most common approaches are to use either a stage-discharge regression (STGQ model) or Manning's equation (MANSQ model). In both of these instances, the user can instruct the PHABSIM interface to extract the water surface elevations for a single cross section from the existing STGQ or MANSQ results by selecting the **WSP/STGQ** or **WSP/MANSQ** methods for the downstream-most cross section in the **Models/WSL/Method** tab. It is highly recommended that practitioners place the downstream-most cross section on a hydraulic control. This enables use of the STGQ or MANSQ model to establish starting WSL's for unmeasured discharges at the control cross section. Use of either STGQ, MANSQ, or another source of the initial conditions for backwater modeling, is the analyst's responsibility. The predictions of the water surface elevations produced by STGQ or MANSQ are transferred to the WSP model by the PHABSIM interface when the WSP/STGQ or WSP/MANSQ options are selected. If the water surface elevations for unmeasured discharges are obtained from an outside source, the user may enter those values using the **WSP/User supplies initial WSL** option in the **Models/WSL/Method** tab.

Regardless of the method used to supply initial WSP water surface elevations, the user must set appropriate RMOD values for all discharges prior to use of WSP for production runs. As stressed previously, the user should then check the overall quality of the hydraulic simulations by checking the longitudinal water surface profiles over the full range of simulated flows.

A Step-by-Step WSP Calibration Strategy

The WSP program is used most often in those instances where multiple stage-discharge measurements are available. The following approach is provided as a guideline to calibrate the WSP model.

1. Select WSP as the water surface profile simulation method in /**Models/WSL/Method**. Note the downstream cross section must have an entry of **WSP/STGQ**, **WSP/MANSQ**, or **WSP/User supplies initial WSL** and that the MANSQ or STGQ models must have been calibrated for the downstream cross section where WSP will be used. Supply an RMOD value for each discharge in the **../WSP Options** tab. Initial RMOD values can all be 1.0.

2. Run the WSP program and examine the results and ZOUT files to find the computed slope for the downstream-most cross section and use Equation 2-22 or trial-and-error to estimate a revised Manning's n value for the study site. Edit the cross section data so the all cross sections have this Manning's n value. Note: an error message: "WSP Terminated with an Unknown Error" usually indicates you did not supply an RMOD value for each discharge.
3. Re-run the WSP model and note the agreement of predicted WSL with observed values at the base discharge. Based on the difference between predicted and observed WSL, adjust the global Manning's n value for all cross sections and re-run the WSP model. Continue to change the Manning's n value until the predicted and observed water surface elevations are as close as can be obtained with the global n applied to all cross sections. Some variation between the observed and predicted WSL values is likely to occur at some transects. But the overall error should have been minimized.
4. Adjust local (cross section by cross section) n values (within 10% ~15%) to reduce the remaining error between the observed and predicted water surface profile. Make those adjustments with the physical processes in mind and avoid adjustments that cannot be physically justified, i.e., do not "curve fit". Evaluate if the agreement error is within the tolerance limits that meet your study objectives. Remember, the WSP model works in an upstream manner and therefore the predicted WSL at the second cross section will be the starting WSL for making the predictions of the WSL at the third cross section, and so on proceeding upstream. For example, a low predicted WSL at the second cross section will "start" the model lower than wanted while

attempting to reach the WSL at the next cross section. This can result in supplying unusual Manning's n values at the next upstream cross section in order to get agreement at that cross section. The user should also note that in many instances, exact agreement is not always possible and WSLs at some cross sections may be high while at others they will be low. Again, some level of professional judgement, based on experience, will be necessary in order to determine how close predicted versus observed water surface elevations must be to be acceptable for individual cross sections or for all cross sections. Once suitable agreement between predicted and observed water surface profiles has been obtained for the base discharge, proceed to step 5.

5. Once the initial longitudinal water surface profile has been calibrated by selecting the appropriate Manning's n values at each cross section, broaden the evaluation to include the remaining calibration discharges and starting water surface elevations at the down stream cross section. Select the other calibration discharges in **/Models/WSL/Output Options.** Initially the roughness multipliers (RMODs) for these new calibration flows can be set to 1.0. Or, based on whether the other calibration flows are higher or lower than your initial calibration flow, you can set the RMODs to be greater or less than 1.0 based on the relationship shown in Figure 2-15. New calibration flows greater than your initial calibration flow will require a Manning's n lower than 1.0, while new calibration flows lower than the initial calibration flow will require a Manning's n greater than 1.0. The relative magnitudes of the RMOD estimates will be a function of how different the magnitude of the discharges are relative to your initial calibration flow.

6: Re-run the WSP model with the new roughness modifiers and compare the predicted and observed WSL at all cross sections at these new calibration flows. Adjust the RMODs at the new calibration flows until suitable agreement between predicted and observed water surface elevations are obtained. Each discharge is computed independently within WSP so once an RMOD is found which works for a specific calibration flow, that RMOD can be left unchanged while continuing your work at the remaining calibration flows. RMODs should be adjusted to obtain an overall minimum error between predicted and observed WSL for all calibration discharges.

7. Perform a linear regression between the logs of the RMODs and the logs of the discharge and use this equation to estimate the RMODs for all flows of interest for the study that you plan to use the WSP model to predict the water surface elevations.

8. Use the STGQ program or MANSQ program to supply initial WSL's to WSP at the most downstream transect for all other discharges to be simulated. That is, use **WSP/STGQ** or **WSP/MANSQ** at the WSP starting transect in the **Models/WSL/Method** tab. Remember a starting water surface elevation must be specified for all flows of interest at the first or downstream-most cross section when using the WSP model. if the STGQ or MANSQ models are used for WSP initial conditions, those models must be calibrated first before proceeding with WSP.

9. Add any additional desired discharges to the PHABSIM project using **Edit/Discharges**. RMODs determined from Step 7 must be associated with each of these flows (see the **WSP Options** tab) and the water surface elevation simulation must have those discharges specified in the **Models/ WSL/ Output Options** tab.

10. Check the quality of the hydraulic simulations by plotting the longitudinal profiles of the water surface elevations for all simulated discharges (use the **../Results/Longitudinal** graph button). Zoom in on the calibration discharges for one last comparison of the predicted and observed water surface profiles and make any final adjustments to n or RMOD as needed. If the very highest discharges produce unusual water surface profiles, check for predicted water surface elevations higher than the highest measured bed elevations. The model becomes invalid if WSL's significantly greater than the highest bed elevation are predicted. If such high discharges must be simulated, more field data is needed to define the channel at those heights.

Some Practical Aspects of Calibrating and Use of the WSP Model

The quality of calibration that can be obtained for a stream section will vary with the hydraulic characteristics of the stream and the nuances of the field data. Steep, rough streams often exhibit large fluctuations in water velocities and water surface elevations and may be difficult to calibrate. Typically, achievable agreement between observed and simulated water surface elevations is □ 0.01~0.02 feet (□0.00305~0.0061m) for the profiles at each calibration discharge. However, the investigator must be aware that specific situations may require establishment of more lenient or stricter standards. For example, an investigator may relax this standard somewhat at the highest calibration flow profile in order to achieve a closer agreement at the middle and lowest calibration flow profiles since this lower range of discharges is most important in view of the particular instream flow project under consideration.

Although text book values of Manning's n can serve as a reference point, it should be noted that many of these values are most appropriate for higher discharges at or near bank full conditions and as illustrated in Figure 2-15, may, in fact, be too low under lower flow conditions. In other words, do not be surprised if the calibration Manning's n values do not match the ranges reported in the hydraulic handbook values. This should not be a source of concern as long as a physically based meaning can be attached to the values. Perhaps the most critic al factor should be how well the model is able to reproduce the observed data. This of course assumes that any obvious data collection and entry errors have adequately discounted or corrected.

The WSP model will produce unreliable results if water surface elevations significantly higher than the highest cross section elevations are necessary to simulate the desired discharges. Always review the longitudinal profile for realism of the simulation. When very high discharges must be simulated as part of a PHABSIM study, it is imperative that at least bed elevations high on the bank and water surface elevations for a discharge in the vicinity of the desired high discharge be collected to ensure the PHABSIM models can run within reasonable bounds.

Hydraulic Controls

Transects should start and end at hydraulic controls if at all practical. Calibration problems are greatly exacerbated when starting and ending transects are not located at hydraulic controls. The effect of hydraulic controls in a WSP calibration are often profound. It is often possible to alter the water surface profile through an entire reach simply by modifying the roughness at the downstream control. One overriding principle of the WSP model is that the downstream-most transect must be on a control and all other controls in the reach should be defined by a transect. This means the downstream control associated with specific habitat features, such as a pool, should be included even if they are of no interest for representing the habitat feature of interest.

Divided Flow

Flow partitioning is a necessity when the channel around one side of an island is longer than the other side. When the length of one channel exceeds the length of the other by a factor of approximately 1.5 or more, or the channel configurations differ significantly, flow partitioning should be considered. In essence, flow partitioning involves breaking up the total discharge of the stream into component discharges for each channel. The WSP program is calibrated for each channel at the component discharge as if it were a separate stream (see below). At the calibration discharge(s), this is a relatively easy procedure because field notes should contain all the information needed to break out component discharges. The problem arises when alternative stream flows are modeled. At discharges other than the calibration discharge(s), the proportion of the total flow carried by either channel changes as a function of total discharge. The process of flow partitioning often is very difficult. It is advisable to consult an experienced hydraulic engineer before attempting this type of analysis. Basically, the problem is to determine the component discharges at a range of unobserved flows so that a rating table can be built. This is done by first calibrating the component channels as measured; then for some unobserved total discharge, component flows for each side channel are split out by estimation and run individually through the model.

Calibration of the WSP model can be difficult when flow splits into two or more channels. In general, the water surface elevation models in PHABSIM are not designed to work in split channels. A few streams may have small enough differences between channels on either side of an island to follow one of the transect placement or data adjustment approaches described below. However, in most cases, those approaches will introduce considerable error. MESC recommends users partition the flow empirically through each of the channels and treat each channel as if it were a separate stream to be calibrated and simulated separately. This means that discharge measurements for the full channel and each side channel must be made for at least the calibration discharges. A regression of side channel discharge against full channel discharge (or other means to build a rating table) can then be used to determine the flow split for the unmeasured discharges to be simulated in the study.

When partitioning the flow, care must be taken to ensure that the water surface elevations simulated at the top of each separate channel are the same (or within an acceptable tolerance) for all discharges. This allows an island to be represented by four backwater models: main channel downstream of the island, left side channel, right side channel, and main channel upstream of the island. A backwater simulation can be run for the main channel downstream of the island to produce the starting water surface elevation for both side channels for all discharges of interest. Then the two side channels are simulated with Manning's n calibrated to produce the same water surface elevation at the top of the island. And finally, the main channel upstream of the island is simulated using the initial water surface elevations derived for all flows from the simulation of the two side channels. In PHABSIM for Windows, this will require four projects covering the four separate portions of the channel and ensuring that the transects at the partitions are duplicated in the appropriate data sets. Though tedious, this is the only way to assure that the flow conditions around the island are modeled accurately over a wide range of discharges.

When there are small differences between the two channels around an island and the study site is represented with a single backwater model, two generic types of problems are presented by divided flow. The first, and most common, is unequal water surface elevations on both sides of a flow division. The most common cause of this problem is crossing an island with one straight transect when a dogleg transect should have been used (see Figure 2-15). By their very nature, islands rarely have the same bed and water surface elevation at equidistant points along the bank. Ideally, the transect should cross the island with a dogleg in order to obtain an equal water surface profile on both sides of the island. In braided channels, this is the rule rather than the exception. The two elevations may be averaged if the discrepancy between two water surface elevations is small compared to the difference in elevations between transects for all calibration flows. What constitutes small in this instance is a matter of judgement. However, if the discrepancy between water surface elevations is large, bed elevations of the smaller channel may be raised or lowered a distance equal to the difference in water surface elevations. All of these manipulations of the data may introduce their own noise in the analysis. Again, splitting the study site into four backwater models is preferred.

The energy loss between the two channels must be the same for water surface elevations to equalize at the head of the island. The two component flows giving the same energy loss for both channels (which should equal the total flow in the channel) are the proper component flows. If finding flow rates and energy losses that satisfy these conditions seems extremely tedious and difficult, it is! Alternatively, such ratings can be built empirically by collecting both water surface elevation and discharge data at several flows over the range of discharge of interest to the study. Hence, if you have split flow, plan on making many more water surface and discharge measurements in both the main channel and side channels.

Water Surface is Equal on Both Channels

Running the WSP Model WSP must have starting conditions supplied at the downstream-most transect to which it will be applied. In the **/Models/WSL/Method** table select either **WSP/MANSQ, WSP/STGQ,** or **WSP/Supplied**for the

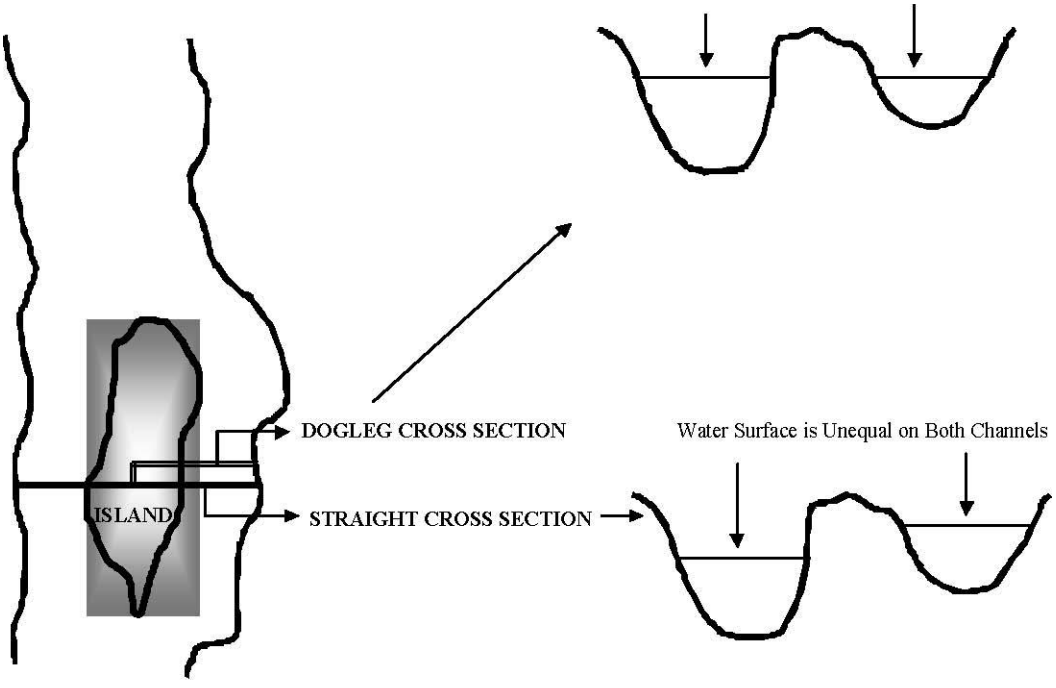


Figure 2-15. Dealing with uneven water surface elevations across an island.

downstream starting condition at each starting transect for each discharge. Then fill with **WSP** upstream (fill down in the table) over the extent of the river to which WSP is to be applied. Make these selections by clicking on the model, e.g., **WSP/STGQ** and then clicking each of the transect/discharge boxes in the table to which that model is to be applied. An example of a completed WSL method table is shown in Figure 2-16.

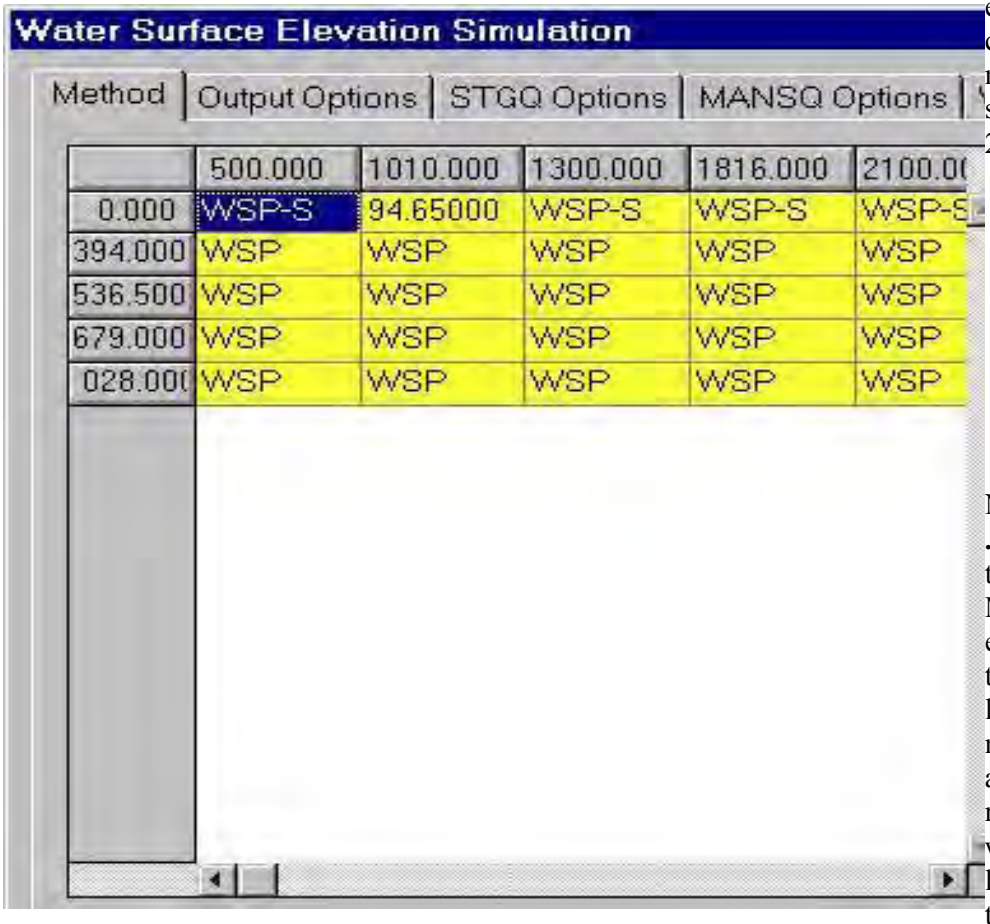


Figure 2-16. Water surface elevation method table showing entries for WSP analysis.

Next, in the **../WSP Options** tab, enter a Manning's n for each transect in the table on the left. Roughness modifiers, which are entered in the right hand table, will be discussed later. While in this tab, select the desired options using the check boxes and click **Apply**. Note, all combinations of WSL simulation models are run at once by clicking the **Run** tab in **../Method**. As with STGQ and MANSQ, after the models have run, compare simulated with observed water surface elevations using the tables and graphs in **../Results**. In general, for cross sections where WSP is applied, Manning's n should be increased when the predicted WSL is low and decreased when predicted WSL is high. The WSL at the downstream transect is not changed by the WSP model. The laboratory exercises will provide you with experience with the WSP calibration process

Several key hydraulic parameters related to the computational procedure within WSP are output to ZOUTnn. Although not all of these variables are in the output for each cross section, they are usually located somewhere in the output from a WSP run. Their definitions are provided below and have been illustrated in Figure 2-4.

HF1 = Head loss computed at downstream section. HF2 = Head loss computed at upstream section. HSF = Slope (S_e) of energy grade line at section. HV1 = Velocity head ($v_1^2/2g$) computed for downstream section. HV2 = Velocity head ($v_2^2/2g$) computed for the upstream section. Total Head = Total head loss (h_f) between sections.

Remember to review the output file for error messages and inconsistencies in the data. Error messages in the form of notes or other statements may be written to the output file and not appear on the screen or cause the program to abort. Output from the WSP model is both extensive and variable depending on the particular run options that the user selects. Examination of WSP output is deferred to the laboratory exercises.

Modeling Of Velocities In PHABSIM

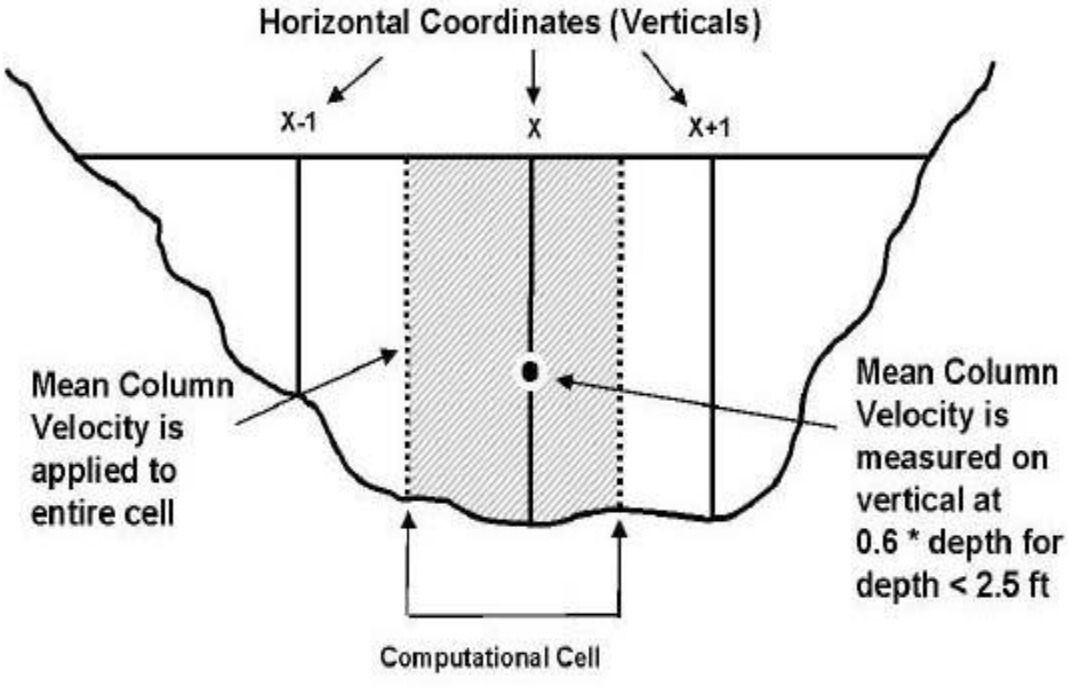
The second major step of hydraulic modeling within PHABSIM involves simulating velocity profiles at each cross section within the river. Transect based open channel flow models face a serious limitation in simulating velocity distributions across the channel. Both step-backwater and stage-discharge type models were developed and have been verified only for whole channel calculations. Thus, lacking a theoretical method of distributing velocities, PHABSIM relies on empirical means to approach this problem.

PHABSIM models velocities for individual cross sections and as such treats the cross sections independently regardless of the model employed to generate the WSLs. In most cases, only limited resources are available to do field work in any particular instream flow study; hence, a limited number of velocity profile readings are used to estimate the velocity distribution at flows for which velocities were not measured. Within PHABSIM, the VELSIM model is used for all velocity predictions. Those velocity values are subsequently used in the habitat modeling portion of PHABSIM. Figure 2-17 illustrates the relationship between a measured velocity at a cross section vertical and a computational cell as viewed by the VELSIM model.

Note that both the STGQ and VELSIM programs define a computational cell as the region one-half way between two sets of adjacent verticals (see Figure 2-17). A vertical is a measurement point specified as the X (distance from the head stake) coordinate values (see Chapter 1). All references to the computational cell are then made to the vertical. Note that this definition of a cross-sectional cell is different from that used by the habitat models. These differences are discussed in more detail under the appropriate habitat models in Chapter 5.

In PHABSIM, each computational cell in a cross section is treated separately, with its own depth, substrate, and average velocity. In the VELSIM program, there is a one-to-one correspondence between mean column velocities and the X coordinate of the vertical at which the velocity was observed or simulated. Velocities can only be provided at X coordinate values in **/Edit/Cross Sections/Coordinate Data**. PHABSIM for Windows does not limit the number of subdivisions (or cells) used to define the velocity distribution across a cross section. Obviously, the more computational cells per cross section, the more detailed the description of the velocity distribution. The VELSIM program defines a cell as the region half way between two sets of adjacent verticals as illustrated in Figure 2-17.

Figure 2-17. Measured velocity and computational cell velocity.



Calibration and Simulation of Velocities

In the following discussions, approaches to estimating the velocity distribution at a cross-section are described. The first section describes use of Manning's equation where no velocity measurements are made to calibrate the equation. The second section discusses the use of Manning's equation with measured velocities at one flow while the third section describes procedures using more than one set of measured velocities.

VELSIM with No Measured Velocities

The VELSIM program can be used to simulate velocities at a cross section although no velocities were measured. This is accomplished by rearranging Manning's equation to solve for "n" in terms of the measured discharge and individual cell attributes and substituting the depth of flow for the hydraulic radius:

$$^{1/2} * d_i^{2/3}]/q_i$$

$v_i = [1.49 * S_e$ (2-24) The net effect of this approach is that the magnitude of the velocity predicted at any vertical across the cross section is directly related to the depth of flow, and, therefore, the relative magnitudes of the velocity distributions will mimic the channel geometry as illustrated in Figure 2-18. Note that in VELSIM, if a user specifies a Manning's n value at a particular vertical, the VELSIM program will use that Manning's n to compute velocities when employing Manning's equation. The user should always check this type of simulation for realism. Experience has shown that under some circumstances, this approach yields satisfactory results, while in other circumstances it is not acceptable. Viewing plots, such as shown in Figure 2-18 in **/Models/Velocity/Results,** allows visual detection of unusual velocity distribution patterns. Note that the velocity profile in Figure 2-18 is proportional to depth.

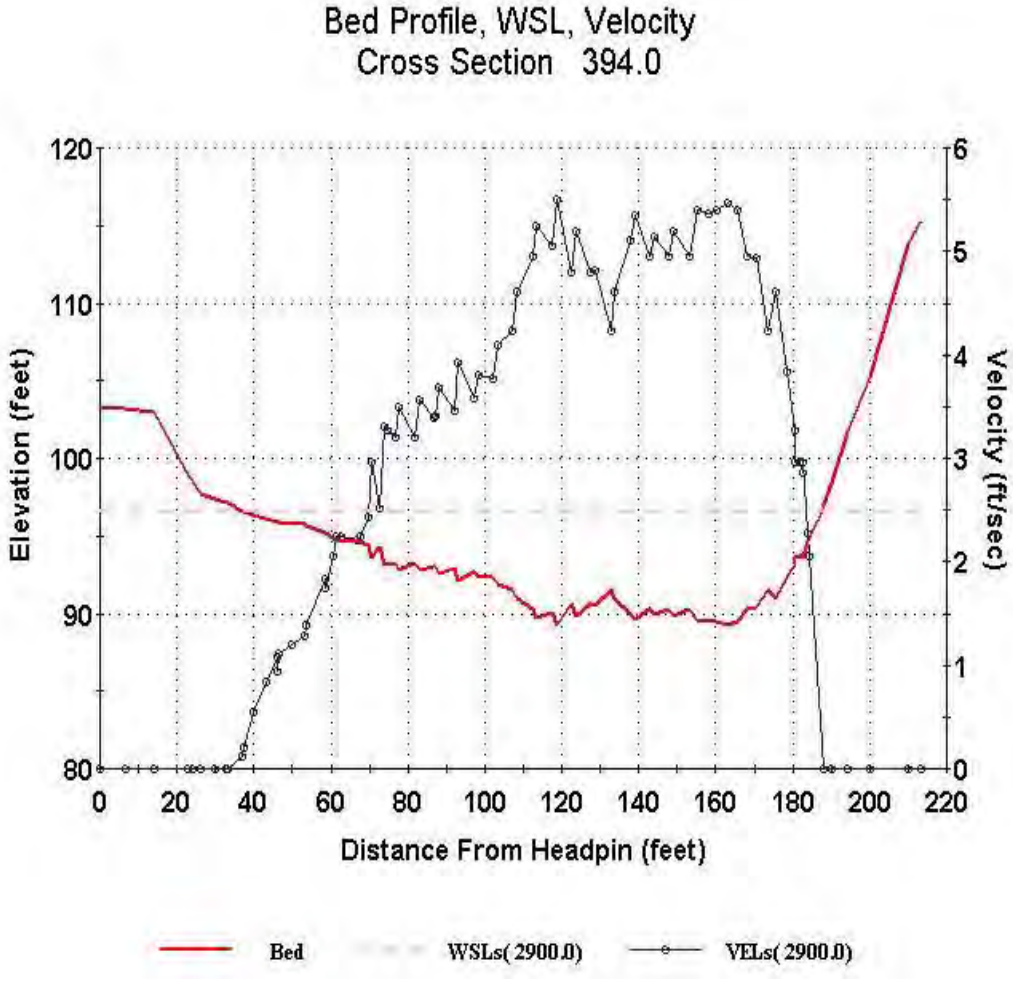


Figure 2-18. Simulated velocity distribution with no calibration data.

MESC suggests that this approach be limited to those cases where field conditions or equipment failures prevented collection of at least one velocity data set and limits of time (deadlines) or resources prevent collecting at least one velocity profile at a later time. The judgement is left up to the investigator and the particular objectives of the model application.

VELSIM with a Single Velocity Data Set

If one set of velocities is used to calibrate the VELSIM program, a different approach is taken based on an initial solution of Manning's equation to obtain an estimated Manning's n at each vertical along a cross section. This approach treats the observed velocity profile as a template for describing velocities for other discharges. Since slope, water surface, and observed velocity are given as part of the calibration data, Manning's equation can be solved for n_i at each vertical:

$$n_i = [1.486 * S_e^{1/2} * d_i^{2/3}]/v_i \quad (2\text{-}25)$$

where: n_i = estimated Manning's n value at vertical i
S_e = energy slope for transect
d_i = depth at vertical i
v_i = measured velocity at vertical i

Note in this equation, that depth d_i at the vertical has been substituted for the hydraulic radius and is computed from the difference between specified water surface elevation and bed elevation at each vertical. The measured velocity (v_i) at each vertical is obtained from the input data. If a slope has not been provided (i.e., specified in /**Edit/Cross Section Data**) a default slope of 0.0025 will be used. The specific slope used is not critical to the calculation of velocities using this approach as illustrated below. Having obtained individual Manning's n values at each vertical, individual cell velocities can be computed at any alternative discharge by solving Manning's equation for velocity and using the initial Manning's n value derived from the calibration velocity set:

$$v_i = [1.486/n_i] * d_i^{2/3} * S_e^{1/2} \quad (2\text{-}26)$$

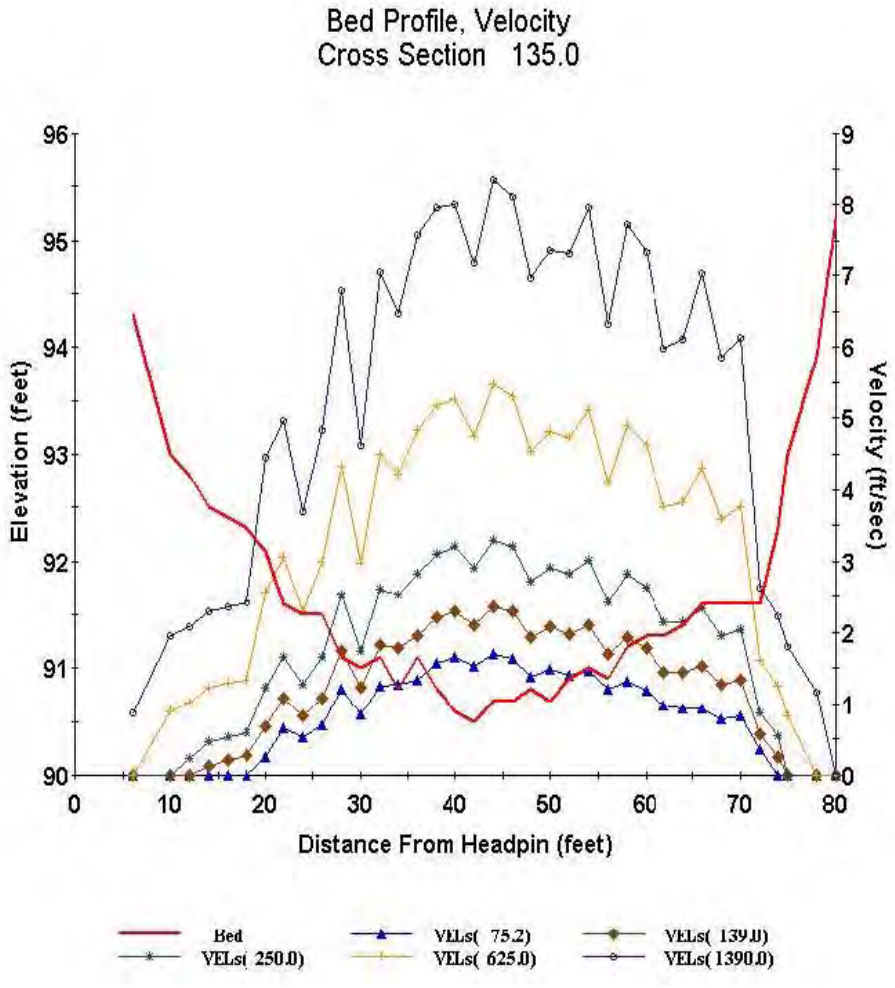
As noted above, if a user specifies a Manning's n value at a particular vertical, the VELSIM program will use that Manning's n in the computation of velocities when employing Manning's equation even though an initial calibration velocity had been provided. Figure 2-19 provides an example of a single observed velocity calibration set with the associated predicted velocities at the calibration flow. Since the best estimate of the discharge is typically used in the simulation of water surface elevations and the VELSIM maintains mass balance for the discharge, the simulated velocities at the calibration flow will not exactly "match" the observed velocities.

During simulation, if VELSIM simulates a water surface elevation at a cell for which no velocities were available for estimation of Manning's n or a Manning's n value was not supplied, the program will search for an adjacent cell to obtain an estimated or user-specified n value for use in the computation of velocities at that vertical. The user has several options for setting Manning's n in VELSIM either through a calibration velocity template or by estimation. These options are discussed in more detail at the end of this section.

VELSIM with Multiple Velocity Data

Although the investigator may have measured multiple velocity sets for use in the study, MESC recommends that the multiple velocity calibration data sets be treated as independent data sets for modeling purposes. The recommended strategy uses the highest observed velocity data set to simulate at all flows higher than the highest measured flow, the lowest observed velocity set to simulate flows lower than the lowest measured flow, and user judgement for which discharge ranges between observed velocity sets to assign each calibration velocity set. For example entirely different velocity distributions between a high flow velocity data set and a medium or low flow velocity calibration set may be found when channel geometry is very different at the associated stages. In this instance, the use of a single calibration data set over all ranges of discharges would not accurately reflect the observed velocity profiles at alternate discharges. One strategy would be to "switch" among different calibration data sets at the break in the channel geometry. The investigator would only need to determine the elevation at which this break in channel shape occurs and then determine the appropriate flow from the water surface modeling. It should also be apparent that this exercise is somewhat idealistic in that only a single cross section is shown. In practice, the user would need to consider all cross sections within the modeled reach and will therefore likely need to find a single "compromise discharge" where velocity calibration sets are changed in the model.

Figure 2-19. Velocity distribution for a single calibration discharge.



Following the strategy recommended above will result in dissimilar velocity profiles for discharges immediately above and below the break between assigned flow ranges. In some channels, this effect can be pronounced. Lacking additional velocity profile measurements, the exact transition between the calibration set velocity profiles is unknown.

An alternate scheme is provided in PHABSIM for Windows to handle this situation. That is to replace the velocity values in the ranges between observed calibration flows with a smooth transition based on the assumption that a log-log linear transition takes place. After VELSIM has been run with calibration sets assigned to each discharge of interest, the **Velocity Regression** tab is accessed. When clicked, the Run Velocity Regression button causes velocity values for each cell in the ranges between calibration discharges to be predicted using a two point regression. These values replace the values produced by running VELSIM. Note: this approach affects only the velocities in the discharge ranges between calibration discharges.

VELSIM Computational Procedures and Mass Balance In order to more fully understand the remaining computational aspects of velocity simulation within the VELSIM program, the following section describes the governing equations and process by which the VELSIM program maintains a mass balance between the requested simulation discharge and computed discharges, given its implicit computation of individual cell velocities.

The area of the cell is computed by the following equation:

$$A_i = \frac{1}{22} *[(d_i+d_{(i-1)})*(X_i-X_{(i-1)})*1/2] + \frac{1}{2} *[(d_{(i+1)}+d_i)*(X_{(i+1)}-X_i)*1/2] \quad (2\text{-}27)$$

where: A_i = area of cell i
X_i = horizontal distance along the transect to point i
d_i = depth at vertical i

The "trial" discharge computed for a requested simulated discharge at the transect is then determined by using the velocity predictions for each computational cell derived from the velocity simulation method selected. These values are used to calculate cell discharges which are summed for all cells across the transect:

$$Q = \underset{\text{trial}}{} \sum_{i=1}^{ncell} A_i * v_i \quad (2\text{-}28)$$

This apparent or trial discharge is not necessarily the same as the discharge requested in the simulation. Reference to Figure 2-15 shows the relationship between discharge and roughness and should indicate that a particular Manning's n value derived from a velocity calibration set at a single discharge will not be the "correct" Manning's n value at higher or lower discharges. This is the same basic concept that led to the use of RMODs in the calibration of the WSP program. An index of the difference between the requested simulation discharge and computed discharge derived from the velocity simulations is called the Velocity Adjustment Factor (VAF) and is computed by the following equation:

$$VAF = \frac{Q_{\text{requested for simulation}}}{Q_{\text{calculated from velocitysimulations}}} \quad (2\text{-}29)$$

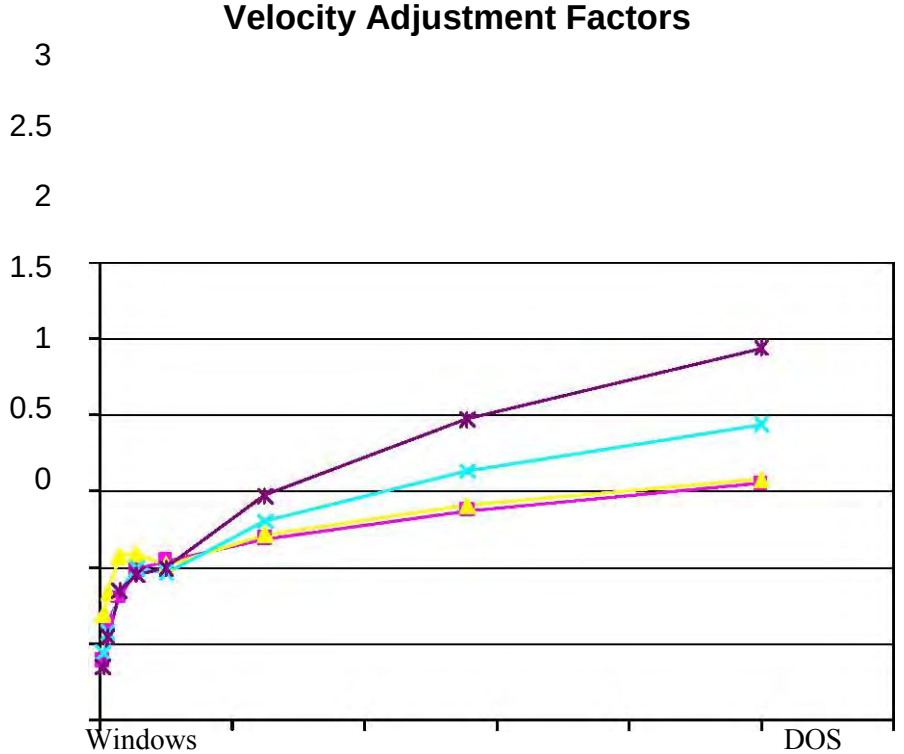
This ratio is then used to adjust individual cell velocities, v_I, which also adjusts the computational cell discharges. This adjustment proceeds until the calculated discharge for the cross section equals the requested or simulated discharge. The adjustment of the individual simulated discharges is accomplished with the VAF by adjusting the individual computational cell velocities by the following equation:

$$V_{new} = v_{initial} * VAF \quad (2\text{-}30)$$

The use of the VAF in the VELSIM program represents an empirical approach to approximate the role of the RMODs in the WSP program. The relationship shown in Figure 2-15 indicates that at simulated flows lower than the velocity calibration flows, the Manning's n value derived from the velocity calibration flow will be too low. Since the roughness (i.e., Manning's n) values used to estimate the velocities are too low, the estimated velocities at each vertical will be too high (see Manning's equation). This results in a computed trial discharge for the cross section that is greater than the requested simulation discharge and the resulting VAF would be less than 1.0 (see Equation 2-30). Conversely, at simulated discharges greater than the velocity calibration flow, the estimated Manning's n values will be high and the resulting individual computed cell velocities will be low. This results in a computed trial discharge that is less than the requested simulation discharge and the VAF will be greater than 1.0. This process suggests that in most cases the relationship between discharge and VAF should be approximately an

inverse of the relationship shown in Figure 2-15 and resemble the example illustrated in Figure 2-20. Although this general pattern is typical of most cross sections, there are occasions where the VAF versus discharge relationship will not and should not follow this generalized pattern such as when lateral bank vegetation increases the composite roughness at intermediate discharges.

In Figure 2-20, there are two ranges of discharges for which the VAF plot ascends in what appears to be different patterns. The apparent break in the VAF plot at about 250 cms is due to using different calibration sets to produce the velocity template used for velocity simulation. Within the range of discharges for which a particular set of calibration velocity measurements were used to develop the Manning's n template, an ascending VAF relationship indicates the expected outcome of velocity simulation. It should also be noted that the VAF at the calibration flow will not always be equal to 1.0. For example, during the modeling process, the user may have selected the best estimate of discharge for a group of cross sections where the measured variability in computed discharges may have been 15–20%. For any cross section that has a computed discharge based on a set of calibration velocities that is not exactly the same as the best estimate of the discharge, the VAF will deviate from 1.0. The magnitude of the deviation will depend on the magnitude of the deviation between the best estimate of the discharge and the discharge computed using the calibration velocity set.



Windows		DOS	Differ
Cell bed elevation	91.65	91.65	0
Water surface elevation	92.456	92.47	0.01
Depth	0.806	0.82	0.01

Figure 2-20. Velocity adjustment factors.

It is also reasonable to expect that the VAF relationships for sections with similar cross section geometry will be similar in their functional relationships and the variation between VAF versus discharge relationships will be directly related to the degree of variability in the cross section geometry. As a final note on VAFs, there is no rational basis for judging the "validity" or quality of the hydraulic simulations based strictly on the magnitude of the range in computed VAF values. That is, there is no specific set of envelope values that the VAF should absolutely lie within. It is only an index of the relative change in discharge from the calibration discharge used at the calibration velocity versus the simulated discharge which follows the relationship between roughness and discharge shown in Figure 2-15. The shape of the VAF versus discharge plot is a better indicator of model performance than the VAF magnitude. When a monotonically increasing VAF relation is not obtained, it is not necessarily an indication of model failure. Rather, it simply is an indication that the model calibration and simulation steps should be reviewed. Some channels exhibit non-standard VAF plots even when the models are performing well.

Significance of Initial Slopes and Manning's n Values in VELSIM

Note that slope does not appear in the four equations above which describe the computation of velocity and mass balance in the VELSIM program. Also, the slope used in the initial calculation of Manning's n will not influence the final calculation of the velocity. The slope is important only in being able to compare individual Manning's n values at cross section verticals from one cross section to another or from one stream to another. The selection of Manning's n values to add to a data set to control velocity simulations is easier however, if a reasonable estimate of slope is used to calculate roughness from the calibration velocities. The Manning's n value at this point within the VELSIM program really represents a velocity distribution factor. The user should not be too surprised if individual cell Manning's n values do not fall within the expected ranges reported in hydraulic roughness tables for cross sections containing a particular substrate characteristic. Handbook values are estimated for whole channel conditions (often for high flow conditions as well) and not for a particular vertical within a cross section.

The role of Manning's n in VELSIM is important since it functions strictly as a velocity distribution factor and can have an impact on results of the habitat models. In general, since velocities are not measured at previously dry verticals, n values will have to be estimated by the program or supplied (i.e., estimated) by the user. However, the Manning's n values for velocity distribution are derived in one way or another. Whether they are calculated from observed velocities, estimated for the cell by the VELSIM program when no velocity data is supplied, or supplied by the user, that Manning's n values are used to calculate the cell velocity for all simulated discharges. This is primary importance when simulating higher flows because, when simulating down from a measured velocity calibration set, the program will have Manning's n values computed from known velocities at all verticals.

Simulation of higher discharges can, however, lead to problems at the edge of the stream where fringe cells may contain very small cross sectional areas at the calibration discharge. When Manning's n_i values for dry cells are not supplied by the user, the program will search adjacent cells for a given or calculated n_i or will assume a value of 0.06 if none are found. However, the VELSIM program will occasionally predict unrealistically high velocities on the stream margin (e.g., 20 feet/second!) due to the combination of Manning's n estimation and application of the VAF to achieve mass balance. Since these areas may be very important to certain life stages of aquatic species being studied, the user should carefully examine the velocity simulation results for these "artifacts" of the computational process during VELSIM calibration. Use the **Cross Section** plot button in **Models/Velocity/Results** to view simulated velocity profiles and the tabular velocity results to determine which cells need to have n values supplied to improve erroneous edge velocities. In these instances or where other factors may warrant, the value of n_i for dry cells (or wet cells) should be supplied by the user in the **/Edit/Cross Section/Coordinate Data** tab. This is covered in more detail in Laboratory 6 on velocity calibration and simulation.

Nose Velocities

Much attention has been given to the debate on mean column versus nose velocities (also called focal point velocities) in PHABSIM applications for prediction of available habitat. The HABTAE model offers the user a variety of modeling choices for the computation of nose velocities either based on the distribution of bed material particle sizes, regression equations based on mean and nose velocity measurements, or by empirical relationships based on the 1/7 power law, to name a few. The application of these techniques however, is limited to those situations where nose velocity habitat suitability curves are available and sufficient field data has been collected to support use of these hydraulic modeling options. Additional descriptions of nose velocity calculations and options are included later in this manual under the HABTAE model program and will not be discussed further here.

Control of VELSIM Calibration and Simulation Options

Much of the utility of the VELSIM program lies in the ability of the user to provide very specific control over all aspects of the computational procedures. The user should review available options for the VELSIM program listed in Table 2-6. This review often results in some confusion for the user to decide which combination(s) of options should be selected to achieve the desired results. This problem can be overcome by breaking up available options into several discrete conceptual parts that are provided below.

Windows		DOS	Difference	% difference
Cell bed elevation	91.65	91.65	0	0.00
Water surface elevation	92.456	92.47	0.014	0.02
Depth	0.806	0.82	0.014	1.71
Depth Suitability Index	0.0708	0.096	0.025	26.25
Combined Suitability Index	0.0644	0.087	0.023	26.25
Weighted Usable Area	8.698	11.79	3.096	26.25
Acknowledgements				**i**
PREFACE				**ii**
A Brief History of PHABSIM				
Use of this Document				
Changes Between PHABSIM Version 2 and PHABSIM for Windows				
Conventions Used in this Document				
Chapter 1, Introduction to the Physical Habitat Simulation System				**1**
Objectives				
Associated Laboratory Exercises				
An Overview of IFIM				
The Purpose of PHABSIM				
The Structure of PHABSIM				
Application of PHABSIM				
Scoping				
Selection of Target Species and Suitability Curves				
Selection of Target Species				
Types of Suitability Curves				
Transferability of Suitability Curves				
Segmenting the Study Area and Study Site Location				
Critical Reach				
Mesohabitat Study Site Selection				

Table 2-6. Options in the VELSIM program.

Table 2-6. Concluded.

Windows		DOS	Difference	% difference
Cell bed elevation	91.65	91.65	0	0.00
Water surface elevation	92.456	92.47	0.014	0.02
Depth	0.806	0.82	0.014	1.71
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A Brief History of PHABSIM
Use of this Document
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Conventions Used in this Document
Chapter 1, Introduction to the Physical Habitat Simulation System **1**
Objectives
Associated Laboratory Exercises
An Overview of IFIM
The Purpose of PHABSIM
The Structure of PHABSIM
Application of PHABSIM
Scoping
Selection of Target Species and Suitability Curves

Velocity Adjustment Factor and Mass Balance

Use Velocity Adjustment Factor: {tc /l4 "*Use Velocity Adjustment Factor* }This option in essence will allow the user to ignore application of the VAF to achieve a mass balance within the VELSIM model. If this option is not checked, mass balance determined from application of the VAF will be ignored. In most cases, this box should be checked so mass balance will be enforced and the VAF applied.

Controlling Roughness: Several options are available to the user to control the way in which the VELSIM program will use roughness.

Calculate N for Wet Cells {tc /l4 "Calculate N for wet cells}: This option allows the user to control the way in which the VELSIM program will calculate roughness or how it uses the roughness if supplied (i.e., Manning's n).

If not checked: This option instructs the VELSIM program to use roughness for a cell if it is input in the coordinate data. If n is zero, the VELSIM program will compute the Manning's n value if a velocity is available, use an adjacent value if available, or use the default value of 0.06.

If checked: This option will result in VELSIM calculating the Manning's n value for cells that are wet, using Manning's n if supplied for dry cells, or estimating Manning's n for dry cells if the Manning's n value in the cell is 0.

*Limit Manning's n {tc /l4 "Limit Manning's n}:*This option allows the user to specify the maximum and/or minimum value of the roughness computed with the Manning's equation during the simulation of velocities. The maximum and/or minimum value is specified in the input cells provided in the **/Models/Velocity/Options** Window.

If not checked: This will result in no limit on value of the estimated Manning's n value.

If checked: This will impose the limit for the maximum and/or minimum as specified on the NMAX data line. IF the estimated Manning's n value exceeds these limits, it will be set to the appropriate limit for use in all simulations of velocities in that cell.

Variable roughness coefficient {tc /l4 "Variable Roughness Coefficient}: This option allows the user to adjust the roughness in a cell as a function of depth in a cell. This option can help reduce the negative impacts arising from too high a roughness at edges of the stream calculated at lower discharges that would be expected to become less rough as flow (i.e., depth) increases. NOTE: Leave the Velocity Adjustment Factor box blank or the results will be irrational when using this option.

If not checked: The program will not calculate variable roughness.

If checked: The program will adjust roughness as a function of discharge and requires the user to specify a B exponent in the box provided in the **/Models/Velocity/Options** Window.

The general equation for changing roughness as a function of depth is:

$$N = n_c * (d/d_c)B \quad (2\text{-}31)$$

where: n = depth adjusted Manning's n value for the cell
n_c = calibration Manning's n value for the cell
d = depth of the cell at the current discharge
d_c = depth of cell at the calibration discharge
B = an empirical coefficient in the range from -2.04 to 0.0

The estimation of "B" for use in variable roughness has received little discussion in the literature and only those with an advanced familiarity with hydraulic modeling should consider the use of this option.

Evaluating Quality of the Hydraulic Modeling

In the preceding sections, the basic theory and steps to achieve the calibration and simulation of both water surface elevations and velocities were presented. This section address some of the more fundamental issues in evaluating the quality of the hydraulic modeling effort. Evaluation of water surface elevations is discussed first followed by a discussion of velocities.

Evaluation of Water Surface Modeling

Predicted Versus Observed Water Surface Elevations at the Calibration Flows

Perhaps the most fundamental diagnostic of the quality of hydraulic modeling of the water surface elevations is how close are the predicted and observed water surface elevations at the calibration flows. This leads to the question of how close is close enough? Unfortunately, no readily available answer can be dogmatically stated. In general, the user should attempt to match the observed and predicted water surface elevations with no error, but this represents a case not readily achieved in applied hydraulic modeling. The user will often be faced with trading accuracy at one set of measured calibration flows to achieve a better fit at over the full range of calibration flows. For example, the user may be able to replicate the observed water surface elevation longitudinal profile using WSP at the lowest calibration flow but no RMOD can be found to achieve an exact match for the high calibration water surface profile. An alternative re-calibration of the WSP model to the high flow may result in replication of the longitudinal profile, but again, no RMOD can be found which adequately replicates the low flow profile. In this instance, the user is likely to use the WSP model which is most accurate nearest to the flow range in which the

instream flow questions are likely to be the most contested. As a general guideline, in most applications predicted versus observed water surface calibration errors which are on the order of 0.01–

0.02 feet can be achieved. It is not uncommon; however, that a single or a few cross sections may deviate more (e.g., 0.03–0.05 feet or more) depending on the characteristics of the channel geometry, gradient, left versus right bank differences in water surface elevations (remember that only a single value is used for all models). Potentially, a hydraulic control may have been missed during field collection or a hydraulic control is migrating within the channel over the range of discharges collected. It is possible however, to evaluate the application or performance of each of the models and demonstrate that the "best" calibration/model combination achievable with the available data is actually used in the study. It may not be possible to overcome poor model performance with the collection of new or additional data. In such a situation, the degree of uncertainty must be clearly reported and kept in the forefront during the evaluation of study results.

Longitudinal Profiles of the Water Surface Elevations

A second measure of the quality of the modeling for water surface elevations is the examination of the longitudinal profiles of the water surface elevations over the entire range of simulated discharges. That is, where the cross sections are all measured to a common survey datum, the longitudinal WSL plots can be examined to determine whether or not water "flows uphill". Such a situation would indicate that the range of simulated discharges should be restricted for the application of that particular WSL model to flow ranges over which the results are consistent (i.e., water flows downhill). In many applications, one or more models (e.g., STGQ and MANSQ) may perform well within the range of the measured calibration discharges but only work well at some reduced range of extrapolated discharges. At these higher discharges of interest, the only WSP model may be adequate and the user can elect to WSP to simulate over all ranges of flows or for only the higher flows where the other models would not be appropriate.

Valid Ranges of Simulated Discharges

Some individuals have used the absolute range of simulated discharge, that is, how much higher than the highest calibration flow and how much lower than the lowest calibration flow, as a measure of the quality of the simulations. In earlier PHABSIM manuals, ranges of "acceptable" simulations have been reported as 0.4 to 2.5 times the measured discharges. Under some circumstances a range of 0.2 to 1.5 has also been reported. The user should note that, from a functional, algorithmic, or mathematical perspective, **none** of the models (i.e., STGQ, MANSQ, or WSP) are inherently restricted to any range of acceptable simulation limits from a hydraulic perspective. In some applications, very restrictive ranges are required due to channel configuration, model performance and adequacy of the available data, while in others, extremely wide ranges (i.e., 0.1 to 10) are justified by model performance. What constitutes a valid range of simulated discharges in the absence of poor model performance (i.e., "water flowing uphill", large calibration errors, etc.) is a matter of professional judgement. At present, no rigorous peer reviewed evaluation of WSL simulation limits using any of the hydraulic models for specific types of channels and site specific field conditions has been undertaken. The user is cautioned that a reasoned limit to the reliable range of simulations should be based on model performance given the available data rather than an arbitrary "rule of thumb".

Evaluation of Velocity Modeling

Perhaps one of the most difficult aspects of evaluating hydraulic simulations involves the evaluation of the velocities. When no calibration velocities are available, it is a matter of professional judgement as to the utility of the velocity distributions based on depth as long as the obvious "errors" such as high velocity artifacts at the stream margins have been corrected. Another potential indication of problems in the simulations would be extremely "odd" VAF relationships which have no rational basis in physical characteristics at a cross section.

In those instances in which a single velocity set has been used in the simulations, it is a matter of professional judgement as to the quality of the simulations, assuming that any erroneous velocity errors have been accounted for. However, if during a review of the channel characteristics for the cross sections it is determined that gross changes in channel geometry occur at some "threshold" water surface elevation (i.e., discharge), then the velocity simulations should be carefully examined to determine if the distribution across the change in channel geometry makes rational sense. This situation often arises where only a single velocity set was collected at a low flow or alternatively at only the high flow and a large "floodplain" type geometry exists. It is unlikely (but not impossible) that a standard application of the single calibration velocity set will reflect the velocity magnitudes and distributions across such a radical change in channel geometry. Modification of the velocity simulations using professional judgement is the only real option if the collection of an additional velocity calibration set(s) cannot be accomplished under the constraints of the project.

In those instances where multiple velocity sets have been collected, the user can easily check the validity of the velocity simulations by comparing the predicted velocities to one or more of the other calibration velocity sets. In the event that the predic ted versus observed velocity profiles are not within an acceptable range, then one or more of the other calibration velocity sets should be used for the appropriate range of discharge. Channel geometry changes in this situation can often provide guidance to the analyst for the water surface elevation and hence discharge ranges, that a particular velocity calibration set might be most appropriate. Again, any VAF functional relationship which deviates from the "expected" relationship should have a physical justification based on site-specific characteristics.

Chapter 3. Habitat Suitability Criteria

Objectives

This chapter briefly introduces the basic nomenclature and common types of habitat suitability criteria used in PHABSIM. For a more detailed discussion of this subject, the reader is referred to Bovee et al. (1998).

Laboratories

The associated exercise for this material is Laboratory 7. That exercise reviews the HSC numbering convention and the mechanics of managing HSC curve sets within the PHABSIM for Windows environment.

Introduction

Successful implementation of PHABSIM requires the acquisition of accurate and realistic habitat suitability criteria for the target organism(s) being evaluated. Perhaps more important than accuracy and realism, however, is buy-in from the stakeholders. Because the output from PHABSIM is extremely sensitive to even subtle differences in habitat suitability criteria, establishing the credibility of the criteria can be of utmost importance. Sometimes, establishing credibility requires a scientifically designed study to define a species' habitat characteristics. At other times, the habitat suitability is the result of expert opinion and negotiation. A key concept for PHABSIM analysts is that there is no universal best way to develop habitat suitability criteria. There are many ways to develop criteria, and alternative approaches to using them in PHABSIM, all of which have certain advantages and disadvantages. In simplest terms, criteria can be distinguished by their format and the type of information used to develop them.

Format

Use of the term format refers to the way that the habitat suitability criteria (HSC) are presented. In practical terms, there are only two viable formats for use in PHABSIM: binary or univariate curve (Figure 3-1). The binary format, shown as a shaded rectangle, brackets a range of a continuous variable (e.g., depth, velocity, distance from shore). Binary criteria act as simple on-off switches: the suitability index for a variable is 1.0 if it falls within the bracket and is 0.0 otherwise. Different ranges can be used to represent distinct categories of microhabitat quality for the target species. For example, a relatively narrow range can define habitat conditions preferred or selected by a life stage or a more all-encompassing range can define conditions the organism will use, but not seek out. Binary criteria can even be used to describe conditions avoided by the target species. In this case, the output from PHABSIM would quantify unsuitable, rather than suitable, microhabitat. **Note**: Binary criteria as used in PHABSIM are really specialized forms of the univariate curve, because vertical lines (e.g., two y-values for a single value of x) are illegal. Separating the x-values at the edges of the rectangle by a razor-thin difference closely approximates binary relations. For example, in Figure 3-1, the minimum usable depth for the binary criteria is 0.65 m. The coordinates entered into PHABSIM would be (0.649, 0.00) and (0.65, 1.00).

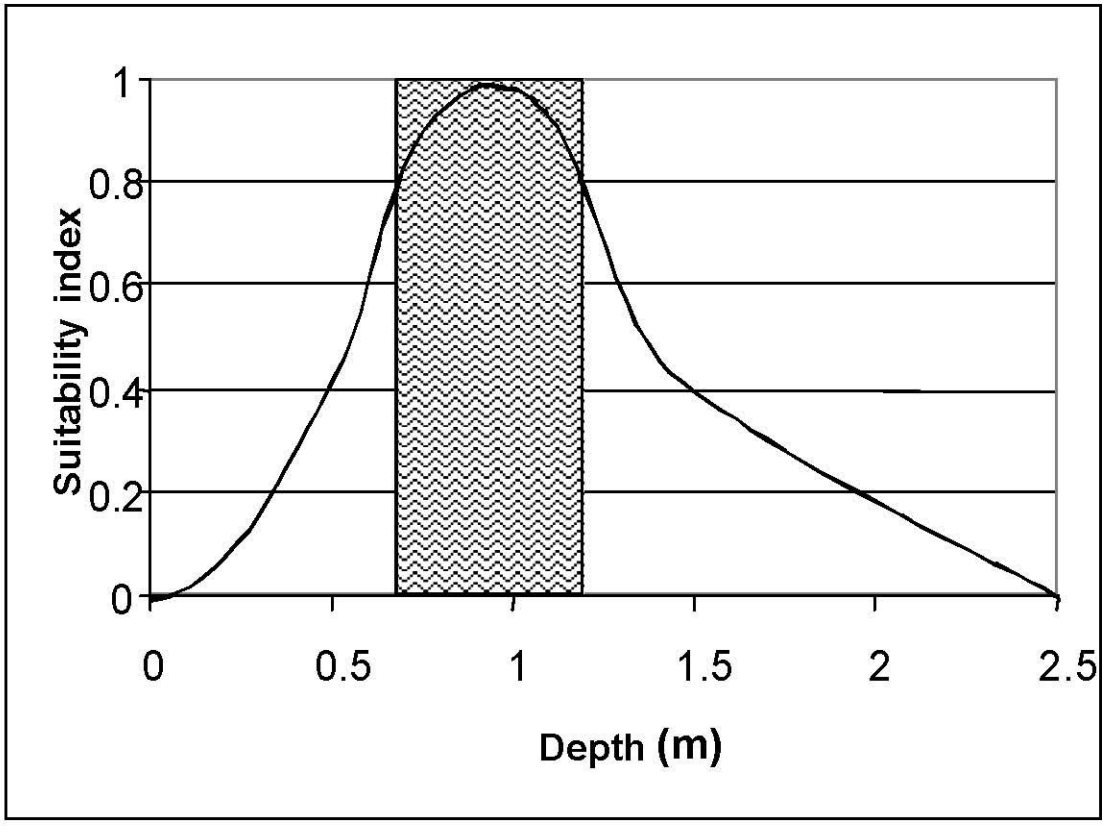


Figure 3-1. Comparison of binary and univariate curve formats for habitat suitability criteria.

Waters (1976) proposed the use of the univariate curve (Figure 3-1) as a more robust alternative than binary criteria for expressing habitat suitability. Since then, this has become the most familiar criteria format associated with PHABSIM. The tails of the curve are designed to encompass the entire suitable range of a continuous variable, but the narrow peak of the curve represents the optimum. Intuitively, the appeal of the univariate curve is that it is all-inclusive. Credit can be granted for conditions that are of intermediate habitat value, between optimal and barely useful. As popular as it is, however, the univariate curve has its detractors. Morhardt and Mesick (1988) summarized the concerns about univariate curves and the physical habitat generated by PHABSIM as follows:

1. When calculating the composite suitability index, PHABSIM treats variables independently so potentially significant interactions between variables are ignored.
2. Weighted usable area, which results from the use of univariate curves, is an index and cannot be measured directly.
3. Different estimates of weighted usable area can be obtained by using different methods of aggregating the composite suitability index.

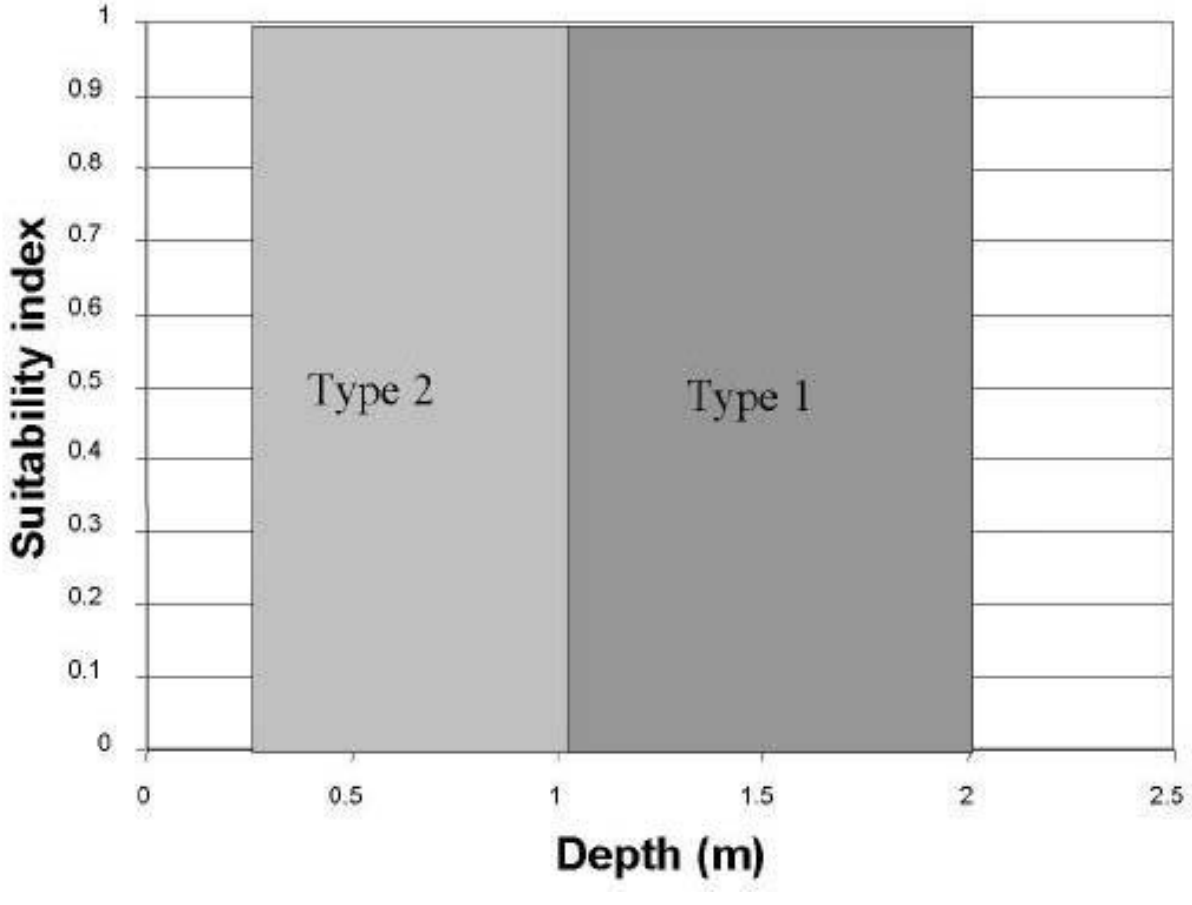
Weighted usable area combines elements of habitat quantity and habitat quality. A large area of low-quality habitat can produce the same weighted usable area as a small amount of high-quality habitat. **Conditional criteria** are used to depict interactions among habitat variables that are known to be biologically important (Bovee 1986). An example of a biologically significant interaction is the use of deep water as a form of overhead cover by some species of fish. The fish will occupy shallow water areas if overhead cover is present, but will only use deeper areas where cover is absent. This phenomenon can be represented through the use of two sets of criteria: one where overhead cover is present and one where it is absent (Figure 3-2). Presence or absence of cover can be designated in the HSC by clever usage of the channel index (e.g., 1 = no cover and 2 = cover in the cell). Wherever a channel index of 1 is encountered, usable habitat is tallied only for cells with adequate depth according to the deep-water criteria. Where the channel index is 2, usable habitat is accounted using the

shallow-water criteria. In the PHABSIM software, this is accomplished by using two sets of HSC, one for deep water and the other for shallow water. The habitat areas for the two simulations are then summed to determine the total habitat, with and without cover. Similarly, surface turbulence can be modeled as a form of overhead cover by using the Froude number (a ratio of potential to kinetic energy) instead of velocity to compute the composite suitability. In this case, cells without overhead cover would be unsuitable unless the Froude number was high enough to indicate surface turbulence. As currently programmed, specialized habitats such as Froude number dependence require review of the computational details in the project.ZOUTn file to extract and sum habitat for the appropriate cells.

Figure 3-2. Categorical depth criteria. Type 1 applies to cells that do not contain overhead cover. Type 2 applies to cells with overhead cover.

HSC Categories

The term category refers to the type of information and data treatment used to generate the criteria. Criteria that are derived from personal experience and professional opinion, or from negotiated definitions are defined as **category I**. These criteria can be developed relatively quickly and at minimal cost, compared to more data-intensive approaches. Because the criteria are negotiable, obtaining consensus about the criteria may also forestall conflict over their subsequent use in PHABSIM. The principal drawback to category I criteria is that they are based on opinions instead of data. Credibility problems can arise when the criteria are presented to groups that were not involved in the original development process.



Category II criteria are based on frequency distributions of microhabitat attributes measured at locations used by the target species. These criteria are known as **utilization or habitat use functions** because they represent the conditions that were being occupied by the target species when the observations were made. This approach for criteria development dates back to the conceptual precursor of PHABSIM, a planimetric mapping method developed by the Washington Department of Fisheries (Collings, et al., 1972). The **Washington method** was designed to measure the amount of spawning area available to Pacific salmon at various streamflows. Because the methodology was oriented to spawning, criteria development consisted primarily of finding salmon redds and measuring depths and velocities at various locations around them. After a sufficient number of redds were measured, binary criteria were developed to encompass a specified range of the observations.

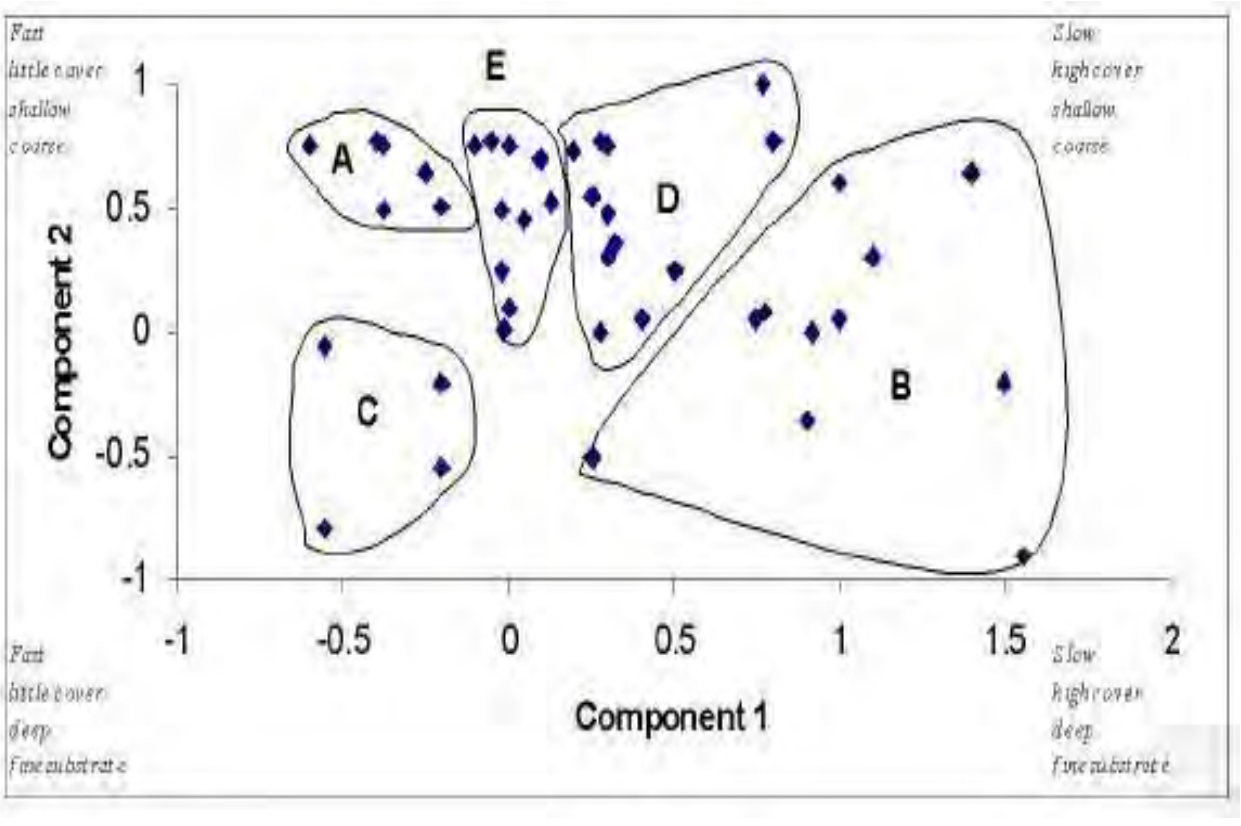
During the formative years of PHABSIM, the same basic approach for developing habitat suitability criteria was expanded to other species and life stages. One popular sampling method was to use a team of divers to intensively search numerous small reaches of stream to find locations occupied by the target species. At the end of each search, the depth, velocity, cover type, substrate (and other pertinent data) were measured at each occupied location. After measurements had been taken at 100 to 200 locations, the investigator either defined a binary range for the criteria or fit the data to a univariate curve.

Another approach to developing category II criteria is exemplified in the work of Knight, et al. (1991). They used a pre-positioned electrofishing grid to sample randomly selected locations throughout their study area. To take a sample, a grid was positioned at a pre-determined (random) location and left undisturbed for at least 15 minutes to allow fish to resume their normal activities. At the end of the waiting period, fish were collected by electrifying the frame for approximately 20–30 seconds. Immediately after activating the power supply, a seine was placed downstream of the frame so that stunned fish were swept into it. With the power active, one person kicked through the frame to dislodge benthic species. Fish captured at each location were preserved for later identification in the laboratory. Habitat attributes (e.g., depth, substrate type, cover type, and velocity) were measured at the four corners of the frame for each sample, and averaged.

A multivariate analysis of variance (MANOVA) was used to detect differences in habitat composition between samples that contained a particular species and those that did not. Principal components analysis (PCA) was used to illustrate the position of each fish species in habitat space (Figure 3-3). These analyses were used to identify habitat attributes that consistently corresponded to high abundance and diversity of fish species. Variations of this method have also been described by Felley and Hill (1983), Bain, et al. (1988), Scheidegger and Bain, (1995), and Bowen (1996).

The benefit of category II criteria is that they are based on data, not on someone's opinion. However, error can be introduced to these criteria through a **bias of environmental availability**. Manly, et al., (1993) describe this bias in the following way. Even though a resource item is highly favored by a species, it will not be used much if the resource is hard to find. Conversely, less favored resource items will be used in larger proportion if they are the only ones available. In the context of microhabitat utilization, this means that individuals will be forced to use sub-optimal conditions if optimal conditions are unavailable. By observing only the conditions used the most often in a given stream, an investigator could confuse optimal microhabitat with conditions that were merely tolerable.

Figure 3-3. Mean species locations in habitat space defined by principal components analysis of pooled data from seven streams in the Alabama River basin. Irregular circles encompass species with similar habitat use (e.g., Group C includes saddleback darter [*Percina vigil*], Alabama hog sucker [*Hypentelium etowanum*], black redhorse [*Moxostoma duquesnei*], and highfin carpsucker [*Carpiodes velifer*]. From Knight et al. (1991).



Category III criteria are designed to reduce the bias associated with environmental availability. These criteria are also referred to as **electivity or preference functions** . Resource selection refers to the utilization of resources disproportionate to their availability (Manly et al. 1993). For example, suppose that 10% of the stream mesohabitats occur as riffles, but 90% of the target species are found in riffles. Such disproportionate use is interpreted as an active selection on the part of the target organism.

A wide variety of mathematical indexes have been developed to indicate selection, and in some cases, avoidance of various resource units. The index of electivity usually involves a comparison of the proportion of the resource used with the proportion available or unused. [Available includes both used and unused proportions of the resource.] The most familiar index of selection, at least with respect to habitat suitability criteria, has been the forage ratio:

$$E = (3\text{-}1)\ \frac{U}{A}$$

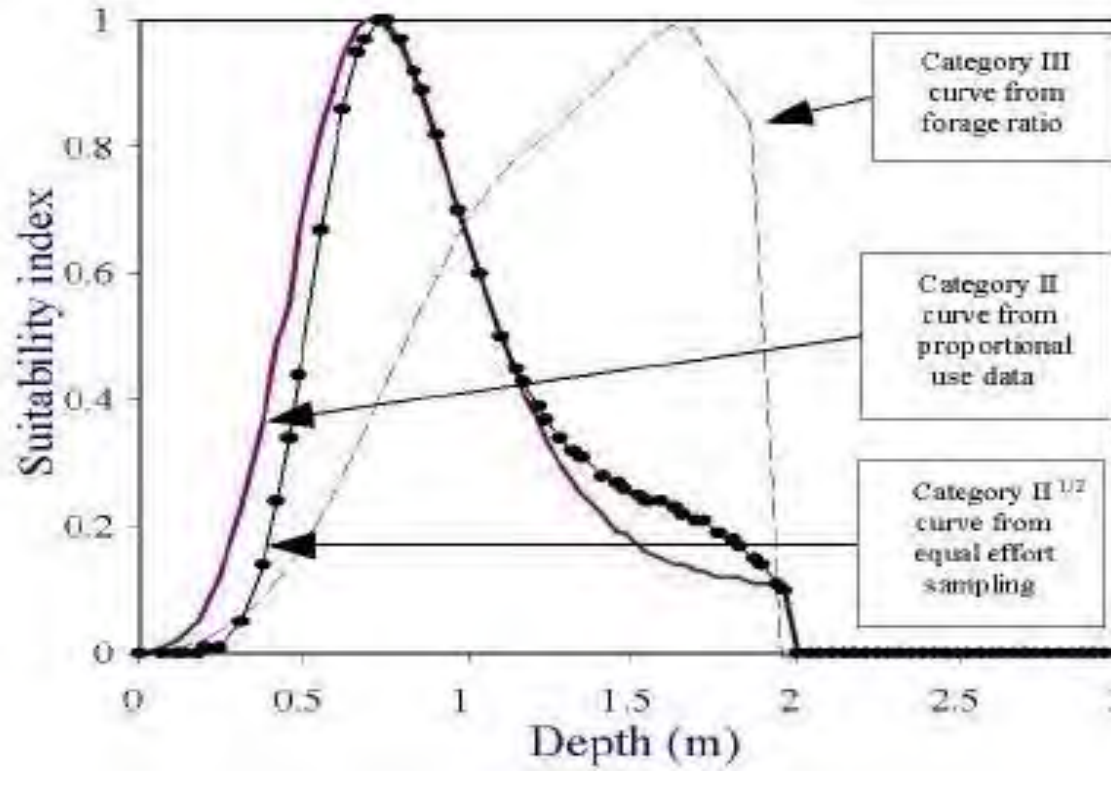
where E is an index of electivity, U is the proportion of used habitat units of category I (for example, depths between 1.0 and 1.5 m), and A is the proportion of habitat units of category I available in the sample. The use of the forage ratio was promoted as the preferred approach for developing habitat suitability criteria during the mid-1980s (Bovee, 1986). Since then, the method has fallen from favor (Bovee et al., 1998) because the forage ratio can result in an over-correction of the criteria (Figure 3-4). An alternative approach originates from the definition of preference given by Johnson (1980), who described preference as the likelihood that a resource will be selected if offered on an equal basis with others. Conceptually, the way this definition applies to habitat suitability criteria would be if it were possible to develop criteria in a stream with a perfectly uniform distribution of an infinite variety of microhabitat conditions. According to Johnson's definition, one could determine habitat preference simply by measuring use, because all microhabitat conditions would be equally available. Obviously, streams fitting this description are few and far between (as in non-existent). However, it may be possible to approximate this condition by altering the sampling design when collecting habitat utilization data. Following this

strategy, each mesohabitat type would be sampled equally, regardless of its relative abundance in the stream. The premise underlying the concept of **equal-effort sampling** is to equalize the availability of microhabitat conditions within the sampled sub-population, to the extent possible.

Criteria Verification

Although not a required element for running PHABSIM, criteria verification is always a good idea. Remember that in IFIM, the currency for negotiations is total habitat and alternatives are evaluated by comparison with a baseline. What this means is that habitat does not necessarily have to have a demonstrated biological connection, as long as the currency is meaningful to the stakeholders and decision-makers. For negotiations of low to medium levels of conflict, criteria can be verified simply by obtaining their acceptance among the stakeholders. When it becomes impossible to obtain consensus among the stakeholders, however, it may be necessary to conduct an empirical verification test.

Figure 3-4. Comparison of depth suitability curves for active adult brown trout derived from proportional use data (category II), equal effort sampling (category II ½), and forage ratio correction for availability (category III).



If PHABSIM sites are already established, one method to verify the criteria is to measure the standing crop in each site, calculate the habitat availability at the same discharge, and relate the two statistically. This procedure has two advantages. First, a significant correlation is unlikely if the criteria are incorrect, so the chances of committing a Type I error (accepting criteria when they should be rejected) are fairly remote. Second, a significant correlation lends credence to the idea that microhabitat is biologically meaningful. The disadvantages of this procedure are that the correlation may not be significant for reasons other than inaccurate criteria and the results are sensitive to the timing of the surveys. One often overlooked reason for poor correlation is the error associated with the estimate of standing crop. Before getting too excited about a lack of significant correlation, it is a good idea to examine the confidence intervals for the population estimates at each site. You may find that differences in standing crop cannot be quantified reliably enough to perform this type of test. A related problem occurs when trying to validate criteria for sport fish, because places that have good fish habitat also attract fishermen. Sometimes sites with the best and most abundant microhabitat will have the smallest standing crop, simply because all the good habitat may be "fished out."

Thomas and Bovee (1993) presented a more robust statistical test for criteria verification. This test can be performed without having to establish a PHABSIM site and is less influenced by fishing pressure than the previous method. Also, the results of the Thomas-Bovee method are not dependent on accurate estimates of standing crop. The primary disadvantages of this method are that it requires relatively unbiased habitat use and non-use data. The results are meaningful at the individual level, but not necessarily at the population level. In other words, the criteria may be transferable, in the sense that they describe fish behavior, but there is no guarantee that habitat estimates from the criteria are related to fish numbers.

Under the Thomas-Bovee method, habitat use is determined either by complete census or sampling and a random sample of **unused** habitats is taken. Criteria to be tested are converted from univariate curve to binary format, with the optimum range for a variable defined as having a composite suitability index greater than 0.85. Usable microhabitat is defined as having a composite suitability value between 0.2 and 0.85. Suitable microhabitat is defined as the full range of conditions in which the target organism is observed. Unsuitable microhabitat is defined as all values outside the suitable range. From the criteria, each used and unused location is classified as being optimal or usable, and suitable or unsuitable.

Then, each sampled location is cross-classified (e.g., occupied-optimal, unoccupied-usable) into a 2 x 2 contingency table (Table 3-1). The null hypotheses H_{01} (optimal locations will be occupied in the same proportion as usable locations) and H_{02} (suitable locations will be occupied in the same proportion as unsuitable locations) are tested using a one-sided chi-square test (Conover 1980). The test statistic T is given as:

$$T = \frac{N\,(ad - bc)}{\sqrt{(a+b)(c+d)(a+c)(b+d)}} \qquad (3\text{-}2)$$

$$\frac{\sqrt{N}}{\sqrt{(a+b)(c+d)(a+c)(b+d)}}$$

where N is the total number of measured locations, a is the number of occupied optimal locations, b is the number of occupied usable locations, c is the number of unoccupied optimal locations, and d is the number of unoccupied usable locations. Suitable locations are substituted for optimal locations and unsuitable locations for usable to test classifications of suitable and unsuitable microhabitat.

For a set of criteria to be considered transferable, both null hypotheses should be rejected at the 0.05 level of significance. [Note: The critical value of T at this significance level is 1.6449, and is obtained from the normal distribution table, not from the chi-square distribution. See Conover (1980) for a full discussion.]

Discussion Items

- In PHABSIM, it is equally important to describe habitat variables used over a broad range as to find narrow habitat preferences. Sometimes, these criteria appear as thresholds, above or below which there is little selection. The empirical frequency distribution of used microhabitat may be artificially narrow, either because the range of available conditions was narrow or because of the method used to fit the criteria to the data. Such artificially narrow criteria can make PHABSIM output unrealistically sensitive to changes in discharge. If this phenomenon is suspected, it should be brought to the attention of the stakeholder group. Modifying a data-based curve on the basis of professional judgement is acceptable, if not encouraged.

- Category I criteria are as valid in an application of IFIM as data-based criteria, if they are supported by a consensus of opinion among the stakeholders. Criteria developed by a committee are often somewhat broader than those based on data, because the ranges of the criteria are often negotiated. In this respect, category I criteria rarely exhibit artificial narrowing, but can be too all-inclusive. If the criteria are too broad, PHABSIM output may be relatively insensitive to changes in discharge.

- The principal components analysis approach presented by Knight et al. (1991) differs most dramatically from the other methods we discussed. A unique advantage of this method is that it can be used to define habitat use guilds and critical habitat types. This allows the analyst to concentrate on only a few key habitat types, rather than analyzing habitat for multiple species and life stages. Furthermore, potential biological connections between the habitat type and the biology of the stream can be quantified through the statistical analysis.

- It may come as a surprise to newcomers to PHABSIM, but it is just as valid to develop habitat suitability criteria for a mesohabitat type as it is for a species. For example, suppose that riffles are considered to be a critical mesohabitat type. A riffle could be defined with binary criteria, as having a depth range between 1 and 75 cm, velocities between 45 and 90 cm/sec, and a gravel/cobble substrate (or other definitions as negotiated among stakeholders). PHABSIM could then be used to determine how much area met those criteria over the range of simulated discharges.

- There is no unbiased way of collecting habitat use data. Every kind of sampling gear or observation technique has some sort of limitation that can result in biased data. For example, even with good visibility, divers are more apt to spot fish in shallow water than in very deep pools. They are also more likely to find active fish than those at rest, because the human eye is attracted to movement. As another example, electrofishing is less effective in deep water, and for safety reasons may be restricted to depths less than 1 m. When evaluating criteria, consider the limitations of the methods used to obtain the data in the context of the source stream from which the data were collected. If you believe that the criteria are unduly biased, refer to the first observation.

- One of the assumptions related to the estimation of resource selection functions is that the variables, which actually influence selection, have been correctly identified and measured. Perhaps the most common misconception about PHABSIM is that the only microhabitat variables that can be used are depth, mean column velocity, and substrate. In fact, PHABSIM can accept a wide range of variables, provided that they are related to the hydraulics or the structural characteristics of the stream. Examples of alternative microhabitat variables include: nose velocity, adjacent velocity (important for feeding stations), cover type, distance to cover, distance from shore, proximity to another habitat type, sheer stress, Froude number, depth-velocity products (important for recreational activities), and depth as a form of cover. Additionally, it is possible to use PHABSIM in conjunction with commercially available spreadsheets to derive alternative habitat indexes, such as habitat diversity. Be aware that

you are not limited to the "default" variables. With a little imagination, it is usually possible to tweak PHABSIM to include microhabitat attributes known to be important to the target species.

Organization of Habitat Suitability Criteria in PHABSIM

HSC number in PHABSIM for Windows arranges habitat Suitability Criteria (HSC). The HSC numbering convention consists of a four digit species identifier followed by a two digit life stage identifier. Each species and each life stage is also identified by a text description. A typical HSC curve would be identified as follows:

100102 Brown Trout Fry

The species identifier 1001 is associated with Brown Trout and the life stage identifier 02 is associated with fry. The PHABSIM software organizes HSC selection options and the format of the results from habitat calculations based on this number and text convention. Thus, it is important that each species/life stage have both a unique numerical and text identifier.

One may have different kinds of habitat suitability criteria for the same species in a project. That is, one may have a day time HSC series denoted by 1001 for Brown trout and a night time series denoted by 1101. Following this example, an HSC numerical identifier of 110102 would represent Brown Trout Fry habitat suitability at night. No strict correspondence between numerical identifier and life stage is enforced. Thus a curve number 110126 could be used for nocturnal Brown Trout Fry and the software would process it properly.

Problems can arise, however, if one attempts to assign different text identifiers to the same numerical species identifier and if either the species or life stage text identifiers are left blank. The PHABSIM for Windows interface is looking for consistent association of species text and numerical identifiers across all life stages and for unique life stage names associated with the numerical life stage identifier.

The HSC are entered in PHABSIM as x,y pairs of data to describe univariate relations for the suitability of depth, velocity, channel index, and temperature. Each variable must have an initial ordinate of 0 and a final ordinate of 100. Often, these curves begin with 0,0 and end with 100,0. A typical set of HSC is illustrated in Table 3-2.

Table 3-2. Brown trout adult HSC ID number and criteria coordinates.

Brown Trout – Adult HSC ID Number: 100101 Velocity SI Depth SI Channel Index SI

0.0 0.40 0.0 0.00 0.0 1.00
0.5 1.00 1.0 1.00 1.0 1.00
2.5 0.00 100.0 1.00 9.0 1.00
100.0 0.00 100.0 1.00

From this format, it can be seen that exact binary criteria cannot be represented. Rather, a close approximation is used. For example if binary velocity criteria for adult brook trout consisted of a range from 0.5 to 2.0 ft per second that had a suitability of 1.0 and all other suitability values were 0.0, the representation in PHABSIM might be as follows (Table 3-3).

Table 3-3. Representation of binary brook trout adult velocity criteria coordinates.

Velocity SI
0.00 0.00
0.49 0.00
0.5 1.00
2.0 1.00
2.01 0.0
100.0 0.00

Accessing Habitat Suitability Criteria in PHABSIM for Windows

HSC are entered and managed in the **\Edit\Suitability Curves** window. This window has menu items for **File, Edit** and **Curve**. The **File** menu allows for importing existing HSC criteria from text files (PHABSIM Version 2. Curve files) or from other PHABSIM for Windows projects. Thus it is possible to use an existing curve set in a new study by simply importing the old HSC data. Similarly, the import feature makes it possible to create a project with the purpose of maintaining a library of HSC curves and select the desired HSC for each study as needed.

The **Edit** menu allows the user to interactively add new curves, copy curves to new curve ID numbers and species/life stage names and to delete individual curves. One may add a new curve by supplying ID numbers, species/life stage names and the respective HSC coordinates for depth, velocity and channel index. To change from velocity to depth, channel index or temperature, one clicks the appropriate radio button in the **Curve Type** box to the upper right. Click the desired radio button (i.e. depth) and enter the HSC values in the table. Be sure to fill in all HSC tables before exiting. Or, for example, new channel index criteria can be assigned to an existing curve by making a copy of the curve, supplying new identifying information and then entering new coordinate data for the channel index values. The delete function deletes the curve currently displayed in the window.

The **Curve** menu allows selection of the curve displayed in the window by ID number or by moving backward and forward in the list of HSC contained in the project. It also provides for displaying graphs of individual curves or of the four HSC in each curve set.

One can display the individual HSC as they are being entered when adding curves under the **Edit** menu by clicking the **Graph** button located at the lower right of the window. By sizing or dragging the graph window and the Suitability Curve window one can view data as it is being entered and catch data entry errors as they occur. For more complicated HSC graphs, using the zoom feature may enhance viewing of particular portions of the curve. The graph automatically updates when a different curve is selected. As you click the different radio buttons for depth, velocity, etc. the graph changes to that variable.

Summary of Chapter 3

This chapter covered a brief outline of the numerous considerations needed when using HSC in a PHABSIM analysis. Because HSC are often the source of the greatest variability in PHABSIM study

results, it is of utmost importance that consensus as to the form and numerical values of the criteria be achieved among stakeholders **prior** to beginning the actual PHABSIM work. The processes for developing habitat suitability criteria are outside the scope of the PHABSIM for Windows software so the discussion in this chapter is provided as a very brief introduction to the topic. Readers are referred to the various references for more detailed coverage of this topic.

The chapter concludes with a description of the HSC data management capabilities of PHABSIM for windows. In any study, the HSC need to be entered into the PHABSIM project before proceeding to the habitat analysis process. Habitat analysis in its numerous forms is described in Chapter 4.

Chapter 4. Habitat Modeling

Objectives

The objectives of this chapter are to introduce the basic concepts of habitat modeling used within PHABSIM followed by a presentation of the specific computational processes important to the successful application of each habitat model within PHABSIM.

Laboratories

The associated laboratory exercises for this chapter will introduce the specifics of the two average parameter models AVDEPTH and AVPERM in Laboratory 8, general habitat modeling (HABTAE) in Laboratory 9, conditional velocity modeling in Laboratory 10, and finally lateral migration in Laboratory 11.

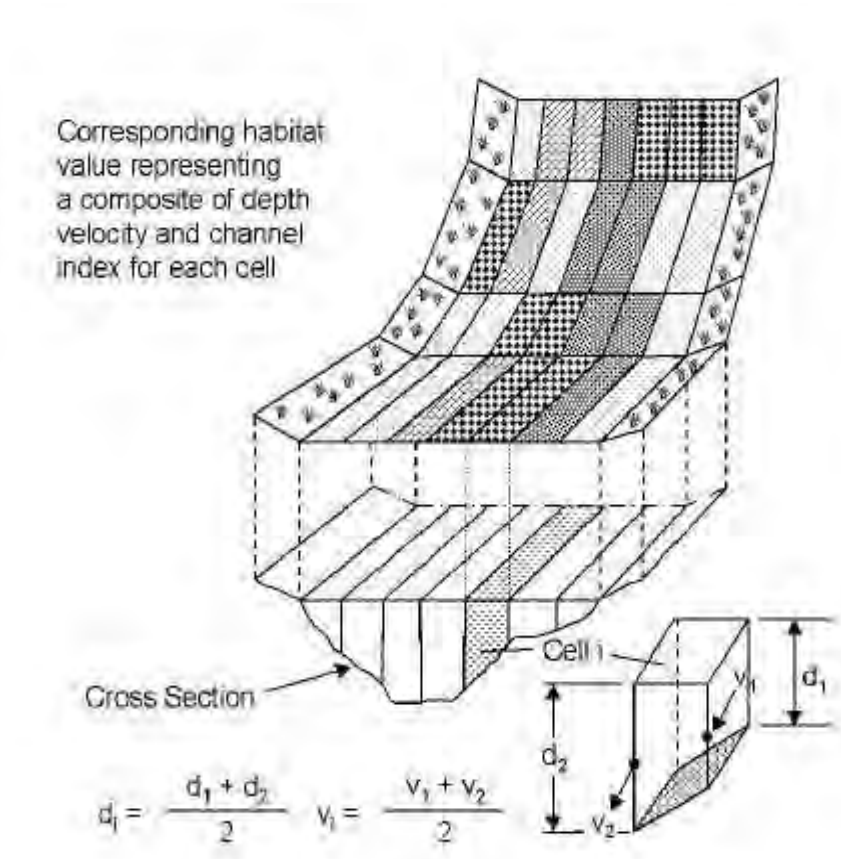
Introduction

At this point in a PHABSIM analysis, the needed hydraulic model(s) has/have been applied to determine characteristics of the stream in terms of depth and velocity as a function of discharge for the full range of discharges to be considered for the study. In the habitat modeling process, this information is integrated with habitat suitability criteria (HSC) to produce a measure of available physical habitat as a function of discharge.

The general theory behind the habitat modeling programs within PHABSIM is based on the assumption that aquatic species will react to changes in the hydraulic environment. These changes are simulated for each cell in a defined stream reach. The stream reach simulation takes the form of a multi-dimensional matrix of the calculated surface areas of a stream having different combinations of hydraulic parameters (i.e., depth, velocity, and channel index) as illustrated in Figure 4-1. The depth and velocity for each cell is the average of the simulated depth and velocity values obtained from the hydraulic simulation phase of PHABSIM. Depth and velocity attributes vary with simulated changes in discharge, causing changes in the amount and quality of available habitat. The end product of the habitat modeling is a description of habitat area as a function of discharge as illustrated in Figure 1-4 reproduced here as Figure 4-2 for ease of reference.

This habitat-discharge relationship is the basis of further analysis from which fishery and recreation management decisions are developed in IFIM. By linking the habitat-discharge relationship with flow time series data, a habitat time series can also be developed as described in Chapter 5. This information can assist in identifying critical time periods for a given life stage, limiting habitat availability for each life stage (i.e., physical carrying capacity), and limiting habitat availability for different species. When combined with a habitat time series, the habitat discharge relation is particularly useful in evaluating potential changes in species composition, because of the associated changes in the hydraulic characteristics of the stream reach as a function of discharge.

Figure 4-1. Matrix of habitat cell attributes in a PHABSIM study site.



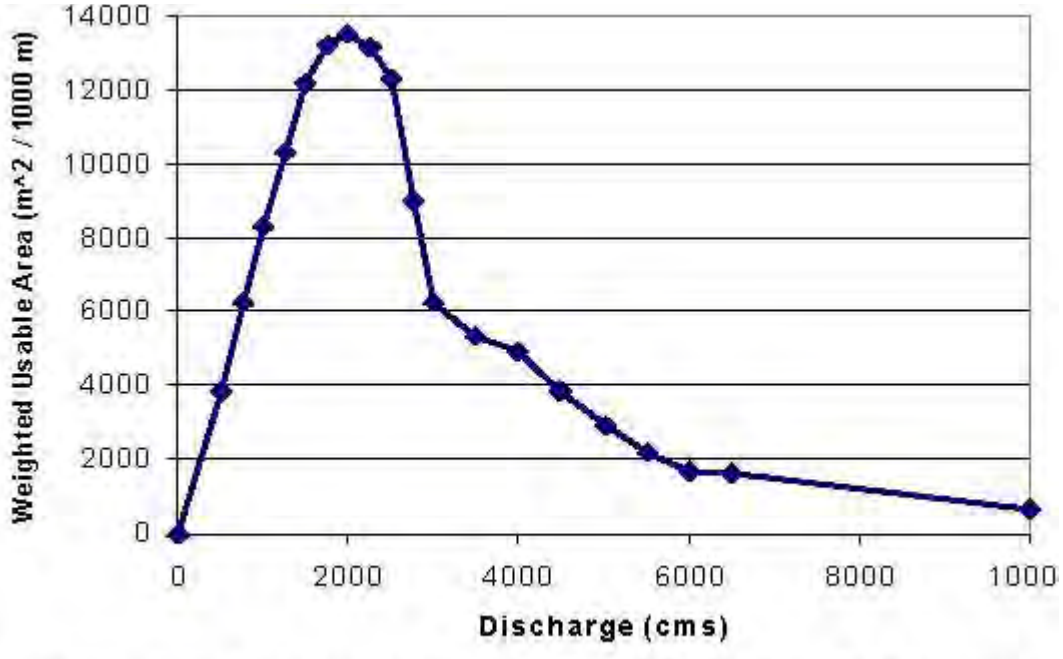


Figure 4-2. Habitat-flow relation for one species/life stage derived from a PHAB SIM analysis.0 2000 4000 6000 8000 10000 **Discharge (cms)**

This chapter presents material on how the habitat models view a stream based on the information passed from the hydraulic simulation programs; how the habitat models use the reach lengths, upstream weighting factors, and their linkage to habitat mapping or representative reaches to derive area (or volumes); and the generalized conceptual and analytical approaches used in the habitat models to integrate the hydraulic and suitability curve data to produce the basic metrics of habitat quantity and quality. The chapter concludes with a detailed description of each of the specific habitat models within PHABSIM and the available computational options within each habitat model.

The following section provides a discussion of several ways in which the output from the habitat models can be interpreted and how model results fit within the broader context of ecological assessment of alternate flow regimes.

Habitat Model Computational Cells

Figure 4-1 shows a generalized representation of a river segment for a series of transects that define a matrix of habitat cells with their associated attributes of depth, velocity and channel index (i.e., substrate and cover). These habitat cells represent the basic computational cells used by the various habitat programs to derive relevant indices of available habitat. This information is obtained from the hydraulic simulation models, as described in Chapter 2. In PHABSIM for Windows, all habitat models view a habitat computational cell the same way. In previous versions of PHABSIM there were two different cell definitions. As noted in Chapter 1, the change to one type of habitat cell definition may affect the computed habitat values when certain conditional habitat options are selected.

As noted above, all habitat programs now represent the habitat computational cells as bounded by the points where verticals were measured in the field. The hydraulic models define a cell as one-half the distance to the next vertical in each direction. Thus, the hydraulic models simulate depths and velocities (shown as d_1 ,d_2 ,v_1 and v_2 in Figure 4-1) at the verticals used in the habitat models.

Deriving Habitat Computational Cell Areas and Volumes

During the discussion of the project data (see Chapter 2), the distance from the previous cross section and upstream weighting factors supplied in **/Edit/Cross Sections** were described. The distance from the previous cross section (or reach length) and the upstream weighting factors (or reach length weighting factors) are used by the habitat models to assign a length to the habitat computational cells in the longitudinal direction for each cross section and, thereby, impart a surface area to each cell. Since the bed elevations are also known, several habitat model options can also be used to derive individual cell volumes and stream bed areas for use in calculating available habitat. A clear understanding of the relationship between the reach lengths and reach length weighting factors is necessary for proper use and interpretation of the habitat modeling results as illustrated in Figure 4-2 and discussed below.

Representative Reaches

Figure 4-3 illustrates a stream segment in which three cross sections have been used to characterize this "representative" reach. Each cross section was placed in a unique habitat feature as indicated. In Figure 4-3, the reach lengths measured between the left and right bank head pins at each cross section have been indicated, starting at the downstream cross section and moving in an upstream direction. The reach length at the downstream-most cross section by definition is zero (0) since there is no previous cross section and this is the value entered in the **/Edit/Cross Sections/Cross Section Data** field for length for the first cross section.

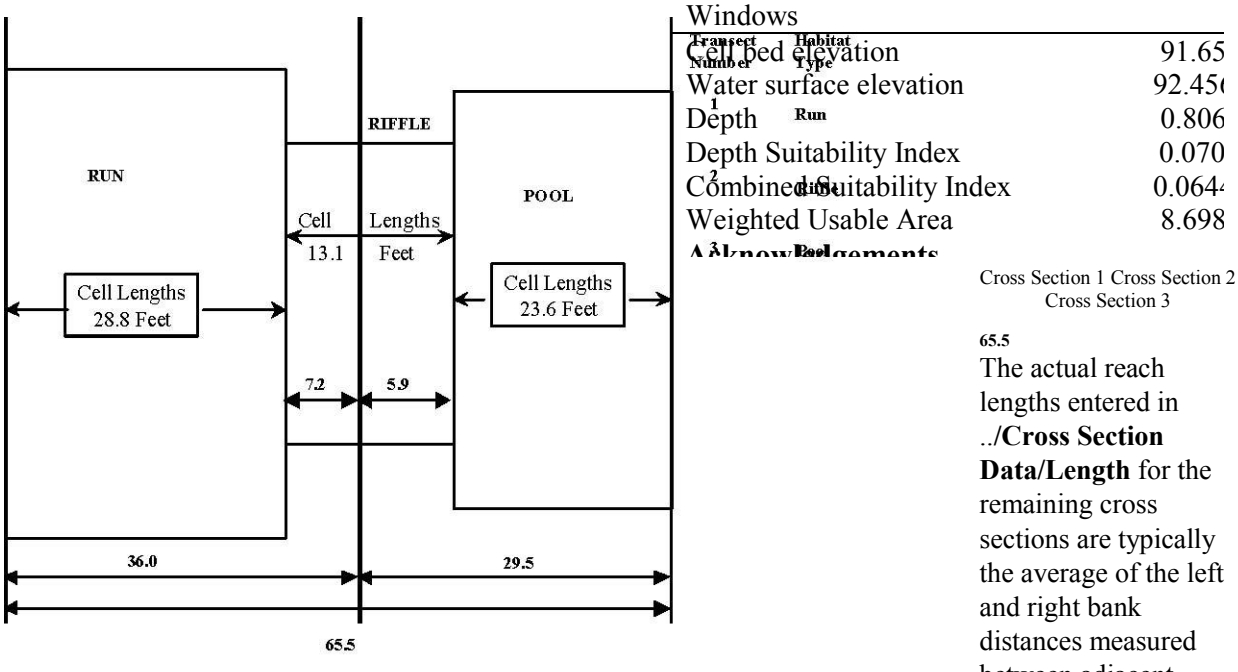


Figure 4-3. Derivation of reach length weighting factors.

The actual reach lengths entered in **../Cross Section Data/Length** for the remaining cross sections are typically the average of the left and right bank distances measured between adjacent cross section head pins. The reach lengths in this instance define the physical spacing of the cross sections within the reach as plan view rectangles without ”bends”. Use of the **Left** and **Right Bank Weighting Factors** can accommodate the actual left and right bank distances to preserve the spatial orientation or ”bends” is discussed later in this chapter.

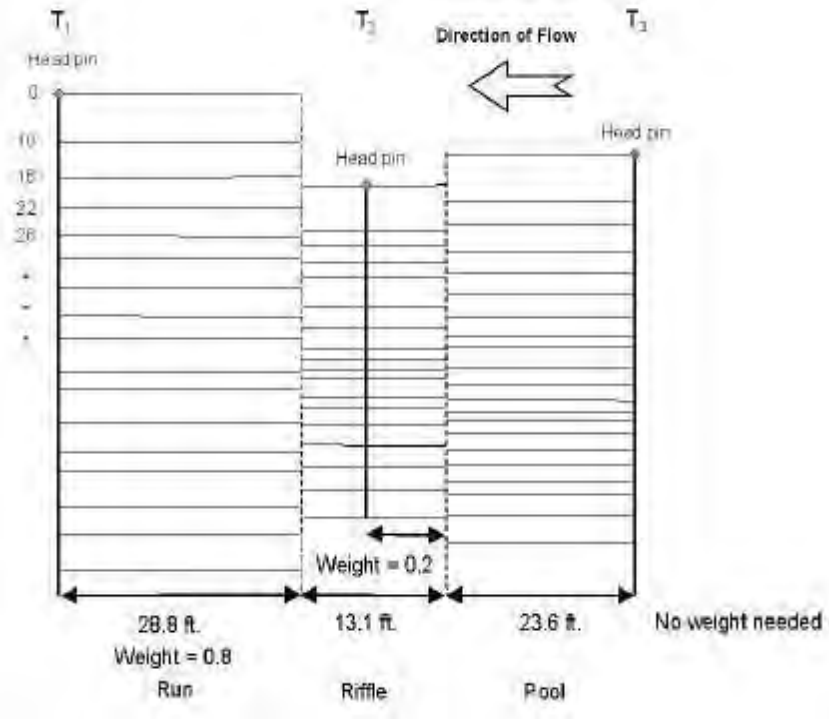
The **Reach Length Weighting Factors** (upstream weighting factors) are the values used in the habitat models in conjunction with the reach lengths to derive the longitudinal distance represented by cells at each cross section. In the example illustrated in Figure 4-3 in which a representative reach approach has been undertaken, the investigator would define during field data collection how far in the upstream direction, the attributes represented at the current cross section (i.e., habitat feature) extend toward the next upstream cross section. This upstream weighting factor is entered in the **/Edit/Cross Sections/Cross Section Data** field for **Upstream WF** for that cross section. For example, the investigator may have decided that the run habitat type represented by the downstream most cross section extends approximately 80% of the average distance upstream to the second cross section located in the riffle. In a similar manner, the investigator may have also decided that the second cross section located in the riffle only represents characteristics approximately 20% of the distance moving upstream to the transect located in the pool. This would result in an upstream weighting factor for the downstream-most cross section having a value of 0.80 and a value of 0.20 at cross section two. Any value between 0.0 and 1.0 may be supplied at the last cross section located in the pool since there is no upstream cross section and the area upstream of the last cross section will not be considered when calc ulating habitat. The resulting cell lengths for the downstream cross section would therefore be derived by distance calculated from the product of the Reach Length Weighting Factor at Cross Section One (i.e., 0.80) times the Reach Length Distance at Cross Section Two (i.e., 36.0) or (0.80*36.0) = 28.8 feet in Figure 4-3. This implicitly defines a longitudinal distance for cells at the second cross section of 7.2 feet in the downstream direction (i.e., 36.0–28.8). The remaining longitudinal distance in the upstream direction at cross section two would be computed by taking the upstream weighting factor at cross section two (i.e., 0.20) and multiplying it by the reach length value entered on the XSEC data line at cross section three (i.e., 29.5 feet) to derive an upstream longitudinal distance of 5.9 feet. The **total** longitudinal distance (e.g. length) of all cells at cross section two is then derived by the addition of these two parts and would yield 13.1 feet for this example. The length of all cells at cross section three is derived by subtracting the upstream distance at cross section two (i.e., 5.9 feet) from the reach length distance entered for cross section three. In

this example it would be 29.5–5.9 or 23.6 feet.

Note that the last cross section does not have a contribution of a longitudinal distance in the upstream direction and that the first cross section does not have a length contribution in the downstream direction. Figure 4-4 illustrates the final ”internal” representation of the habitat computational cells as defined in the previous example.

Figure 4-4. Habitat computational cells represented within the habitat models.

From this approach to cross sections weights, if the upstream weighting factor at cross section two had been specified as 1.0, then cross section three would have no length in the habitat model and, therefore, not contribute to the computation of available habitat. Similarly, if the upstream weighting factor at cross section one had been set to 1.0 and



the upstream weighting factor at cross section two had been set to 0.0, then cross section two would have effectively been eliminated from use in the habitat models. The use of reach lengths and, in particular, upstream weighting factors to ”eliminate” a cross section or cross sections such as hydraulic controls used for hydraulic simulation purposes only, is easy to accomplish using such an approach.

Changing upstream weighting factors to reflect relative contributions of specific types of habitat and impacts on the overall contribution to habitat availability can also be facilitated using these concepts. The next section illustrates use of the reach lengths and upstream weighting factors to represent stream segments in which specific types of habitats were sampled and which represent the proportions that these specific habitat features occur within a longer stream.

Habitat Mapping and the Idealized River Reach Approach

Table 4-1. Example of transect weighting based on reach length and upstream weights to duplicate percentage of habitat types within a study reach.

Windows		DOS	Difference	% difference
Cell bed elevation	91.65	91.65	0	0.00
Water surface elevation	92.456	92.47	0.014	0.02
Depth	0.806	0.82	0.014	1.71
Depth Suitability Index	0.0708	0.096	0.025	26.25
Combined Suitability Index	0.0644	0.087	0.023	26.25
Weighted Usable Area	8.698	11.79	3.096	26.25

Acknowledgements **i**
PREFACE **ii**
A Brief History of PHABSIM
Use of this Document
Changes Between PHABSIM Version 2 and PHABSIM for Windows
Conventions Used in this Document

For illustration purposes, assume that a river segment has been habitat mapped (see Bovee, et al., 1998 and Morhardt, et al., 1983) over some suitable length and it was determined that four distinct habitat types were recognizable and were found to occur in the following proportions based on measured longitudinal distances:

20% pools 60% runs 10% riffles 10% glides

The investigator randomly selected two locales of each habitat type and subsequently collected data from each set of four habitat types and now has successfully modeled the hydraulic conditions at 8 cross sections (i.e., 4 habitat types X 2 cross sections / habitat type). The investigator would now like to conduct habitat modeling at all 8 cross sections such that the weight given the individual cross sections reflects their proportional contribution as measured by the habitat mapping indicated above. Therefore, it is desired that both cross sections in pools total 20%, both cross sections in runs total 60%, both cross sections in riffles will total 10%, and both cross sections in glides total 10%. Because a stratified random sampling procedure was used, all 8 cross sections were collected independently and were spread out over 20 miles of river so the representative reach approach described in the previous section is not an option. The following example is one of several possible approaches which combine reach lengths and upstream weighting factors to weight the relative contribution of each cross section in order to produce the desired habitat mapping weighting in the calculated WUA results.

First, assume that all the transects represent 100% of an idealized river reach or alternatively, consider the idealized river as being 100 feet long. The basic strategy, is to specify reach lengths and upstream weighting factors for each **/Edit/Cross Sections/Cross Section Data** field such that the combination of distance and weights produce the following results: (1) both of the pool transects have a combined total habitat computational cell length of 20 feet (or 20%), (2) runs represent a total of 60 feet, (3) riffles represent 10 feet, and (4) glides represent 10 feet. This approach requires using the STGQ and/or MANSQ programs because these programs treat each cross section independently. Note, WSP can be used to simulate a pool transect provided that the control transect governing the pool is "weighted out" as described above and the pool transect reach length fits into the overall distance weighting scheme. Assuming the investigator has decided to enter the data grouped by habitat type and in the order of the habitats listed above, we only need to specify the appropriate reach lengths and upstream weighting factors at each cross section, which could be accomplished as indicated in Table 4-1.

Note that the "solution" for this example could have been handled in any number of different ways to yield the same basic results. The habitat models will produce an index of habitat availability (i.e., WUA) in units of square feet per 1000 feet of stream and therefore using total distances of 1000 or 10,000 for the total idealized reach will only "scale" the WUA magnitudes by factors of ten. This is different than that obtained from using a representative reach since, in that approach, the actual reach lengths are spatially dependent. If the relative combinations between reach length and weighting factors result in approximately the same relative contributions of specific habitat types sampled, then the functional relationship between habitat and discharge will be nearly the same using either approach.

The "end product" of these efforts within the hydraulic simulations using STGQ or MANSQ is the generation of an

array of stream cells representing each cross section as illustrated in Figure 4-1 at each simulated discharge. This "array" of cells and corresponding attributes of depth, velocity, and channel index is passed to the habitat programs and, as indicated above, represent the basic habitat computational cells. The use of these attributes and associated area, volume, or bed area in each cell in conjunction with the HSC curve coordinate data to generate an aggregated index of available habitat is discussed in the next section.

Integrating Habitat Suitability Criteria Curves and Computational Cell Attributes

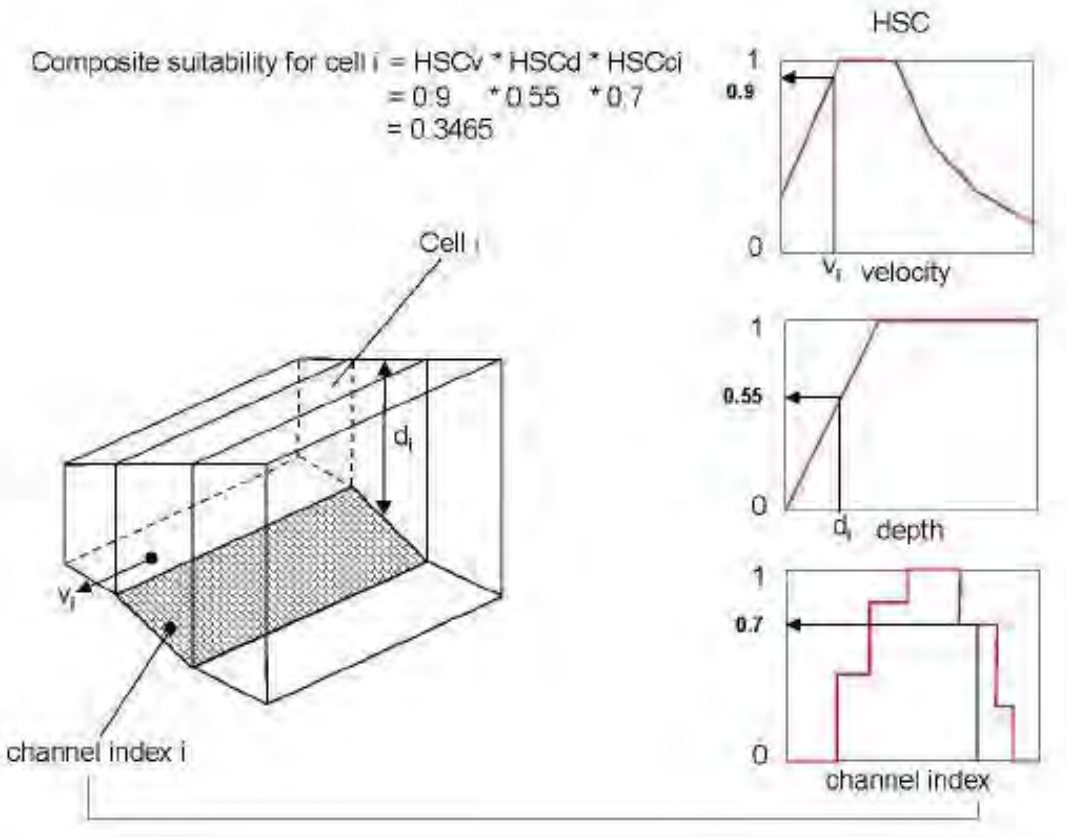
The habitat models rely on HSC relating hydraulic and channel characteristics to the habitat requirements of fish, other aquatic species, or even recreational activities. These HSC are used to describe the adequacy of various combinations of depth, velocity, and channel index conditions in each (or the adjacent) habitat computational cell to produce an estimate of the quantity and or quality of habitat in terms of surface area, bed area, or volume. As noted earlier, this metric is referred to as Weighted Usable Area (WUA) and has units of square feet per 1,000 linear feet of stream length (regardless of stream width). WUA is computed within the reach at a specific discharge from:

$$WUA = \frac{\sum_{i=1}^{n} A_i * C_i}{\text{Reachlength (1,000 feet)}} \quad (4\text{-}1)$$

where: A_i = surface area of cell i C_i = combined suitability of cell $_i$ (i.e., composite of depth, velocity and channel index individual suitabilities)

The combined suitability of the cell is derived from the component attributes of each cell (see Figure 4-1) which are evaluated against the species and life stage habitat suitability curve coordinates for each attribute to derive the component suitabilities as illustrated in Figure 4-5. Once the individual component suitabilities have been determined, the user has the option to select several different ways of aggregating them for a cell into a single composite cell suitability.

Figure 4-5. Habitat suitability criteria attributes for a habitat cell, showing multiplicative aggregation option.



The most common method is a multiplicative aggregation given by:

$$C_i = V_i * D_i * S_i \quad (4\text{-}2)$$

where: C_i = composite suitability of cell I V_i = suitability associated with velocity in cell I D_i = suitability associated with depth in cell I S_i = suitability associated with channel index in cell I

Second, the geometric mean can be used. This implies a compensation effect between the component suitability values. If two of three individual composite suitabilities are within the optimum range and the third is very low, the third individual composite suitability has a reduced effect on the computation of the composite suitability. The geometric mean is calculated as:

$$C_i = \sqrt[3]{V_i * D_i * S_I} \quad (4\text{-}3)$$

Third, the most locally limiting individual suitability factor can be selected by setting the composite suitability for the cell based on the minimum of the individual cell factors according to:

$$C_i = \text{Min}(V_i, D_i, S_i) \quad (4\text{-}4)$$

Once the composite suitability C_i has been determined, then the amount of WUA using all cells at this specific discharge is computed according to the following equation:

$$WUA = \sum_{i=1}^{n} A_i * C_{i\,(4\text{-}5)}$$

where: WUA = total Weighted Usable Area in stream at specified discharge
C_i = composite suitability for cell i
A_i = vertical view area of cell i (bed area or volume)

This process is then repeated for all discharges simulated and the functional relationship between habitat and discharge as illustrated in Figure 4-5 is obtained. As will be discussed under the HABEF and HABTAM models, the WUA within a specific cell can also be "adjusted" based on the attributes of adjacent cells such as conditional velocities, or on the difference in attributes of the existing cell when compared over a range of paired conditions.

Basic Assumptions in Habitat Modeling

The habitat programs in general are based on the following assumptions:

1. Individual organisms select the most desirable conditions within a steady state stream but will use less favorable areas as the stream becomes more crowded.

2. Desirable conditions can be adequately represented by habitat suitability criteria curves.

3. Each cell can be evaluated independently.

4. The area weighted arithmetic sum of available habitat (as WUA) in each cell is indicative of total habitat conditions at a specific discharge.

5. Physical habitat (not water quality and/or other factors) is limiting the population size.

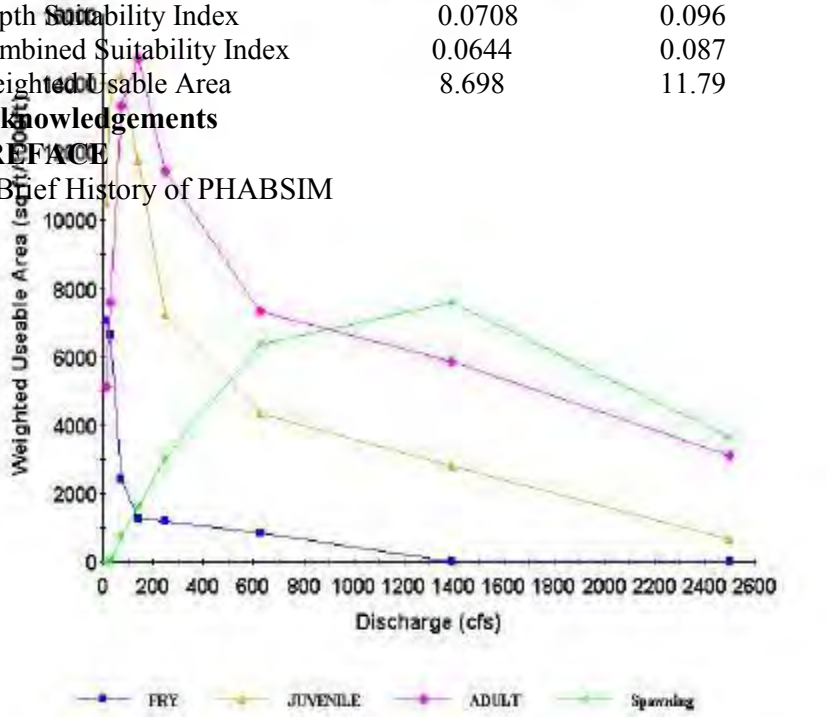
It should be emphasized that prediction of habitat as a metric (i.e., WUA) within PHABSIM is made in terms of changes to physical properties of aquatic microhabitat (i.e., velocity, depth, and channel index) and do not directly predict changes in the biomass of organisms. This fact has led to much criticism in the literature when PHABSIM results were applied and interpreted without consideration for other factors such as water quality, temperature, food availability, and fishing mortality. However, a number of studies have shown that there is a positive relationship between the output derived from PHABSIM and observed distribution and abundance of fish (e.g., Jowett, 1992; Railsback et al., 1995; Bovee et al., 1994; Nehring and Anderson, 1993).

Figure 4-6. Simulated habitat-discharge relation for Rainbow Trout.

Windows		DOS	Difference	% diff
Cell bed elevation	91.65	91.65	0	0.
Water surface elevation	92.456	92.47	0.014	0.
Depth	0.806	0.82	0.014	1.
Depth Suitability Index	0.0708	0.096	0.025	26
Combined Suitability Index	0.0644	0.087	0.023	26
Weighted Usable Area	8.698	11.79	3.096	26

Acknowledgements i
PREFACE ii
A Brief History of PHABSIM

The typical habitat-discharge relationship provided in Figure 4-6 represents the basic output from the habitat modeling phase of PHABSIM. Note that the goal of habitat time series and related project assessment methods in IFIM is to allow the user to integrate this information with the available data on existing and/or proposed alterations of stream flows in order to evaluate proposed management alternatives. Further, the basic relationship between habitat and discharge, illustrated in Figure 4-6, is not the only analytical capability within PHABSIM for development of an understanding of the "controlling" factors, examination of the quality of total habitat, and evaluation of potential effects of alternative flow regimes. The other habitat simulation and analysis capabilities of PHABSIM are considered in the following section, which highlights the specific computational capabilities of each habitat program, and in the following chapter on applying PHABSIM within the IFIM Framework.



Habitat Modeling Options in PHABSIM

The following sections present each of the main habitat models, a description of their primary purpose, computational control options and the basics for their application. Table 4-2 provides an overview when a particular model might be used and distinctive options. The use of each of the main habitat models is also covered in the accompanying laboratory exercises as indicated at the beginning of the chapter.

at model descriptions. Use when these habitat results Other Model are desired Distinctive options comments

Windows		DOS	Difference	% difference
Cell bed elevation	91.65	91.65	0	0.00
Water surface elevation	92.456	92.47	0.014	0.02
Depth	0.806	0.82	0.014	1.71
Depth Suitability Index	0.0708	0.096	0.025	26.25
Combined Suitability Index	0.0644	0.087	0.023	26.25
Weighted Usable Area	8.698	11.79	3.096	26.25

Acknowledgements i

The Average Parameter Model AVDEPTH/AVPERM

The two general types of habitat modeling in PHABSIM are based on either average conditions in an entire stream channel or on distribution of velocity and depth among field measurement cells (i.e., habitat computational cells) and the

Windows		DOS	Difference	% difference
Cell bed elevation	91.65	91.65	0	0.00
Water surface elevation	92.456	92.47	0.014	0.02
Depth	0.806	0.82	0.014	1.71
Depth Suitability Index	0.0708	0.096	0.025	26.25
Combined Suitability Index	0.0644	0.087	0.023	26.25
Weighted Usable Area	8.698	11.79	3.096	26.25

Acknowledgements **i**

Windows		DOS	Difference	% difference
Cell bed elevation	91.65	91.65	0	0.00
Water surface elevation	92.456	92.47	0.014	0.02
Depth	0.806	0.82	0.014	1.71
Depth Suitability Index	0.0708	0.096	0.025	26.25
Combined Suitability Index	0.0644	0.087	0.023	26.25
Weighted Usable Area	8.698	11.79	3.096	26.25

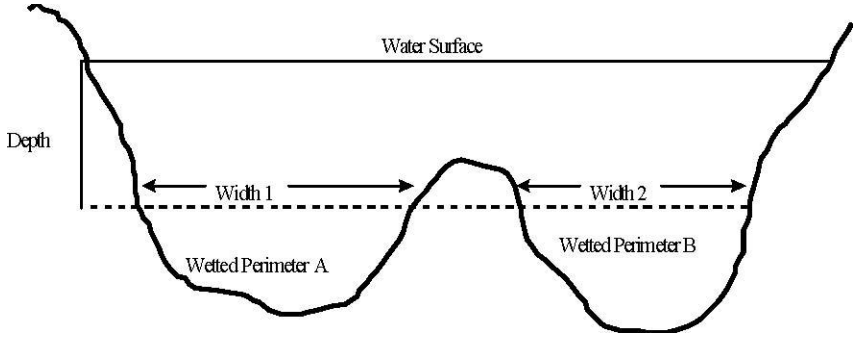
Acknowledgements **i**
PREFACE **ii**

nature of the channel in a stream. The average parameter model AVDEPTH/AVPERM calculates wetted width and wetted surface for flows and water surface elevations supplied by the user. It determines width of a stream with water over a depth specified by the user. The average velocity is also calculated.

Wetted perimeter, wetted width, and average velocity have long been used as indexes to the physical habitat in a stream. In using the wetted width or wetted perimeter, the assumption is made that all the stream area is of equal value to the instream flow activity of interest. The wetted perimeter and wetted width will always either stay the same or increase with depth. The use of the AVDEPTH/AVPERM program can often provide valuable insights into the functioning of the hydraulic simulations at specific cross sections as well as for reach aggregated results and the associated implications to target species and life stages.

PHABSIM programs assume that the hydraulic variables measured at a cross section extend halfway to adjacent cross sections upstream and downstream. If this is not the case, upstream weighting factors should be applied.

The output resulting from AVDEPTH/AVPERM gives information for each cross section and a summary of the average parameters for a whole reach of stream including discharge, depth, cross sectional data, and velocity. In addition, for each of the specified depths (maximum of five), AVDEPTH and AVPERM calculate the total width of the stream that is at least as deep as the specified depth (see Figure 4-7). The use of wetted width is a special case of WUA habitat modeling in that the weights for habitat computational cells are essentially set to 1.0 for all velocities, depths, and channel indexes.



AVDEPTH = WIDTH 1 + WIDTH 2

AVPERM = WETTED PERIMETER A + WETTED PERIMETER B

Figure 4-7. Calculation of width and wetted perimeter in AVDEPTH/AVPERM.

Running AVDEPTH/AVPERM

The AVDEPTH/AVPERM program is accessed from the PHABSIM for Windows interface using **/Models/ AVDEPTH/AVPERM.** The depths to be evaluated are set in the **../Models/Avdepth/Avperm/Avdepth Avperm input** tab which also contains the run button.

If depths are specified, the AVDEPTH/AVPERM program will calculate the total width of the stream that is as least as deep as the depth(s) specified. Depths are entered in the table provided in the **../AVDEPTH/AVPERM Input** tab.

The HABTAE Program

The HABTAE program is the main habitat program in PHABSIM for Windows. It calculates WUA (surface or bed) or weighted usable volume (WUV) for a reach or for each cross section. Depending on the options selected to control the computations, output will contain: (1) WUA, (2) usable surface area (UA) (given a user specified minimum value for combined suitabilities), (3) usable volume (UV) and (4) WUV that is the WUA times the water depth. HABTAE now also contains the conditional or adjacent velocity calculations formerly contained in HABTAV. The adjacent velocity calculations in the HABTAE program simulate situations where fish habitat is determined by hydraulic parameters at the fish's location, as well as by velocities near the fish. (See Habitat Calculations Conditioned on Adjacent Velocities below.)

The user is reminded that the cell boundaries in HABTAE are defined as illustrated in Figure 4-8. HABTAE uses the

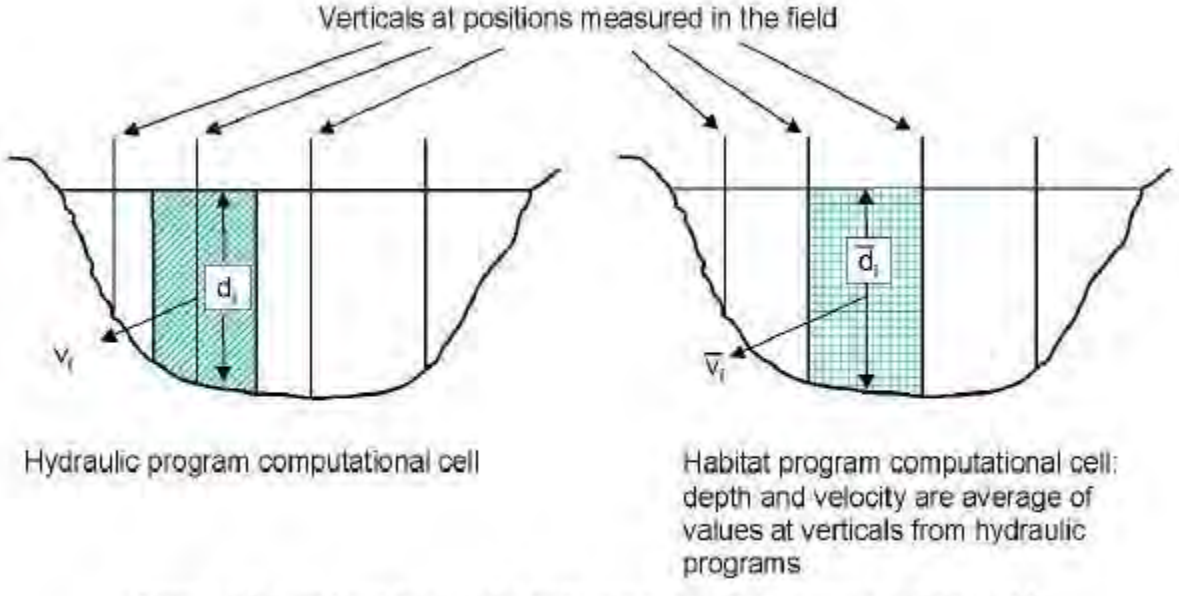


Figure 4-8. Cell boundaries in the hydraulic and habitat programs in PHAB SIM.

channel index value taken from the X coordinate vertical on the upstream-right (not left) side of the cell. This should be kept in mind when entering data.

Figure 4-8. Cell boundaries in the hydraulic and habitat programs in PHABSIM.

The HABTAE program requires that HSC curves for aquatic species or recreational activities be created or imported using the **/Edit/Suitability Curves** menu and successful simulations of water surface profiles and velocity distributions be performed prior to habitat modeling.

Setting HABTAE Options

The HABTAE program uses the options selected in the following tabs under /Models/Habtae: ../Output Options, ../Computations, ../Limits, ../Adjacent Velocity, and ../Velocity Replacement Options. HSC data must have been provided in /Edit/Suitability Curves, and the appropriate hydraulic programs must have been run. The user must select the HABTAE options prior to running the model. The options in the HABTAE program are summarized in Table 4-3. Note that due to enforcing use of the same habitat cell definition across all habitat programs in PHABSIM for Windows, the options formally in the HABTAV program in the DOS version are now contained in HABTAE. Conditional velocity simulations within the HABTAE program are controlled by the combination of selected options for scanning for VLIM and using VLIM and the action to be taken when VLIM is not found. The first option in the /Models/HABTAE/Adjacent Velocity tab directs the program to scan the cross section a user-specified distance out

from the cell for which the habitat is being simulated to locate a user-specified velocity in any adjacent cells. If the velocity is found within this distance, the WUA calculated for the cell is multiplied by one (1.0). In other words, the existing cell WUA remains unmodified. Note that the program can be directed to use the limiting velocity as a minimum or maximum limit. If the user-specified velocity is not found, the WUA calculation when VLIM is not found option directs the program to scan the cross section a second time for an initial velocity. This initial velocity is the first velocity where fish habitat is worth more than zero (0.0) based on the suitability criteria. The program then searches for a velocity, which is between the initial velocity and the user-specified velocity that is closest to the user-specified velocity and then interpolates the velocity suitability value using the suitability curves and the located velocity. This new suitability value is multiplied by the original WUA to obtain a new amount of WUA for the current cell.

Description of Habitat Calculation Options

Several of the options shown in Table 4-3 are self-explanatory. However, others bear further elaboration to ensure clarity as follows.

ZHAQF Options

The **ZHAQF Options** radio buttons in the **Output Options** tab determine the mode of calculation of habitat area. The user may elect to calculate Weighted Usable Area or volume or simply usable area or volume. The weighted usable habitat can be surface area, bed area, or volume. The usable area is all areas with a composite suitability factor greater than 0.001. Volumes are calculated by multiplying weighted cell areas by the depth. Typical PHABSIM applications select "Write WUA or WUV" in the ZHAQF Options portion of the **Output Options** tab and "Calculate WUA for reach" in the **Computations** tab. Note: take care to match WUA or UA in the **Output Options** tab with the option selected in the **Computations** tab.

Using Bends

The **Describe Reach Bends** check box in the **Computations** tab allows the length represented by a cross section to vary from cell to cell (also called variable cell length) across the stream (i.e., a bend). The default is to use cells as rectangles in plan view. Most historical PHABSIM applications have used this default. Supplying the additional information for bends allows a more accurate representation of a study site where bends are significant.

When the **Describe Reach Bends** box is checked, the program uses cells as trapezoids based on the length multiplied by left and right bank weights. To use this option, left and right bank weighting factors must be entered in **/Edit/Cross Sections**. Note that the left and right bank weighting factors are multiplied times the cross section length entered in the second column of the cross section data in **/Edit/Cross Sections**. Thus, one bank should have a weight greater than 1.0 and the other should be less than 1.0 to indicate a bend in the stream. When the longitudinal distances between head pins were measured in the field, it is straightforward to find the ratio of left and right bank weights to the cross section length. If these distances are not known, it may be possible to approximate the distances if accurate maps of the study site are available. The check box must be checked and

Table 4-3. Options in the HABTAE program.

Option description	Action when set to indicated value, notes
Output Options Tab **Write Flow Data** (check box) (IOC 3)	Writes the flow related data for each cross section evaluated at each discharge to ZOUT. It also lists the velocity for each cell that has water in it. The data are a rehash of the hydraulic model results. Recommend leaving blank unless a printed record is needed.
Output Options Tab **Write Computational Details** (check box) (IOC 4)	Writes all the computational details used in determining the weighted usable area, weighted usable bed area, or weighted usable volume to ZOUT. Recommend leaving blank except when details are needed to evaluate the simulation. Strongly recommend using only a few life stages and discharges when using this option.
Output Options Tab **Write Cross Section Data** (check box) (IOC 2)	Writes cross section data to ZOUT. Output is the same as that contained in **/Edit/Cross Sections**. Recommend leaving blank unless a printed record is needed.
Output Options Tab **ZHAQF Options** (radio buttons) (IOC 10)	Determines calculation of habitat area. The weighted usable habitat can be surface or bed area or volume. The usable area is all areas with a composite suitability factor greater than 0.001. Typical applications select "Write WUA or WUV". Take care to match WUA or WUV with the options selected in the **Computations** tab.
Output Options Tab **Discharges** (input table)	User selects which of the discharges used in the hydraulic simulations are to be used for habitat calculations. Default is to use all discharges.
Computations Tab **Describe Reach Bends** (check box) (IOC 12)	Allows the length to vary from cell to cell (variable cell length) across the stream (i.e., a bend). Default is to use cells as rectangles in plane view. When checked, program uses cells as trapezoids based on the length multiplied by left and right bank weights. To use this option, left and right bank weighting factors must be entered in **/Edit/Cross Sections**.
Computations Tab **Use a Minimum Contiguous Width** (check box) (IOC 11)	When checked this directs HABTAE to use a minimum contiguous width. Minimum width (WMIN) values must be supplied for each HSC curve set ID Number (life stage) in the right-hand table in the **Velocity Replacement Options** tab.
Computations Tab **Use Zero CI in Calculations** (check box) (IOC 18) box.	This defines how channel index values of zero (0) are used. If not checked channel index values of zero are converted to 1.0 which effectively removes channel index from the calculation for any cell with a 0.0 CI. When checked, a channel index value of zero is used in the calculation of WUA for that cell. Recommend checking this

Table 4-3. Continued.

Option description Action when set to indicated value, notes

Computations Tab
Near Shore Habitat Analysis
(check box and distance entry box (IOC 22)

Computations Tab **WUA Calculations** (radio buttons) (IOC 1)

Computations Tab **Habitat Calculations** (radio buttons) (IOC 9) These are the typical habitat calculations produced by PHABSIM. Note that the outcome of these calculations is influenced by the other option choices.

Limits Tab **Velocity Limits** (radio buttons) (IOC 15)

Limits Tab
Minimum Effective Composite Suitablitiy Factor (radio buttons) (IOC19) Use to prevent very small CF from accumulating a large area of poor habitat.

Velocity Replacement Options Tab **CFMIN**(column in input table)(IOC19)
Used to define suitable habitat for organisms that require certain combinations of depth and velocity within a given distance of the shoreline. These may be terrestrial as well as aquatic organisms.

Determines if the WUA, WUV, or weighted usable bed area (WUBA), is to be calculated, and if the WUA, WUV, or WUBA is to be calculated for an independent cross section or for a reach.

Controls how the calculation of habitat area will be made. **Standard calculation** -- Combined Suitability Factor (CF) = f(v)*g(d)*h(ci), where: f(v)*g(d)*h(ci)) = variable preferences for velocity, depth and channel index.
Geometric Mean - $CF = (f(v)*g(d)*h(ci))^{0.333}$. **Lowest Limiting Parameter** - CF = MIN(f(v), g(d), h(ci)).

Limits the velocities allowed in the habitat simulation calculations. Choices are: No restriction on velocities; Abort if velocities are <0 or >15; and Convert negative velocities and abort if >15.

Sets a minimum composite suitability for each life stage. The minimum value for each life stage is entered in the CFMIN column in the right-hand table in the **Velocity Replacement Options** tab. When values less than CFMIN are calculated for a cell, the composite suitability for that cell is set to zero.

Data entry location for minimum effective composite suitablity Factor.

Table 4-3. Continued.

Option description Action when set to indicated value, notes

Velocity Replacement Options Tab **Vel Calc** (column in input table) (IOC14) Where various Vel Calc options require additional input parameters, those parameters are supplied in the appropriate columns of the left or right

side input tables in the **Velocity**

Replacement Options tab.

Velocity Replacement Options tab **Dnose, a, b, n, D65** (columns in input table)

Velocity Replacement Options tab **Nose Vel** (column in input table) (IOC16)
Nose depth is supplied in Dnose field of right-hand table.

Note: If **Nose Vel** is not set to 0 for a life stage, **Vel Calc** should also be non-zero. Note: For **Nose Vel** options 1, 2, and 3, **Vel Repl** should be set to 0.
0 = Mean column velocity. 1 = Nose velocity - Empirical equation based a power law equation and user defined coefficients. User supplies the nose depth (Dnose) for which a velocity is to be calculated, and the calibration parameters A and B. These values are entered in the right input table. 2 = Nose velocity - 1/7th power law equation. User supplies nose depth (Dnose) in right input table. 3 = Nose velocity - logarithmic velocity distribution equation. The nose depth and the D65 of the bed material are supplied by the user in the right input table (scroll table to display D65).

4 = Nose velocity - 1/mth power law equation. m is calculated using the equation: $m = D^{0.1667}_{c}, n$ n is the Manning's roughness coefficient (n), and c is 0.105 for traditional units and 0.128 for metric units. The value of m is determined for each cell. The value of n and the nose depth are supplied in the right input table. 5 = Nose velocity - 1/mth power law equation. Same as above except m is calculated using the equation $m = aD^{b}$. Values for a and b and nose depth are supplied in the right input table. 6 = Nose velocity - 1/mth power law equation. Same as above except the nose depth (Dnose) is measured from the surface. The values for nose depth and n are entered in the right input table. 7 = Nose velocity = Shear velocity. To calculate the shear stress (ϑ), the Manning's roughness must be known. Manning's n is entered in the right input table.

Data entry location for nose depth, a and b coefficients, D65 sediment size and Manning's n from above.

0 = Given velocities, or nose velocities, (depending on what Vel Calc was set to) are used for habitat simulation. 1 = Optimum velocities are used for habitat simulation with equal depth from top as from bottom. Nose depth is set by one of two methods:
(a) Dnose in the right-hand table of the Velocity Replacement Options tab; or
(b) if Dnose has not been set, nose depth = .1.
2 = Optimum velocities are used for habitat simulation with unequal depth from top as from bottom. 3 = Mean velocity in a top cell is used in habitat simulation. The velocity used is the mean velocity found in a cell defined between the surface of the water column and the depth specified in the cell field in the right-hand
table in the Velocity Replacement Options tab.

Table 4-3. Continued.

Option description	Action when set to indicated value, notes
Velocity Replacement Options tab **Vel Repl** (column in input table, scroll to view **Vel Repl** column)(IOC17)	Data entry location for specific gravity of the bed material. Permitted combinations of velocity replacement options are shown in the table at the bottom of th the combinations shown can be used. When checked, HABTAE performs adjacent velocity scanning and applies the criteria selected in **VLIM as box** (below).
If **Vel Repl** is not 0, then **Nose Vel** must be 0.	
If **Vel Repl** is 1 or 2, then **Vel Calc** must be 0. If **Vel Repl** is 3, then **Vel Calc** must be set to 7 and Manning's n, D65 of bed material, and the specific gravity must be entered in the right-hand table of the **Velocity Replacement Options** tab. If specific gravity is not specified, 2.65 is used.	$\sqrt{gd}$ where: V = velocity, g = acceleration of gravity, and d = depthgd
Velocity Replacement Options tab **Sp. Grav.** (column in input table)	
Velocity Replacement Options tab	
Adjacent Velocity tab Scan for velocity in adjacent cells (IOC-V 1) (checkbox) 0 = Use given velocity. 1 = Use velocity * depth as velocity. 2 = Use (velocity**2) * depth as velocity 3 = Use Shield's Parameter as velocity. $K_s = \frac{\tau}{D_{65}(S_s - 1)\gamma}$ where: Ks = Shield's parameter, ϑ = shear stress on a bed, D65 = size of bed surface material at which 65% are smaller, Ss = specific gravity of the bed material, and (= unit weight of water. 4 = Use Froude number as velocity. $F_r = \frac{V}{}$	

Table 4-3. Concluded. icated val

Option description	Action when set to
	i n d

Adjacent Velocity tab **Minimum** - Scans adjacent cells within a user-defined distance (**DIST**) for velocity greater than or equal to a **Use VLIM as (IOC-V 1)** user-defined minimum velocity (**VLIM**). That is, **VLIM** acts as a lower bound. If found, WUA for current cell = (Radio buttons) WUA * 1.0.

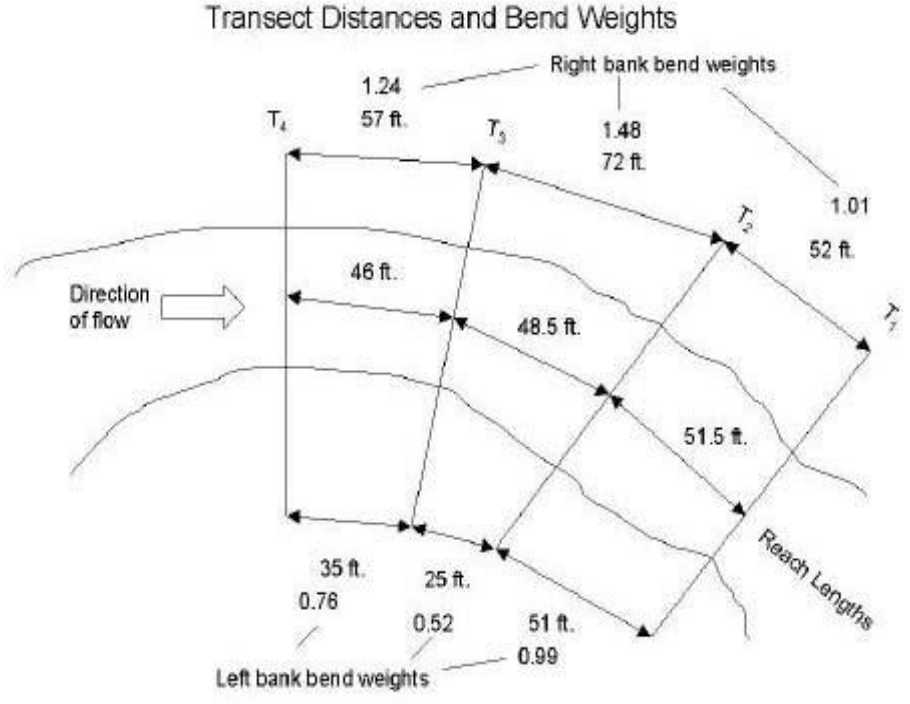
- **Minimum** - Scans adjacent cells within a user-defined distance (**DIST**) for velocity greater than or equal to a user-defined minimum velocity (**VLIM**). That is, **VLIM** acts as a lower bound. If found, WUA for current cell = WUA * 1.0.

- **Maximum** - Scans adjacent cells within a user-defined distance (**DIST**) for velocity less than or equal to a user-defined maximum velocity (**VLIM**). That is, **VLIM** acts as an upper bound. If found, WUA for current cell = WUA * 1. 0. **VLIM, DIST,** and **V0** are supplied in the input table on the **Adjacent Velocity** tab.

Adjacent Velocity tab **WUA = 0 -** If VLIM is not found in adjacent cells, set WUA for current cell to zero. WUA calculation when Scan for initial Velocity (V0) and interpolate – If VLIM is not found in adjacent cells, the program scans a VLIM not found (IOC-V 5) second time for an initial velocity, **V0**, which is the first velocity where fish habitat is greater than 0. (Radio Buttons) Then it searches for a velocity between **V0** and **VLIM** which is closest to **VLIM** and interpolates a multiplier for the WUA for the current cell between 0.0 and 1.0 based on the velocity found by this process.

Adjacent Velocity tab Table where **DIST, VLIM,** and **V0** are supplied by the user. **Scan distance, velocity limit, initial velocity** (input table with these columns)

the left and right bank weights must be set greater than 1.0 on the long bank and less than 1.0 on the short bank for this



option to have an effect. Figure 4-9 illustrates bend weights.

Figure 4-9. Illustration of bend weights.

Note: In PHABSIM the bend weights act like the upstream reach length weighting factors. That is, they are applied upstream from the cross section. In this example, the left bank bend weight for the third cross section would be calculated from the field data as 35 ft divided by 46 ft. So 0.76 would be entered in the **L Bank WF** field of the **/Edit/Cross Data** tab. When bends are included in the habitat calculation, the final weight applied to habitat cells in the cross section is a composite of the bend weights and the upstream weighting factors for the current and the downstream cross section. This is due to the fact that the habitat cell length for cross section B is a combination of one minus the upstream weighting factor for cross section A times the length from B back to A and the upstream weighting factor for cross section B times the length from C back to B. Refer back to Figure 43 of use of upstream weighting factors and reach length.

Using Minimum Contiguous Width

If a species requires a minimum amount of continuous habitat across the stream for the habitat to be usable, this option allows the program to enforce that requirement. When checked, this option in the **Computations** tab directs HABTAE to only count habitat in a cell if it is part of an area that has a minimum contiguous width of suitable habitat. Minimum width (WMIN) values must be supplied for each HSC curve set ID Number (life stage) in the right-hand table in the **Velocity Replacement Options** tab.

Use of a Zero Channel Index Value The **Zero CI in Calculations** check box in the **Computations** tab defines how channel index values of zero (0) are used. When PHABSIM was first developed, channel index values of zero were considered to mean that no information was available. This option allows the user to select how a CI of zero is to be treated. If this box is not checked, channel index values of zero are converted to 1.0, which effectively removes channel index from the calculation. When checked, a channel index value of zero is used in the calculation of WUA for that cell. Care should be taken to ensure that this option reflects the analyst's desired outcome. Recommend checking this box for most applications unless it is known that zero values indicate that channel index is to be ignored.

Near Shore Habitats

The **Near Shore Habitat Analysis** check box and distance entry box in the **Computations** tab is used to define suitable habitat for organisms that require certain combinations of depth and velocity within a given distance of the shoreline. These may be terrestrial as well as aquatic organisms. This option was developed to describe habitat for a water snake that required riffle habitat near basking areas on the shore. Other possibilities include riparian bird species that need feeding areas within a certain distance of the shoreline.

To use this option, check the **Near Shore Habitat Analysis** box and supply the distance from shore that habitat will be counted. All cells more than the specified distance from shore will be eliminated from the habitat sum. As the shoreline moves with higher or lower water surface elevations, different cells will fall within the near shore distance and the habitat value will vary according to the depth, velocity, and channel index combinations in those cells. Note the HSC used in this analysis may actually be HSC for the food organisms of the target species; for example the water snake's preferred prey.

Weighted Usable Area Calculations and Independent Cross Sections

The **WUA Calculations** radio buttons in the **Computations** tab are used to select the most commonly used calculation schemes in PHABSIM. They determine if WUA, WUV, or weighted usable bed area (WUBA), is to be calculated, and if the WUA, WUV, or WUBA is to be calculated for independent cross sections or for a reach. While the selection of WUA, WUV, or WUBA is straightforward, the use of independent cross section or reach aggregation merits further discussion.

Most PHABSIM applications use aggregation of the WUA by reach and result in one habitat-flow relation for each species/life stage for the entire reach. However, this approach assumes the reach length weighting factors accurately capture the desired weighting for each cross section. If the weighting factors are a concern, or if alternate weighting schemes are to be considered in the analysis, calculating WUA for each cross section independently allows the user to perform other analyses outside of PHABSIM for Windows. When using the independent cross section option, the user is advised to take care in tracking the tables of WUA carefully.

The Form of the Habitat Calculation

The **Habitat Calculations** radio buttons in the **Computations** tab direct the form of the habitat calculation. These choices allow the user to select among standard, geometric mean, or minimum parameter calculations. Note that the outcome of these calculations is influenced by the other option choices.

In the standard calculation the combined suitability factor is:

$$(CF) = f(v) * g(d) * h(ci) \quad (4\text{-}6)$$

where: f(v) * g(d) * h(ci) = variable preferences for velocity, depth, and channel index.

This is a simple multiplication of the velocity, depth, and channel index HSC weights and implies synergistic action. It also treats each of the three variables as independent. That is, there are no interaction terms in the multiplication. Optimum habitat only exists if all variables are optimum and low SI values for all three variables can

yield very low WUA values for a cell. The geometric mean produces a combined suitability using:

$$CF = (f(v) * g(d) * h(ci))^{0.333} \quad (4\text{-}7)$$

This technique implies compensatory effects; if two of the three variables are in the near-optimum range, the value of the third variable has less effect, unless it is zero. This option may be selected for organisms that fare well in marginal habitats as long as two of the physical habitat parameters are high.

The lowest limiting parameter approach calculates combined suitability as:

$$CF = MIN\ (f(v) * g(d) * h(ci)) \quad (4\text{-}8)$$

This approach determines the composite suitability factor as the value of the most restrictive variable. This implies a limiting factor concept (i.e., the habitat is no better than its worst component), but is limited only by its worst element. The user is advised to select the habitat calculation form with care based on the available data on the species of interest and the decision environment in which the PHABSIM results will be used.

Velocity Limits and Eddies

The **Velocity Limits** radio buttons on the **Limits** tab allow the user to limit the velocities allowed in the habitat simulation calculations. The choices are: **No restriction on velocities, Abort if velocities are <0 or >15**, and **Convert negative velocities and abort if > 15**. MESC strongly recommends selecting the second or third button. If the "No restrictions" option is required for successful habitat simulation runs, there probably was an error in the hydraulic simulation process.

The “Convert negative velocities” option would apply in situations where reverse flow occurs on part of a transect, such as a transect that runs across an eddy. Care should be taken in such situations to select the calibration velocity set that applies to this situation and not to extrapolate reverse flow to discharges where either the eddy has not yet developed or where it has been washed out at higher flows.

Minimum Effective Composite Suitability

The **Minimum Effective Composite Suitability Factor (CFMIN)** radio buttons in the **Limits** tab allow the user to prevent very small composite suitabilities from accumulating a large area of poor habitat. This option sets a minimum composite suitability for each life stage. The minimum value for each life stage is entered in the **CFMIN** column in the right-hand table in the **Velocity Replacement Options** tab. When a value less than **CFMIN** is calculated for a cell, the composite suitability for that cell is set to zero.

Nose Depth: Empirical Calculation of Velocity at a Given Depth

The **Vel Calc** column in the input table in the **Velocity Replacement Options** tab allows various forms of empirical or assumed vertical velocity distributions to be applied to determining the habitat value based on assuming the organism selects a particular location above the stream bed. This option is particularly useful when the depth-oriented behavior of a particular life stage of a target species is known. Thus, the velocity calculation option varies by HSC curve number as shown in the left-hand table of the **Velocity Replacement Options** tab.

When **Vel Calc** is set to zero (0), only the mean column velocity is used in habitat calculations. This is the default or standard habitat calculation.

When **Vel Calc** is set to 1, nose velocity is calculated using an empirical exponential equation and user-defined coefficients. The user supplies the nose depth (D_{nose}) for which a velocity is to be calculated, and the calibration parameters a and b. These values are entered in the right input table. Nose velocity is calculated as:

$$V_n = Va\left[\frac{D_{nose}}{D}\right]^b \quad (4\text{-}9)$$

where: V = mean column velocity of the cell, and D = total depth of the cell.

When **Vel Calc** is set to 2, nose velocity is calculated using the Prandtl-von Karman 1/7th power law equation. User supplies nose depth (D_{nose}) in right input table (scroll table to display D_{nose}). Nose velocity is calculated as:

$$V_n = V(1+1/7)\left[\frac{D_{nose}}{D}\right]^{1/7} \quad (4\text{-}10)$$

When **Vel Calc** is set to 3, nose velocity is calculated using a logarithmic velocity equation. The nose depth and the D_{65} of the bed material are supplied by the user in the right input table (scroll table to display D_{65}). The relationship is given as:

$$V_n = V\frac{\log(33.2 * d_{nose}/D65)}{\log(12.12 * d_{nose}/D65)} \quad (4\text{-}11)$$

When **Vel Calc** is set to 4, nose velocity is calculated using a 1/mth power law equation. The nose velocity equation used is:

$$V_n = V(1+1/m)\left[\frac{D_{nose}}{D}\right]^{1/m} \quad (4\text{-}12)$$

and m is calculated using: c

$$m = D^{0.1667} \quad (4\text{-}13)$$

where: n = Manning's roughness coefficient, and c = 0.105 for traditional units and 0.128 for metric units. The value of m is determined for each cell. The value of n and the nose depth are supplied in the right input table (scroll table as needed to display n).

When **Vel Calc** is set to 5, nose velocity is calculated using the 1/mth power law equation in the same manner as above except m is calculated using:

$$m = aD^b \quad (4\text{-}14)$$

Values for a and b and nose depth are supplied in the right input table (scroll table to display D_{nose}).

When **Vel Calc** is set to 6, nose velocity is calculated using the 1/mth power law equation in the same manner as above except the nose depth (D_{nose}) is measured from the surface. The values for nose depth and n are entered in the right input table (scroll table to display D_{nose}).

When **Vel Calc** is set to 7, shear velocity is used for nose velocity. To calculate the shear stress (ϑ), the Manning's roughness must be known. Manning's n is entered in the right-hand input table (scroll table to display n). Then:

t

$$\sqrt{\frac{t}{?}} \quad (4\text{-}15)$$

$$\mu_* = \frac{}{?}$$

where: :* = shear velocity, ϑ = shear stress on the bed , and Δ = density of water.

Replacements for Velocity

The **Vel Repl** column in the left input table of the **/HABTAE/Habitat Simulation/Velocity Replacement Options** tab allows the user to make certain replacements for velocity in the velocity calculation algorithm. These replacements enable alternative habitat determinations when sufficient data is available to support their use. All velocity replacement option combinations are subject to the conditions stated at the end of this section.

When using velocity replacements the analyst must take care to ensure that the habitat suitability criteria for velocity reflect the velocity replacement option being used. That is, new HSC must be entered in **/Edit/Suitability Curves** corresponding to the velocity replacements described below. In the option tables in the **Velocity Replacement Options** tab, a different set of velocity calculation options may be supplied for each habitat suitability criteria curve. Thus, an analysis can be performed where most HSC are treated with the standard mean column velocity calculation and certain HSC are used with velocity replacements. This means that the user must be cautious to ensure that the velocity HSC values are Froude number suitability values if **Vel Repl** is set to 4 (see below) for a particular HSC curve set.

When **Vel Repl** is set to 0, the velocity option specified by **Vel Calc** is used.
When **Vel Repl** is set to 1, the product velocity * depth is used as velocity.
When **Vel Repl** is set to 2, (velocity**2) * depth is used as velocity.
When **Vel Repl** is set to 3, Shield's Parameter is used as velocity.

Shield's parameter is defined as:

$$K_s = \frac{t}{D_{65}(S_s - 1)\,g} \quad (4\text{-}16)$$

where: K_s = Shield's parameter, ϑ = shear stress on a bed, D_{65} = size of bed surface material at which 65% are smaller, S_s = specific gravity of the bed material, and τ = unit weight of water. Values for D_{65} and specific gravity are supplied in the right input table (scroll table as needed to display **D_{65}** and **Sp. Grav**.). If the user does not supply specific gravity, 2.65 is used. When **Vel Repl** is set to 4, Froude Number is used as velocity. Froude number is defined as:

$$F_r = \frac{V}{\sqrt{gd}} \quad (4\text{-}17)$$

where: V = velocity, g = acceleration of gravity, and d = depth.

The following conditions apply to combinations of **Vel Repl** and **Nose Vel**. If **Vel Repl** is not 0, then **Nose Vel** must be 0. If **Vel Repl** is 1 or 2, then **Vel Calc** must be 0. If **Vel Repl** is 3, then **Vel Calc** must be set to 7 and Manning's n, D_{65} of bed material, and the specific gravity must be entered in the right-hand table of the **Velocity Replacement Options** tab. The permitted combinations of **Nose Vel**, **Vel Repl**, and **Vel Calc** are given in a table

at the bottom of the **Velocity Replacement Options** tab.

Nose Depth: Use of “Optimum” Velocities for a Portion of the Water Column

The **Nose Vel** column in the input table in the **Velocity Replacement Options** tab allows the analyst to select the portion of the water column where velocities will be calculated. The velocity calculated in the selected portion of the water column is sometimes referred to as an “optimum” velocity. Note: if **Nose Vel** is not set to 0 for a life stage, **Vel Calc** should also be non-zero. Further, for **Nose Vel** options 1, 2, and 3, **Vel Repl** (see below) should be set to 0.

When **Nose Vel** is set to 0, the simulated mean column velocities, or nose velocities, (depending on what **Vel Calc** was set to) are used for habitat simulation.

When **Nose Vel** is set to 1, optimum velocities are used for habitat simulation with equal depth from top as from bottom as follows: A “top of cell and bottom of cell” are removed from the water column. Within the remaining water column, the velocities in the habitat simulation calculations are optimized, i.e., it is assumed that the fish can move vertically to find the "best velocity" in the remaining water column. This "best velocity" is used with the nose velocity calculated by the selection of **Vel Calc**. If **Vel Calc** = 0, and **Nose Vel** = 1 or 2, the program will calculate nose velocities as if **Vel Calc** = 2. The "optimum (best) velocity" is defined as the velocity that is found within the range of nose depth down from the surface (top) and nose depth up from the bottom that has the highest suitability index value on the HSC relation for that species/life stage. Nose depth is set by one of two methods, (a) **Dnose** in the right-hand table of the **Velocity Replacement Options** tab, or (b) if **Dnose** has not been set, nose depth has a default value of 0.1.

When **Nose Vel** is set to 2, optimum velocities are used for habitat simulation with unequal depth from top as from bottom. The top portion of the cell that is removed is the distance between the water surface and the depth specified in the **Cell** field in the right-hand input table in the **Velocity Replacement Options** tab (scroll the table to find the **Cell** column). The bottom portion of the cell that is removed is defined by the **Dnose** values.

When **Nose Vel** is set to 3, the mean velocity in top portion of each a top cell is used in habitat simulation. The velocity used is the mean velocity found in the region of the cell defined between the surface of the water column and the depth specified in the **Cell** field in the right-hand table in the **Velocity Replacement Options** tab.

Habitat Calculations Conditioned on Adjacent Velocities

In some situations, fish habitat is determined not only by hydraulic parameters at the fish’s location, but also by velocities near the fish. The adjacent velocity calculations in HABTAE provide a mechanism for lateral scanning of velocity conditions that can be used to evaluate such phenomena as feeding stations. Each cell on a cross section is evaluated for its proximity to desired nearby velocity conditions. The habitat in each cell is included in the total WUA when the desired adjacent velocity conditions are met and excluded when those conditions are not met. The adjacent velocity calculations are controlled by a checkbox that determines if adjacent velocity calculations are to be performed and by combinations of the following menu items in the **Adjacent Velocity** tab. When adjacent velocity scanning is performed, the program starts at the center of the current cell and scans in both directions to find velocities that satisfy the adjacent velocity conditions.

Simulation of a feeding station would take the following form: Velocity HSC for the target species would indicate that habitat was most suitable in the low velocity range expected to be found behind a rock or other cover object. The adjacent velocity criteria would search for a significantly higher velocity within the sight distance of the species using the minimum adjacent velocity criteria (the **Use VLIM as Minimum** radio button in the **../Habtae/Adjacent Velocity** tab). For example, if the “feeding” velocity HSC for a species peaked at 0.5 fps, the VLIM value was 2 fps, the search distance was 3 ft and the minimum adjacent velocity criteria caused the program to search for velocities within 3 ft that were greater than 2 fps, the program would sum habitat for only cells that had low velocities within 3 ft of high velocities. The paragraphs below describe how to set up adjacent velocity calculation options.

Selecting the Form of the Adjacent Velocity Calculation

Figure 4-10 shows the computational options within the HABTAE program based on conditional velocity simulations. The options are discussed below.

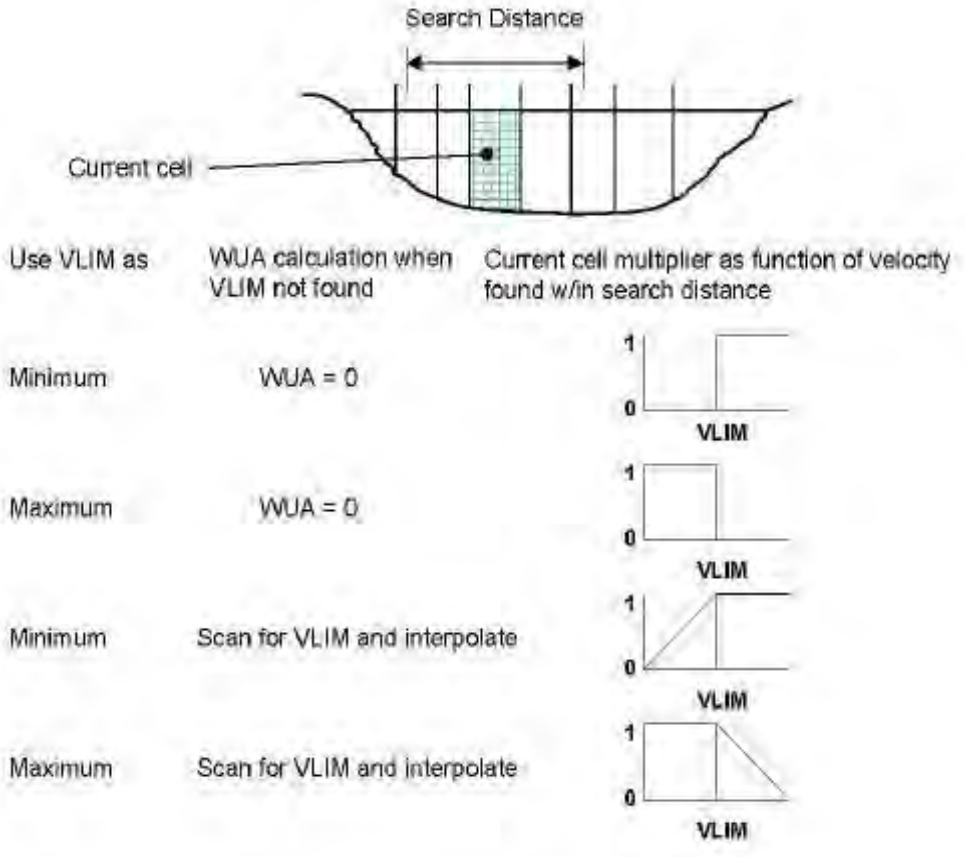
The **Use VLIM as** radio button selection allows the user to choose if a minimum or maximum adjacent velocity limit is to be scanned for when the **Scan for velocity in adjacent cells** box is checked. When **Minimum** is selected, the program scans adjacent cells within a user-defined distance (**DIST**) for velocity greater than a user-defined velocity value (**VLIM**). That is, the limiting velocity acts as a minimum. If a velocity greater than VLIM is found, WUA for the current cell is retained by multiplying original WUA * 1.0. When **Maximum** is selected, the program scans adjacent cells within the user-defined distance (**DIST**) for a velocity less than or equal to the user-defined velocity (**VLIM**). If a velocity less than VLIM is found, WUA for the current cell is retained by multiplying WUA * 1. 0.

Cells containing the desired minimum or maximum velocity may not be encountered when evaluating adjacent cells within the scan distance DIST. The **WUA calculation when VLIM not found** options provide for dealing with this situation by either setting the current cell WUA to 0 or by interpolating a scaled value of the WUA when no cell within DIST of the current cell satisfies the VLIM constraint. The **WUA = 0** option directs the program to set the WUA in the current cell to zero if the appropriate minimum or maximum velocity is not found in adjacent cells within the scan distance. The **Scan for initial Velocity (V0) and interpolate** option directs the program to scan adjacent cells a second time using a relaxed velocity limit, **V0**, and searches for the adjacent cell velocity that exceeds (or falls below) **V0** by the greatest amount. The program then interpolates a multiplier for the WUA for the current cell between 0.0 and 1.0 based on the velocity found by this process. The multiplier is calculated as:

$$Mult = \frac{Vfound - V0}{VLIM - V0} \quad (4\text{-}18)$$

Then the WUA for the current cell is calculated as the original WUA * Mult.

Figure 4-10. Illustration of adjacent velocity VLIM calculation options in HABTAE.



A caution on the different combinations of adjacent velocity options:

- If **Scan for velocity in adjacent cells** is checked, **Use VLIM as** is set to **Minimum**, the **WUA = 0** radio button is selected, and **V0** is greater than **VLIM**, it is illogical to supply a **V0**. These settings do not have the same result as **VLIM** nor **V0** being found in adjacent cells, hence, **V0** is ignored.

- Similarly, if **Scan for velocity in adjacent cells** is checked, **Use VLIM as** is set to **Maximum**, the **WUA = 0** radio button is selected, and **V0** is less than **VLIM**, it is illogical to supply a V0. These settings also result in neither **VLIM** nor **V0** being found in adjacent cells so **V0** is ignored.

Adjacent Velocity Calculation Example

While most of the habitat calculation processes are relatively straightforward, the adjacent velocity calculations merit an example to illustrate the process. Assume the adult life stage of a trout species can be assigned a search distance (**DIST**) of 10 ft. and a velocity threshold (**VLIM**) of 2.7 ft. per second. Further, assume the velocity threshold is treated as a lower bound (minimum) such that the purpose of the simulation is to find velocities that are above the minimum within the search distance from each cell. How is the habitat for a cell determined? Figure 4-11 shows the velocity distribution for cross section 0.0 of the sample study site at a discharge of 139 cfs. Consider the cell spanning from X = 48 feet to X = 50 feet. When VLIM is treated as a lower bound (minimum) the program searches out from each side of the cell over the 10 foot search range shown in the figure. If a velocity above the minimum threshold is found within the search range on either side of the cell, the habitat for that cell is included in the total habitat calculated for the study site. Here, a velocity slightly above the threshold is found 8 feet from the right side of the cell (at X = 58 feet) and a velocity of nearly 3 fps (feet per second) is found exactly 10 feet from the cell (at X = 60 feet). Thus, the habitat value for X = 48 feet is included in the conditional habitat total. None of the habitat to the left of X = 48 feet was included in the site total because no velocities satisfying the criteria of exceeding VLIM were found within 10 feet of those cells. What will be the last cell on the right to be included in the conditional habitat total?

Table 4-4 contains the cell velocities for cross section 0.0 at 139 cfs and the values found in the **Habitat Results** table of the **/Models/Habtae** window. Note that the first cell counting from the left bank (X = 0.0) where the adjacent velocity weight (**Ad Vel**) becomes 1 is at X = 48, and the last cell is at X = 82. Also note that the velocity 2.72 fps is the first velocity above the threshold value and is located 8 feet from the right side of cell 48
50.

This table illustrates the case where VLIM is used as a lower bound (minimum threshold) and the sought-after velocity is greater than VLIM. If VLIM was used as an upper bound (maximum threshold), which cells would be, included in the adjacent velocity conditioned habitat and which would not? That is, within the search distance, which cells are within 10 feet of velocities less than VLIM? Use Figure 4-11 and Table 4-4 to determine the answer.

Evaluating HABTAE Results

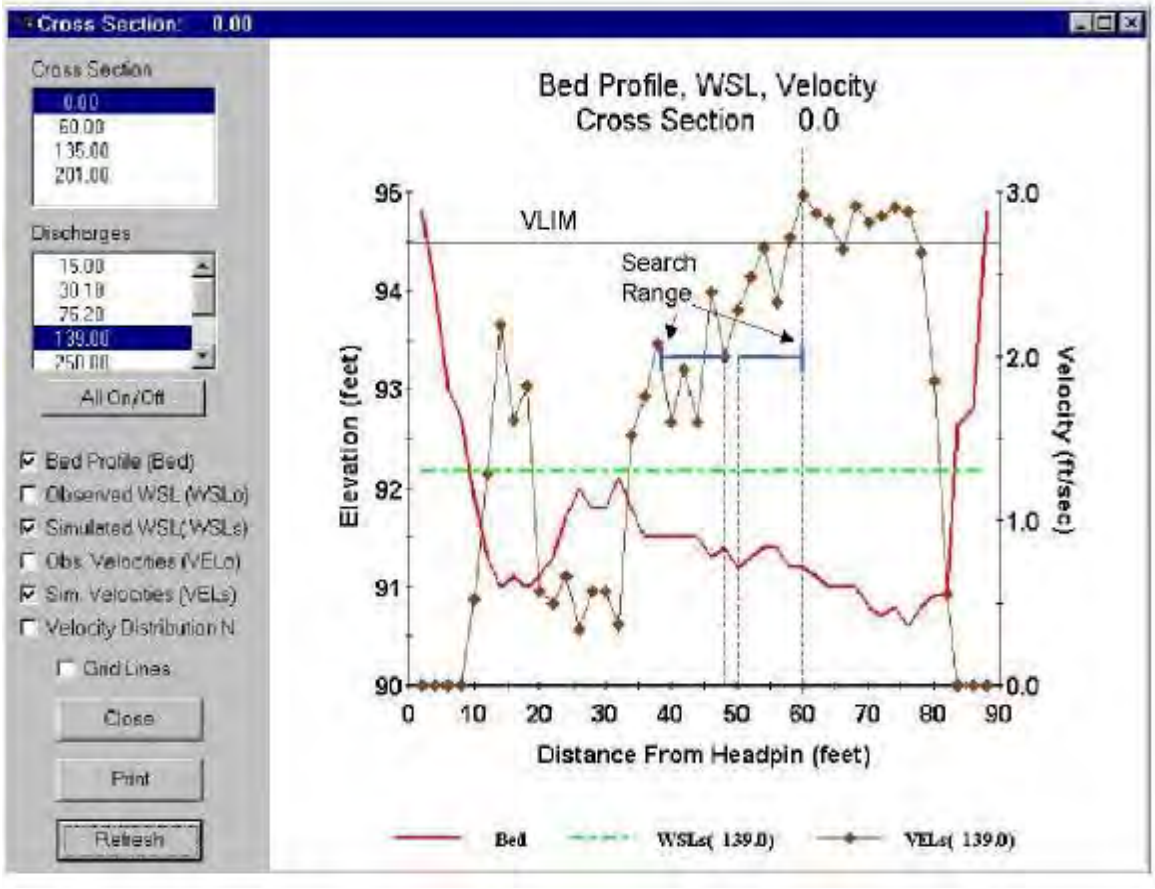
HABTAE program results are accessed on two tabs within the **/Models/HABTAE** window. The **../Habitat Results** tab displays the composite suitability for each wet cell and the **../Zhaqf Results** tab displays the WUA versus discharge relation produced by HABTAE.

In the **../Habitat Results** tab, the user may select the species/life stage, transect, and discharge to display. This allows evaluation of precisely which part of the stream is supplying habitat to each life stage of each species used in the analysis. The **Graph** button in this tab displays a plan view plot of the suitability for the study site. This plot has several interactive selections to display the life stage, discharge, form of habitat output or suitability displayed, etc. Users are encouraged to try all options in this plot to determine which selection best illustrates the habitat feature they wish to display or include in a report. Click the **Refresh** button after making any changes in the plot parameters. A **Print** button is supplied so color copies of the plots can be produced for inclusion in reports.

The **../Zhaqf Results** tab contains the results of the WUA calculation. A plot of WUA versus discharge may be viewed by clicking the **Graph** button. This plot also provides the ability to select the species and life stage(s) to be displayed.

The WUA versus discharge relations produced by HABTAE are the typical output from PHABSIM that are used in instream flow analyses. In many applications, users have ended the analysis at this stage. In an unfortunate number of cases, the discharge producing the highest habitat value has been selected as the recommended instream flow. Such a choice neglects to deal with the feasibility, effectiveness or frequency of occurrence of that flow value. Thus, MESC strongly recommends that users apply PHABSIM in the context of an IFIM study. It is particularly important that habitat time series analysis be performed using the WUA versus discharge relation as a starting point. See Bovee, et al., (1998) for a full development of the IFIM process and how to create and analyze habitat time series.

Figure 4-11. Illustration of adjacent velocity calculation.



Running HABTAE

The HABTAE program may be executed by selecting the desired calculation and output options in the various option tabs and clicking the **Run** button in the **Output Options** tab.

Lateral Migration Analysis using the HABTAM Program

The HABTAM program simulates conditions in which fish can migrate laterally within a cross section in order to make use of the available WUA when there is a change in discharge. Note with the revision of cell definition from DOS PHABSIM, the values of hydraulic characteristics (depth, velocity, and channel index) for each cell are the values of the velocity, depth, and channel index at the right vertical looking upstream.

The HABTAM program calculates WUA at each designated flow using the user supplied suitability curve functions for velocity, depth, and channel index and/or other hydraulic properties within each computational cell derived from the VELSIM program. HABTAM assumes that the available WUA at the user-designated starting flow is fully used and then, based on the user-designated maximum allowable migration distance for each life stage of each species, the program calculates how much of the available WUA at the user-designated ending flow can be used. Fish are permitted to migrate only laterally from cell to cell within a cross section.

Table 4-4. Cell-by-cell adjacent velocity calculations.

Windows		DOS	Difference	% difference
Cell bed elevation	91.65	91.65	0	0.00
Water surface elevation	92.456	92.47	0.014	0.02
Depth	0.806	0.82	0.014	1.71
Depth Suitability Index	0.0708	0.096	0.025	26.25
Combined Suitability Index	0.0644	0.087	0.023	26.25
Weighted Usable Area	8.698	11.79	3.096	26.25

Acknowledgements **i**

PREFACE **ii**

A Brief History of PHABSIM

Use of this Document

Changes Between PHABSIM Version 2 and PHABSIM for Windows

Conventions Used in this Document

Chapter 1, Introduction to the Physical Habitat Simulation System **1**

Objectives

Associated Laboratory Exercises

An Overview of IFIM

The Purpose of PHABSIM

The Structure of PHABSIM

Application of PHABSIM

Scoping

Selection of Target Species and Suitability Curves

Selection of Target Species

Types of Suitability Curves

Transferability of Suitability Curves

Segmenting the Study Area and Study Site Location

Critical Reach

Mesohabitat Study Site Selection

Cross Section Selection and Field Data Collection

Cross Section Selection

Field Data Collection

Hydraulic Modeling

Water Surface Elevation Modeling

Velocity Modeling

Habitat Modeling

The Average Parameter Model

Distributed Parameter Models

Effective Habitat Analysis in PHABSIM

Interpreting PHABSIM and Completing the IFIM Process

Use of the PHABSIM for Windows Menu System

PHABSIM for Windows File Structure

Analysis Limits in PHABSIM for Windows

Summary of Chapter 1

Chapter 2, Hydraulic Modeling in PHABSIM **25**

Objectives

Laboratories

Introduction

Terms and Definitions of Open-Channel Flow

The user designates a starting flow, ending flow, and a maximum allowable migration distance for each life stage of each species in the right-hand table of the **/Models/HABTAM/Options** tab. The program looks only at the user-designated starting and ending flows for the migration calculations, and processes each cross section as a separate entity, that is, fish cannot migrate from one cross section to another. Assuming that the stream is saturated with fish at the starting flow (all WUA is occupied) and that the flow is then changed to the ending flow, the program permits the fish to migrate in either direction within the cross section up to the maximum allowable migration distance for the particular life stage. The program then calculates how much (the maximum amount) of the WUA available at the ending flow can be used by the fish presently existing in the stream. The results will show that either all the available WUA at the ending flow can be used, or there is an excess of WUA available at the ending flow, which cannot be used because there are not enough fish to use it.

The following assumptions are made for the migration calculations:

1. Fish migration is assumed to begin at the cell boundaries. Thus, when a fish is given a maximum allowable migration distance greater than zero, it is automatically permitted to migrate to adjacent cells. Any distance it might have to travel within its cell of origin is ignored.

2. In situations where the maximum allowable migration distance places a fish exactly on the border of two cells the fish is NOT permitted access to the further cell.

3. Since HABTAM calculates a cell width for each new flow it processes, the width calculated at the flow designated as the ending flow is used as the cell width for the migration calculation. Cell widths change with wetting and drying of the extreme edge cells.

4. When a portion of a cell becomes dry at the user-designated ending flow, the fish are not permitted to migrate beyond the dry boundary point.

5. When a given life stage does not or cannot migrate at all, a value of 0.0 should be entered as the maximum allowable migration distance for that life stage. When this occurs, the program will select for the WUA with migration, the minimum of the WUA at the starting flow, and WUA at the ending flow.

Input to the HABTAM program is through the **/Models/HABTAM/Options, ../Computations, ../Migration,** and **../Velocity Calculations** tabs. The program uses these previously entered data and simulation results: (1) HSC curves of aquatic species or recreational activities created in **/Edit/Suitability**, (2) hydraulic simulation results from the WSL and velocity modeling stages, and (3) study site layout (weighting) values from **/Edit/Cross Sections/Cross Section Data**.

Setting HABTAM Options

The HABTAM program provides the user with a wide array of computational and output listing capabilities. Control of computations and output listings is accomplished through several check boxes and data entry fields in the various tabs in **/Models/HABTAM** as described below.

HABTAM options are summarized in Table 4-5.

Table 4-5. Options in the HABTAM program. Option description Action when set to indicated value, notes

Options tab **Write Migration Calculation Details** (check box)(IOC 1)	results. Recommend leaving unchecked for most runs.
Options tab **Write Cross Section Data** (check box)(IOC 2)	Writes cross section data (from **/Edit/Cross Sections/Cross Section Data**) to ZO documenting PHABSIM runs. Recommend leaving unchecked for most applicatio
Options tab **Write Flow Related Data** (check box) (IOC 3)	Writes flow data for each cross section evaluated at each discharge to ZOUT. This for each cell that is wet. This recapitulates the VELSIM output. Recommend leavi using VELSIM output table for documentation of most applications.
Options tab **Write Computational Details** (check box) (IOC 4)	Writes all the computational details for the weighted usable area calculations to Z leaving unchecked except when HABTAM gives unexpected results and further e Output is voluminous, so limiting the number of life stages is recommended when
Options tab **Write Criteria Curve Coordinates** (check box) (IOC 8)	Writes the coordinates of the HSC curves used in HABTAM analysis to ZOUT. R this box.
Options tab **Selected Discharges** (input table with check boxes)	This table of discharges used in HABTAM calculations has check boxes to select Typically, all discharges would be selected. However, for some analyses only a fe needed.
Options tab **Flows for Migration Calculations** (input table)	This table allows the user to set up to 25 pairs of starting and ending discharges to calculations. The discharges used may be the same as those in the **Selected Disch** copy from Selected Discharges and paste to **Flows for Migration Calculations** to values are used.
Computations tab **Use Channel Index Values of Zero in WUA Calculations** (check box) (IOC 7) Writes details of migration calculations to ZOUT. Use when HABTAM produces unexpected	This defines how channel index values of zero (0) are used. If not checked, channe are converted to 1.0 which effectively removes channel index from the calculation 0.0 CI. When checked, a channel index value of zero is used in the calculation of WU Recommend checking.

Table 4-5. Continued. Option description Action when set to indicated value, notes

Computations tab **Describe Reach Bends** (check box) (IOC 12)	management alternatives.
Computations tab **Calculate Habitat as % of Total Area** (check box) (IOC 10)	Controls how the calculation of WUA will be made. **Standard calculation** -- Cor (CF) = f(v)*g(d)*h(ci), where f(v)*g(d)*h(ci)) = variable preferences for velocity, depth and channel index. **Geometric Mean** – C **Lowest Limiting Parameter** – CF = MIN (f(v), g(d), h(ci)).
Computations tab **Habitat Area Calculation** (radio buttons) (IOC 9)	Each HSC identifying number is displayed in the left column of this table. Enter t distance for the species/life stage represented by each HSC.
Migration tab **Enter Migration Distance for Each Curve ID** (input table)	Enter an HSC curve number and additional migration distance for that species/life species you wish to evaluate different migration capabilities. This option is useful than one hypothesis about the species' migration capability.
Migration tab **Enter up to 25 Additional Migration Distances** (input table)	
Velocity Calculations tab **Cell Velocity Options** (radio buttons) (IOC 14)	These options act the same as the **Vel Calc** options in HABTAE. • **Mean column velocity** - Uses standard mean column velocity in habitat c • **Nose velocity** – Uses the 1/7th power law equation. User supplies nose de below. Only the needed items will be activated when these options are selected. • **Nose velocity user defined coefficients** – empirical power law equation a coefficients. User supplies the nose depth (D_{nose}) and the calibration parameters a a entered in the input table below. • **Nose velocity logarithmic velocity distribution** - logarithmic velocity di nose depth and the D_{65} of the bed material are supplied by the user in the input tab
	These options represent the same choices for scanning as for the **Cell Ve locity O**
Velocity Calculations tab **Scan Adjacent Cells for** (radio buttons) (IOC 6) Allows the length to vary from cell to cell (Variable Cell Length) across the stream (i.e., a bend). Default is to use cells as rectangles in plan view. When checked, program uses cells as trapezoids based on the length multiplied by left and right bank weights. To use this option, left and right bank weighting factors must be entered in **/Edit/Cross Sections** .	
Calculates habitat as a % of total area. This output is useful in comparative analyses where different flow pairs are compared for relative impacts of different hydropower flow	

Evaluating HABTAM Results

The HABTAM program performs a standard WUA calculation to obtain the cell-by-cell habitat values prior to evaluating migration. Thus, there are three tabs for results. As with the HABTAE model, the **../HABTAM/ Habitat** Results and the **../HABTAM/ZHAQF Results** tabs contain cell-by-cell composite suitability and WUA versus discharge values, respectively. The result tables and graphical displays on these tabs act the same as those for HABTAE.

The **../HABTAM/Migration Results** tab is unique to HABTAM. Here the WUA resulting from the constraints of the migration calculations is displayed as an output table and a rotatable 3-dimensional surface plot of the migration results is displayed. Simply stated, the highest point on the plot shows the discharge pair that produces the highest habitat value and the lower valued combinations are easily visualized. For many situations, large flow changes will produce relatively poor migration habitat values and small flow changes will produce relatively good migration habitat. That is, small changes in flow will produce migration habitat values that are near the WUA values obtained for the lower of the two discharges.

When comparing fluctuating flow regimes such as hydropeaking management alternatives, the analyst must take care to recognize that not only the magnitude of the flow change but the frequency with which it occurs, will be a factor in determining which alternative may have the most impact on the aquatic organisms downstream of the dam.

Running HABTAM

Once all options and starting and ending discharges have been entered for the items covered in Table 4-4, the HABTAM program is run by clicking the **RUN** button on the **../Options** tab. If a minimum set of options have not been selected, the program prompts with warning messages.

Effective Habitat Analysis using the HABEF Program

The HABEF program calculates physical habitat considering conditions at two stream flows and/or for two life stages or species. The program uses habitat results from either HABTAE or HABTAM as the source of species/life stage habitat information for each cell. The basic equation used in HABTAE for weighted usable area in cell i (wua_i), is given by the equation:

$$Wua_i = A_i * CS_i \quad (4\text{-}19)$$

where: wua_i = weighted usable area of computational cell i
CS_i = combined suitability of computational cell i
A_i = area of computational cell i

HABEF uses A_i and CS_i for each computational cell used in the physical habitat simulation performed in HABTAE or HABTAM. The WUA used in HABEF is derived from the normal calculation used in the principal habitat programs and is defined by the equation:

$$WUA = \sum_{i=1}^{ncell} CS_i A_i \quad (4\text{-}20)$$

The usable area (UA) can also be computed and is derived from:

$$UA = \sum_{i=1}^{ncell} CSi\ Ai \qquad (4\text{-}21)$$

$$\text{if } CS \leq 0.001 \text{ then } CS = 1.0$$

ii

$$\text{if } CS < 0.001 \text{ then } CS = 0.0$$

ii

The user can select either of these habitat definitions for the computation of effective habitat during execution of the program by specifying the appropriate options within the **/Models/HABEF/Options** tab as explained below.

In addition to these basic calculations, the HABEF program can be used to conduct a number of analyses in which comparisons of available habitat on a spatial basis can be examined between species or life stages pairs.

The basic computational options for the HABEF program are listed below with a description of each option provided in the **/Models/HABEF/Options** tab.

Union Of Life Stage 1 With Life Stage 2 -Use two species/life stage HSC Competition Analysis -Use two species/life stage HSC Stream Flow Variation Analysis (Minimum WUA) -Use one species/life stage HSC Stream Flow Variation Analysis (Maximum WUA) -Use one species/life stage HSC Effective Spawning Analysis -Use two species/life stage HSC Stranding Index Analysis -Use one species/life stage HSC

Union Analysis

The first option in HABEF is the Boolean algebraic union of two life stages or species. The WUA results from HABTAE or HABTAM are compared on a cell-by-cell basis for both selected life stages (species/life stage) at all flows in the data set. This may be the union of two life stages of the same species (i.e., fry and juveniles) or it may be the union of two species/life stages (i.e., rainbow and brown trout adults). A union analysis will usually result in a WUA value for the study site for each given stream flow that is greater than the higher of the two independent variables, but less than the sum of the two.

Competition Analysis

Of considerable interest in habitat analyses is the competition of two life stages or two species for the same space. An analysis of habitat competition can be done using Option 3 in HABEF. Most likely, two species will compete for some of the habitat; yet, in other places have the habitat all to themselves (assuming two species are in the stream). In the areas (cells) where direct competition occurs, there are cells where one species/life stage (1) is better suited than the other life stage (2); and other cells where the converse is true. Option 3 gives information on both of these possibilities. It should be noted that this analysis does not explicitly take into account the behavior of either species.

When this option is selected, HABEF first calculates habitat for species/life stage “1” in cells where habitat for the species/life stage “2” is zero. This is combined with the amount of habitat occurring in computational cells where combined suitability is greater than 0.0 for both species but where species “1” has a higher combined suitability value than species “2”. Thus the competition option describes the total WUA for cells where species “1” dominates. The program reports this in the column labeled **WUA 1>2 in 1&2**. The inverse calculation is simultaneously performed for species “2”.

In interpreting the results, situations where one species clearly has superior habitat conditions to the other (for example, if **WUA 1>2 in 1&2** is two or more times greater than **WUA 2 in 1&2**) it is likely that behavior alone would not allow the species with the less favorable habitat to out-compete the species with the more favorable habitat. When the habitat areas derived in the competition analysis do not significantly favor one species over the other, another form of analysis outside of PHABSIM may be needed to determine the effects of competition in the study reach.

To run this option, the two species to be evaluated are selected in the two input cells on the **/Models/ HABEF/Options** tab and the **Competition Analysis** radio button is set, followed by clicking the **Run** button. Changing to the **../Results** tab, the user will find that in addition to the standard WUA result (sum of cell area times composite suitability), the following WUA sums are accumulated under the indicated column heading.

WUA (1 and 2) This is a Boolean intersection of all cells where both species have WUA>0. This column contains the sum of the surface area of all cells that have both species with non-zero habitat. That is, as long as both species have more than 0.001 units of habitat, the cell is counted in this sum. This value is an indicator of the total surface area of the stream where competition may occur.

WUA (1 = 2) Intersection: This value is a sum of the WUA for only those cells where the WUA values for both species are equal . This column commonly contains zeros.

WUA (1 in 1&2) This is the sum of cell WUA values for species 1 for all cells where both species 1 and species 2 have habitat values greater than 0.001. (e.g., this is the Species 1 habitat in potential competition areas.)

WUA (2 in 1&2) This column contains the sum of cell WUA for species 2 for all cells where habitat for both species 1 and 2 is grater than 0. This is the species 2 habitat in potential competition areas.

WUA (1>2 in 1&2) This is the sum of WUA for species 1 where species 1 WUA is greater than species 2 WUA in potential competition cells.

WUA (2>1 in 1&2) This sum is the opposite of the above.

Competition analysis is used to compare the results from a WUA analysis for two species at the same stream flows or for the same species/life stage at all combinations of flows supplied in the **Edit/Discharges** menu. Scroll the results table to display all columns. As with other PHABSIM for Windows results, these may be pasted into a spreadsheet.

Stream Flow Variation Analysis

The purpose of the stream flow variation analysis is to look at available habitat at two flows with both sets of flows varying over a range of discharge. Recall that HABEF output contains all combinations of flows contained in the discharge list. The streamflow variation analysis option allows the analyst to evaluate which variation in flow produces the least or most usable area and Weighted Usable Area. To run this option, the same species/life stage (same HSC curve number) is entered in both input cells on the **/Models/ HABEF/ Options** tab and the **Streamflow Variation Analysis** radio button is set. The **../Results** tab contains entries for the sum of usable area, WUA and minimum or maximum WUA as noted below.

Maximum and minimum values for specific discharges can be obtained from the diagonal of the streamflow variation results matrices as the diagonal represents a no-variation case. The minimum and maximum values can be used to compare the state under one condition (flow, species, etc.) for a specific cell to the state with a second condition in the same cell. The **Streamflow Variation Analysis (minimum WUA)** option determines the minimum WUA value compared between each set of discharges for each computational cell, and the **maximum WUA** option does the converse. The summed results represent the aggregate results of those cell-by-cell comparisons.

Effective Spawning Analysis

In effective spawning analysis, an area available for spawning habitat is only included as habitat if suitable conditions continue to exist over the period of incubation. Thus, it may be useful to run this analysis over the range of discharges that are likely to exist during the incubation period. If the lowest discharge that is likely to be encountered is significantly lower than the discharge at which spawning takes place, then a large amount of streambed that was wet at the time of spawning may become dry or freeze during incubation. Such an event may cause the spawned eggs to die.

The results contain all combinations of flows set in the discharge list. The user may wish to select a smaller range when reporting effective spawning results.

When **Effective Spawning Analysis** is selected, the WUA within a computational cell is determined from the relative amount of WUA in the computational cell at the second discharge. If the WUA in the computational cell at the second discharge is greater than the WUA in the computational cell at the first discharge, then the WUA is set to the WUA within the computational cell at the first discharge. If the WUA at the second discharge for the computational cell is 0.0, then the WUA is set to 0.0.

Stranding Index Analysis

When **Stranding Index Analysis** is selected, the program computes an index of the habitat isolated when the flow drops. Basically, the available WUA in a computational cell is determined in the same manner as for effective spawning above. However, the stranding index is then computed according to the equation:

$$\text{Stranding Index} = \left(1.0 - \frac{\sum WUA_{effective}}{\sum WUA_{q1}}\right) * 100.0 \quad (4\text{-}22)$$

$WUA_{effective}$ = the effective WUA described under Option 7 summed over all computational elements WUA_{q1} = the WUA summed over all computational elements at first discharge

When performing stranding index analysis, users are cautioned to carefully check the output and evaluate only those conditions where the flow is dropping.

Summary of Chapter 4

This chapter presented the wide variety of habitat simulation approaches available in the PHABSIM for Windows software. Using commercial spreadsheet software to aggregate variables in ways that are not explicitly handled in PHABSIM can further enhance some analyses. For example, conditions with and without cover can be aggregated by adding the WUA values for a species/life stage with and without cover to obtain a final habitat – discharge relationship that encompasses both conditions. PHABSIM users are encouraged to adapt the analyses they perform to the problem at hand and not to be limited by the specific processes coded in this software. The next chapter provides some ideas for using PHABSIM in various situations. The ideas and cautions in it are intended as thought provoking examples that can be built upon when using PHABSIM as part of an IFIM-based study.

Chapter 5. Interpretation of PHABSIM within IFIM

Objectives

The objectives of this chapter are to present several approaches to interpreting and using the output from PHABSIM within the context of the Instream Flow Incremental Methodology (IFIM).

Laboratories

No specific laboratory exercises are provided for this material.

Introduction

This chapter presents examples of particular situations and analytical approaches that may occur or be applied within an application of PHABSIM. During the analysis scoping phase of IFIM (see Figure 1-1), the stakeholders involved in an instream flow issue are expected to reach consensus on the type of analysis to be used for the problem, the technology to be applied, and the approaches to interpreting the analytical results. As noted in Chapter 1, an IFIM application may be entirely successful without use of PHABSIM if the issue can best be decided based on criteria other than physical microhabitat. MESC strongly recommends that consensus on these issues (type of analysis, scale of the problem, technology to be used, and interpretation of results) be reached prior to investing time and resources in the study. Doing so has been found to greatly reduce after-the-fact disagreements on methods and interpretations, allowing decision makers to focus on the issue of allocating instream flows.

Once consensus has been reached to use PHABSIM, one of the most challenging aspects in its application is the proper use and interpretation of PHABSIM model results within the IFIM framework. It is important to stress that the basic WUA versus discharge relationships obtained from the habitat modeling process in PHABSIM represent only instantaneous variation of physical habitat with flow and should not be interpreted in the absence of one or more alternative flow regimes for a particular study site. This is why a study employing PHABSIM is not considered to be an IFIM study unless flow and habitat time series including seasonal habitat needs for all life stages are analyzed.

Picking the Peak of WUA Curves

One potential error PHABSIM users commonly make is a “blind” evaluation of the WUA versus discharge function where the instream flow is selected to be the discharge at which the peak (or maximum) WUA value occurs. This can create a number of problems as illustrated by the following example.

In a study, an investigator completed a PHABSIM analysis for a number of target species and life stages. After reviewing the component habitat versus discharge relationships, the investigator selected the most sensitive species and life stage (i.e., habitat in shortest supply) for each month and then recommended an instream flow regime by selecting the flows at the peak of the WUA curve for each month of the year. This seemed a prudent and defensible approach at the time. However, it was found out some time later when the discharge records for the gauge at the study site were examined on a monthly basis, that many of the selected monthly instream flows corresponded to discharges with monthly exceedance values in the ranges between 10–15%. That is, flows greater than or equal to the recommended flows occurred only 10–15% of the time. In essence, the investigator was claiming that near flood flows were necessary for the recommended instream flows in most months. Unfortunately for this particular investigator, no rational biological justification could be offered in defense of the selected flow regime.

This example is provided to highlight the point that failure to evaluate the feasible flow regime(s) at the site during the evaluation of instream flows can lead to problems in negotiating instream flows and is highly discouraged. There are situations, in which flows greater or lesser than the flow associated with the peak of the WUA curve may make rational sense and perhaps the most critical element of the interpretation process is the rational basis or framework for evaluation of model outputs. IFIM emphasizes creation and analysis of habitat time series as a key component in this framework.

For example, the investigator above could examine the monthly flow duration curves and consider where the median monthly flow (i.e., 50% exceedance) or some other exceedance level lies in relationship to the flow at which optimal habitat conditions exist for a target species and life stage. If the median flow was selected for consideration and is higher than the optimal flow, the investigator may consider allowing some level of abstraction down to the flow at which the optimum habitat occurs. If the median monthly flow falls below the flow at which the optimal habitat occurs, then the investigator can examine the magnitude of habitat or percentage reduction and decide if further reductions would potentially represent any level of adverse conditions. In many cases, this type of approach which requires the investigator to consider the consequences of a particular flow regime in light of the amount and or quality of habitat for one or more exceedance ranges is encouraged and permits the consideration of known life history needs that are not directly reflected in the results of the habitat versus flow relationship derived from PHABSIM.

Use of a Most Sensitive Species and Life Stage

In many instream flow studies, a number of species and life stages are considered to be important for evaluation within PHABSIM at an early stage of the project (i.e., scoping). For example, a stream may contain salmon, brown trout, arctic grayling, and dace. After considerable effort in the selection and application of each of these species and associated life stage suitability index curves for representative life stages, the analyst may obtain a family of WUA versus discharge functions as illustrated in Figure 5-1. For some time periods of the year many, if not most, of these species and life stages may be present in the system. Therefore, the investigator is faced with a difficult task of integrating all these curves in a coherent manner to establish a recommended flow regime.

One approach to integrating multiple WUA relationships is to base the instream flow assessment on the single species and life stage that is most sensitive to changes in flow during a critical period. Alternatively, a particular species and life stage may be considered the most important from a management perspective, such as spawning brown trout in a system where the management goal is a self sustaining wild brown trout population. Flows can then be selected based on this single species and life stage while attempting to minimize potential adverse reductions to other species and life stages. In some situations, a reduction in the primary target species and life stage habitat quantity and quality can be made such that other species and life stages can still retain what are considered adequate levels of habitat availability. This approach is sometimes called a “keystone” or “cornerstone” species analysis.

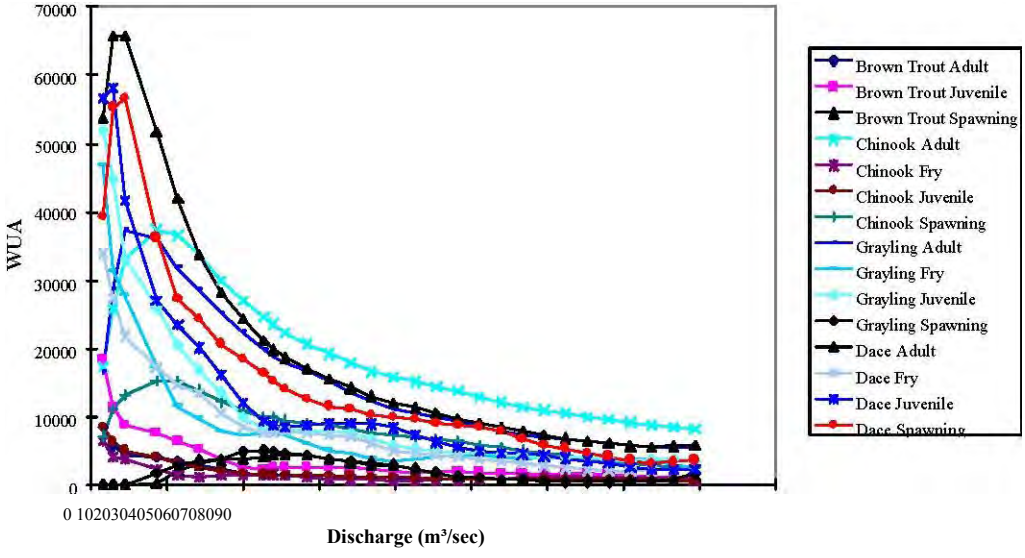


Figure 5-1. Example of WUA vs. discharge relation for a suite of species.

Another approach to the multiple species problem is to apply a two-tiered prioritization process that includes life history stage first, and then species priority. This approach, suggested by Reiser (2001), begins by establishing a list of target species, agreeing on their management priority, and obtaining consensus on the most important life stages of those species at different times of the year. For example spawning habitat may be considered more important than habitat for the adult or juvenile life stages. Then for any given month, if spawning occurs for any of the species, the spawning life stage is given first consideration in the flow analysis. If spawning does not occur for any of the species during that month, go to the next priority life stage for the 1st, 2nd, etc. species and base the flow analysis for that month on that next selected species/life stage. This approach avoids basing the conclusions of the entire analysis on a single "keystone" species. As with all analyses where priorities are established, consensus is vital to avoid conflict after the analysis is complete.

Some applications are not readily amenable to the use of the most sensitive species or critical species and life stage (i.e., they all are the focus of management objectives). In this instance, a post-analysis guilding approach is sometimes possible.

Post-analysis Guilding

A post-analysis guilding approach can take on several forms depending on the context of the project and management objectives. One approach that has been used involves the construction of a community level habitat versus flow relationship. A community habitat curve can be constructed using the original habitat versus discharge relationships or by using a set of normalized habitat versus discharge functions. If normalized habitat functions are to be used, the first step is to re-scale each individual species and life stage WUA versus discharge curve to the maximum value of WUA for each species and life stage (i.e., each curve is re-scaled as a percent of the maximum or optimal habitat) as illustrated in Figure 5-2. The investigator can then combine these curves (or the original unscaled curves) using a weighted arithmetic average to produce a single curve as illustrated in Figure 5-3. The relative weighting factors for a specific critical period for each species and life stage can be selected to represent the management objectives for the system and should be defined during the project-scoping portion of an IFIM analysis.

120

100

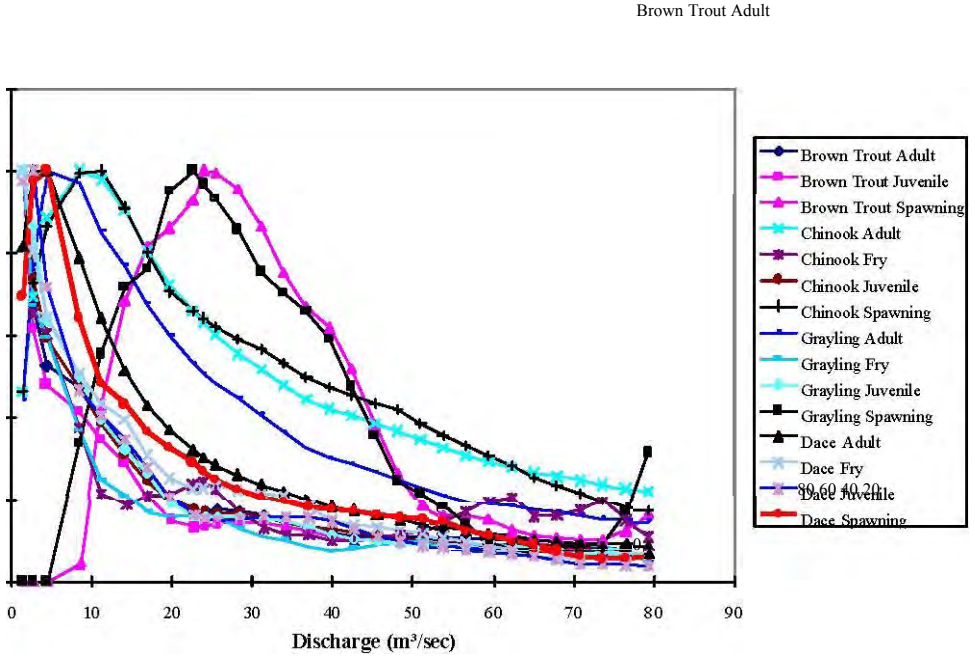


Figure 5-2. Normalized multiple-species WUA relationships.

80

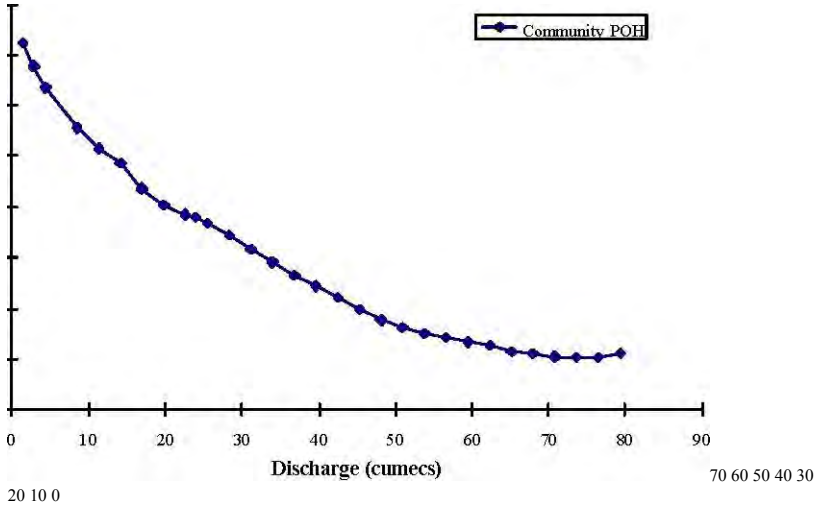


Figure 5-3. Combined community WUA versus discharge relationship.

70 60 50 40 30

20 10 0

In the analysis scoping stage of IFIM, the stakeholders may choose to develop a community curve for specific periods of the year based on the unique combinations of species and life stages identified by the species periodicity table as discussed previously. It is also possible that the relative weighting factors used to construct the community curves may change between time periods to reflect the relative importance or sensitivity of specific species and life stages during a particular time period. For example, an endangered species may receive a weight of 2.0, while all other species and life stages may receive a weight of 1.0, or spawning may be weighted more than fry during the spawning period. The community curves can be used in subsequent evaluations such as time series and habitat duration analyses. It is strongly advised that individual species and life stage habitat relationships be checked to ensure flow regimes selected provide consistency in the results.

Alternatively, parties to an IFIM application may choose to simplify multiple habitat curves to eliminate very similar or "redundant" WUA versus discharge relationships. In this approach, curves that have the same basic magnitude and functional relationship can either be eliminated or averaged to generate a single curve which in essence represents the guild of species and life stages with similar fundamental relationships between habitat and flow. In some instances, this combining or guilding can be accomplished using normalized habitat functions since many applications focus on relative changes in habitat and not necessarily on the actual magnitude of the habitat change. Similarity in the functional relationships between habitat and discharge for different species and life stages in fact is not uncommon and in a sense is to be expected. For example, fry and juvenile curves for many salmonids actually exhibit very similar habitat requirements, which follow known obligate habitat use for these early life stages. It is also not uncommon for different life stages for different species to use similar habitats. This is reflected in similar HSC curves and thus, similar habitat versus discharge relationships.

The final set of guilded habitat functions can then be used to construct a community level curve as described above, or the most sensitive guild within a critical period may be selected for consideration in further analyses. As mentioned previously, in all cases, habitat-discharge relationships must be evaluated using analysis of habitat time series for feasibility, effectiveness, cost, and risk of failure. The reader is referred to Bovee, et al., (1998) for further development of habitat time series analysis.

Consideration of Quantity Versus Quality

As discussed in Chapter 4, the basic habitat versus discharge relationship represents an aggregation of the component cell WUA values across all cells at a specific discharge for a given species and life stage. Therefore, the results presented in a habitat-discharge relationship such as Figure 5-1 cannot be directly used to ascertain the difference between a total magnitude of WUA which is represented by all cells having a low suitability, versus a WUA result where a few cells contain high suitability values. For example, a stream may have a total surface area of 100 square feet at a given discharge that is composed of 10 equal area cells (i.e., each cell is 10 square feet). A computed total WUA could be derived from all 10 cells each having a combined suitability of 0.1, giving $(0.1)(10\ ft^2)(10\ cells)=10\ ft^2$ of WUA. Alternatively, nine of the habitat cells could have a combined suitability of 0.0, while the one remaining habitat cell could have a combined suitability of 1.0 giving $[(0.0)(10\ ft^2)\ (9\ cells) + (1.0)(10\ ft^2)(1\ cell)] = 10\ ft^2$ of WUA. Fortunately, PHABSIM includes options to exclude poor quality habitat (see **Minimum Effective Composite Suitability Factor (CFMIN)** in Chapter 4). This is illustrated in Figure 5-4 for composite suitability greater than 0.75 for adult brown trout. As can be seen, the peak of the total WUA curve does not always correspond with the peak of highly suitable habitat conditions. The investigator should carefully consider the biological implications of selecting flows that maximize total WUA versus the consideration of an alternative flow that may maximize the area associated with high quality habitat. It should be remembered that all the techniques described above could be used with high quality habitat versus flow functions in a manner equivalent to using the total WUA curves.

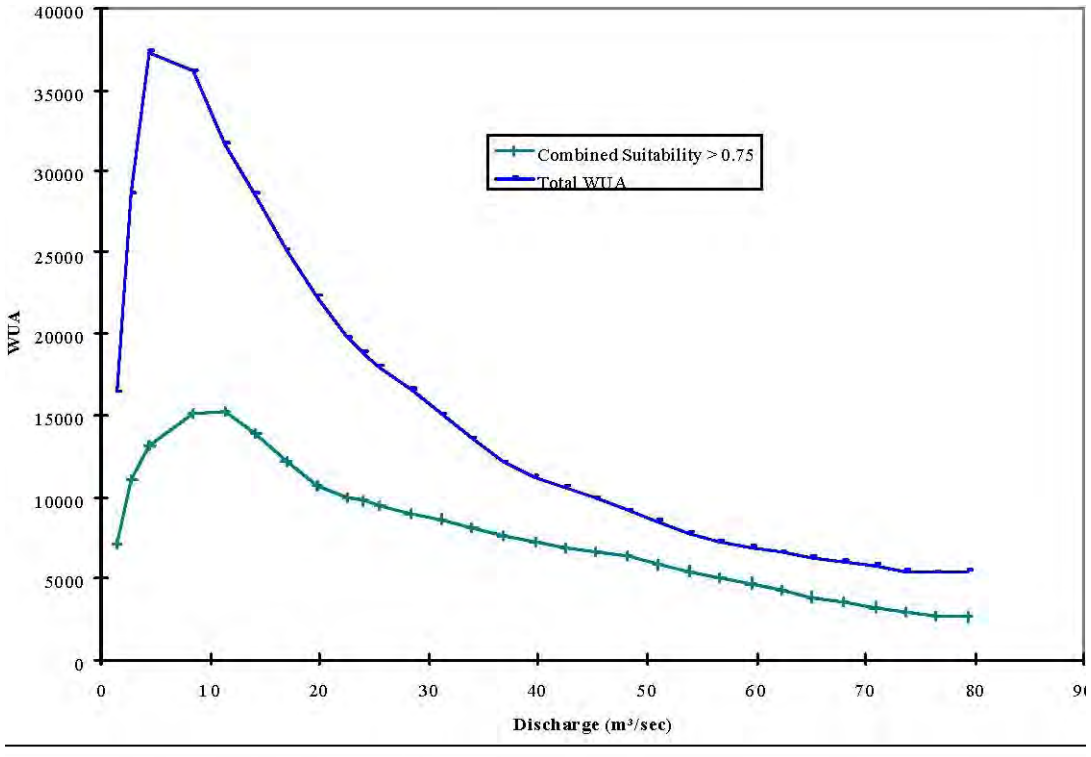


Figure 5-4. WUA vs. discharge for cells with composite suitability > 0.75.

0
10203040506070809 0 **Discharge (m³/sec)**

Evaluation of Mesohabitat-specific Conditions

HABTAE can be used to generate output on a cross section by cross section basis, or for a group of cross sections by selecting pools only versus selecting riffle habitats. Using this sub-sampling approach, the investigator can develop habitat versus flow functions for specific species and life stages on a mesohabitat basis as illustrated in Figure 5-5. This type of analysis can focus the investigation on species and life stage specific sensitivity to particular habitat types that may be important during critical periods of the year. For example, an analysis may focus on riffle type habitats during the spawning season in lieu of other less sensitive life stages and mesohabitats using this approach. This type of analysis can also facilitate the aggregation of mesohabitat versus flow functions into composite WUA versus flow functions when the proportion of habitat types may change as a function of discharge, or where a gross evaluation of habitat improvement works is desired. Such aggregation can easily be accomplished by exporting PHABSIM for Windows results to a spreadsheet.

Evaluation of Habitat Suitability Criteria

Habitat suitability criteria (HSC) have been an area of considerable controversy in PHABSIM applications since its inception. Recognizing that site-specific HSC may best reflect the habitat utilization of aquatic species, MESC has recommended that either local HSC be developed for PHABSIM applications or that the stakeholders agree on the HSC to be used as part of the analysis scoping process in IFIM.

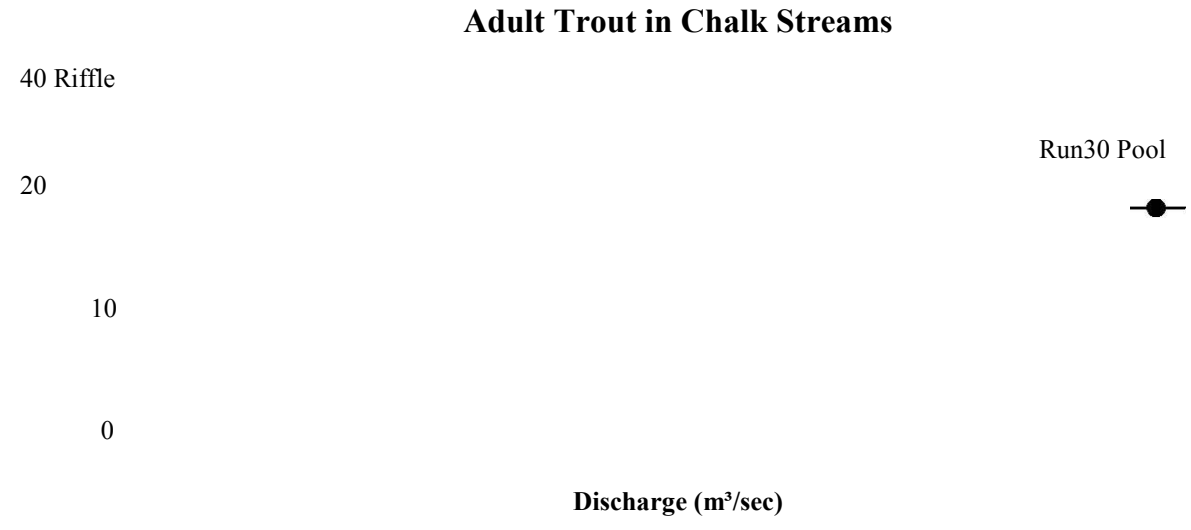


Figure 5-5. Habitat-discharge relationships for mesohabitat types.

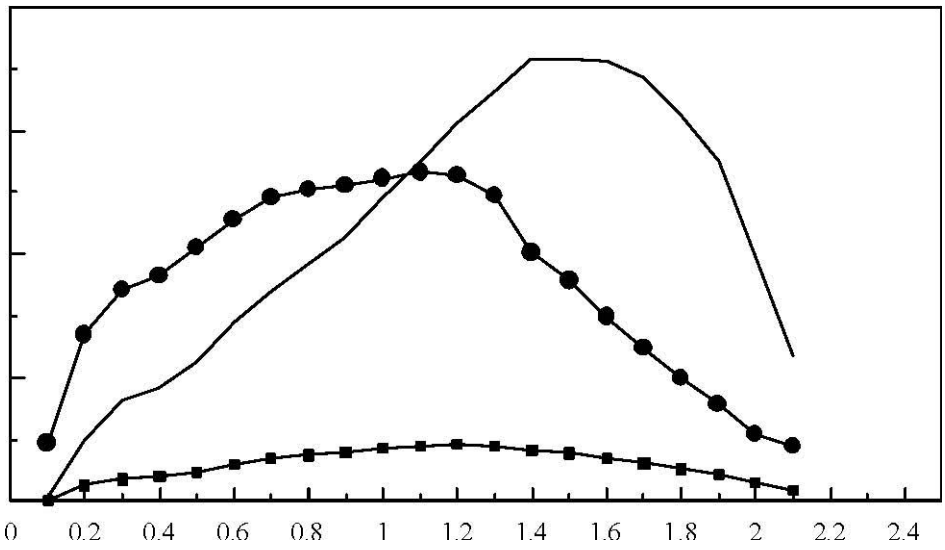
HSC adopted from the literature or other studies may be evaluated for applicability to the study at hand as shown in this example. The investigator may select a cross section at a specific location in the stream where a known habitat activity, such as spawning, was observed. In this instance, the investigator can examine the spatial distribution of combined suitability values across the cross section to determine if the suitability curves correctly demonstrate suitable habitat conditions at the location of known spawning redds as illustrated in Figure 5-6. Prediction of low combined suitability at the known redd location should cause some concern. A more detailed evaluation of the hydraulic simulations (primarily velocity or channel index) in conjunction with a re-assessment of the suitability curves should be undertaken to ensure the habitat conditions are being properly represented.

Decomposition of Single Parameter Suitability

In some streams, one or another of the physical habitat parameters may be the source of greatest change in habitat magnitude with a change in flow. An investigator may find that determining which specific suitability factor is contributing to the estimate of total WUA is important. This can be accomplished, for example, by modifying the suitability curves such that only a single parameter such as velocity is retained, while both depth and channel index are set to a 1.0 for all values. This type of analysis can reveal whether depth, velocity or channel index is the controlling factor over specific ranges of discharges as illustrated in Figure 5-7. Note the relative insensitivity to substrate, but great sensitivity to velocity in this example. In addition, when combined with an analysis of mesohabitat, this type of assessment can lend insight to the physical basis for habitat-specific sensitivity to flow for a critical life stage in the target stream.

% Available Habitat

0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8 2 2.2 2.4


0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4

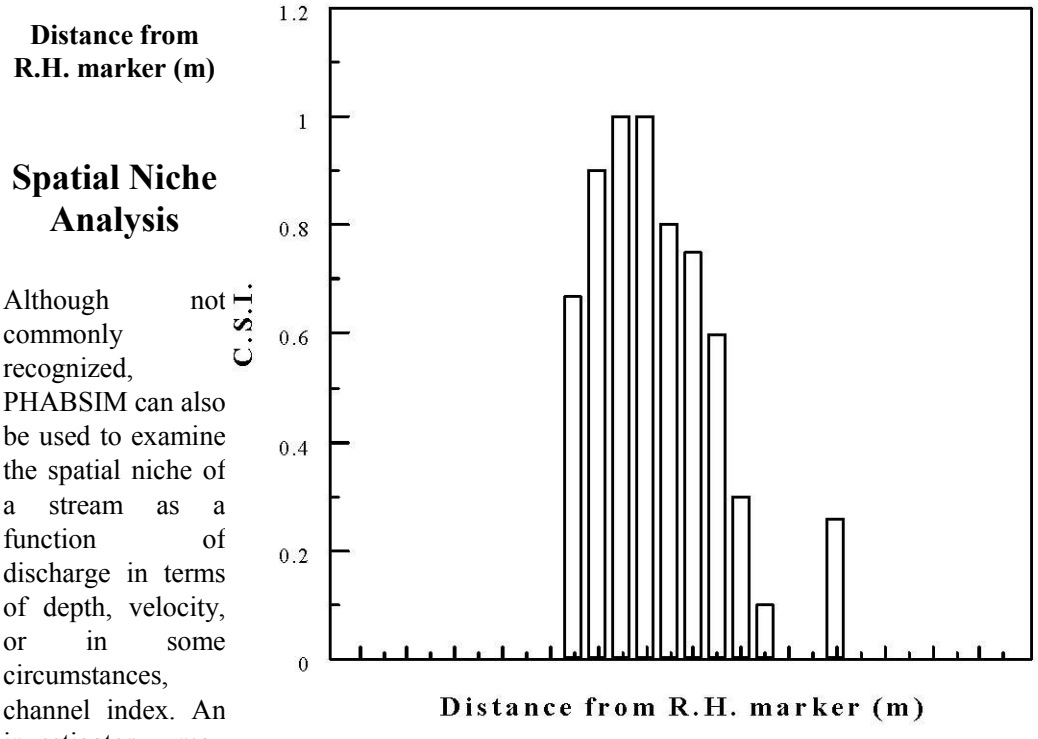
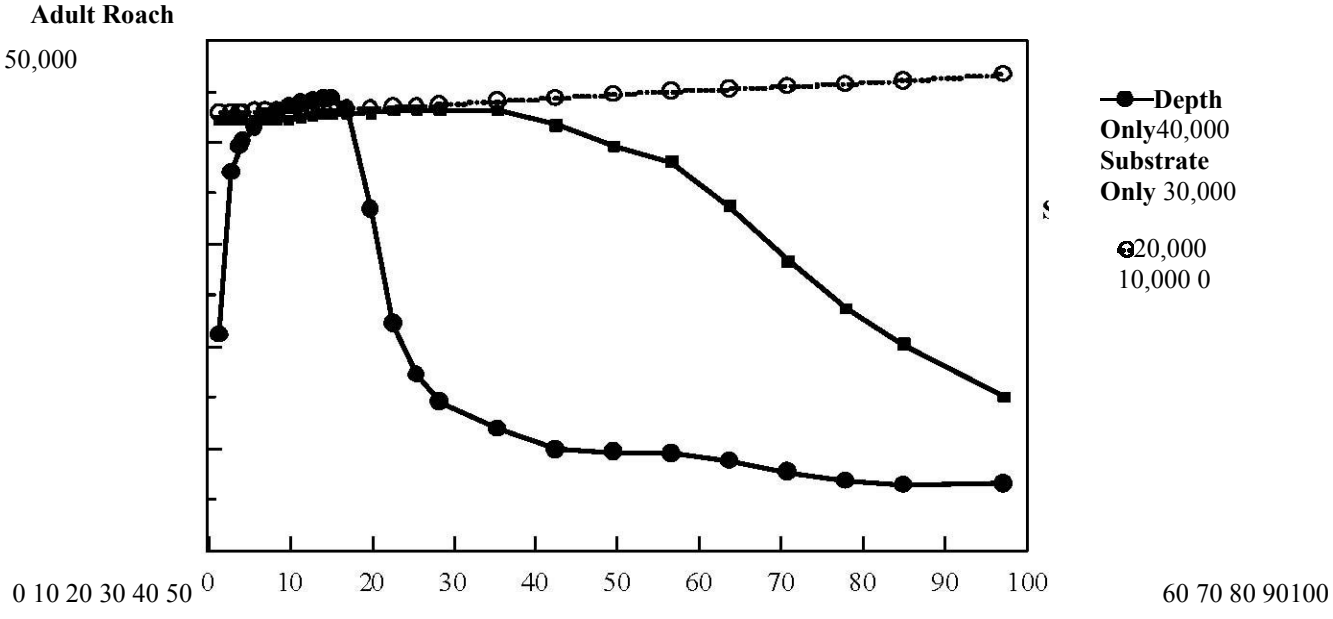


Figure 5-6. Distribution of spawning suitability on a selected cross section.

Spatial Niche Analysis

Although not commonly recognized, PHABSIM can also be used to examine the spatial niche of a stream as a function of discharge in terms of depth, velocity, or in some circumstances, channel index. An investigator may find that HSC curves are not readily available, or may simply wish to examine the flow dependent characteristics of spatial niches as part of the overall study. In this type of approach, a fish community may be partitioned by species and life stages into a simple spatial matrix representing habitat use along a gradient of depth and velocity as illustrated in Table 5-1. Note that in this type of analysis, no species or life stage HSC curves are necessary since only a community level habitat (i.e., spatial niche) partitioning is used. Suitability curves, which define usable habitat as 1.0 over each combination of depth and velocity can be used to compute the area, associated with each spatial niche at each discharge. These relationships can then be aggregated to construct a cumulative area versus discharge relationship as illustrated in Figure 5-8. In this figure, each line represents the component area that each spatial niche in Table 5-1 contributes to the total surface area of the stream at a specific discharge.



Discharge (m^3/sec) Figure 5-7. Single parameter habitat-discharge relationships.

Table 5-1. Example of a hypothetical spatial niche indicating component habitat partitioning by resident species/life stages.

WUA (m^2/1000m)

Depth gradient (m)

Windows		DOS	Difference	% difference
Cell bed elevation	91.65	91.65	0	0.00
Water surface elevation	92.456	92.47	0.014	0.02
Depth	0.806	0.82	0.014	1.71
Depth Suitability Index	0.0708	0.096	0.025	26.25
Combined Suitability Index	0.0644	0.087	0.023	26.25
Weighted Usable Area	8.698	11.79	3.096	26.25

Acknowledgements **i**
PREFACE **ii**
A Brief History of PHABSIM
Use of this Document
Changes Between PHABSIM Version 2 and PHABSIM for Windows
Conventions Used in this Document
Chapter 1, Introduction to the Physical Habitat Simulation System **1**
Objectives

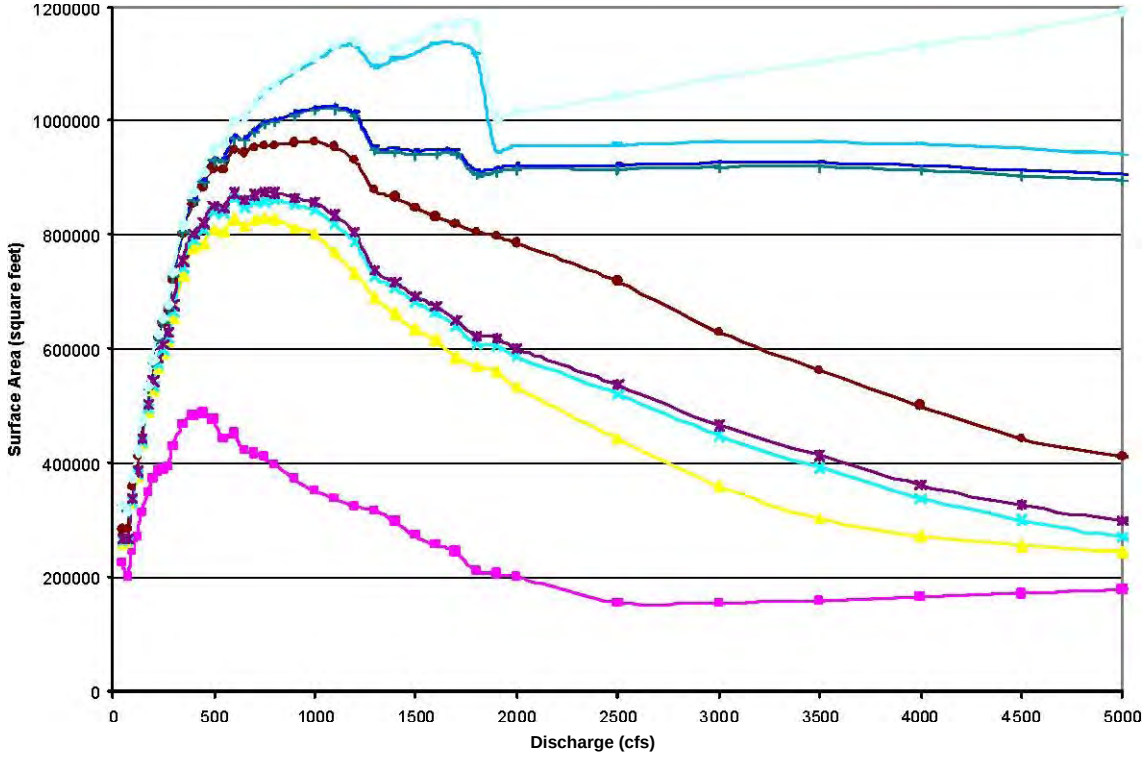


Figure 5-8. Example of spatial niche composition versus discharge, each line represents one item in Table 5-1.

It is also possible to use these results to compute a variety of ecologically-based indices such as a diversity index. The diversity index can be computed using the available habitat areas at each flow to produce a habitat diversity versus discharge relationship. The analyst can then examine these relationships in light of specific discharges and the associated amounts of specific areas represented by specific habitat niches or overall habitat diversity. This may lead an investigator to select a discharge or discharge range, which either maximizes the spatial niche of a particular community element(s) or favors a broader range of diversity of available habitats.

Habitat Time Series

While not explicitly included in the PHABSIM for Windows software, habitat time series analysis is a key part of an application of IFIM. Because of its importance in IFIM and relationship to PHABSIM results, the following discussion of habitat time series is included in this document. All other factors being equal, it is a reasonable assumption that current populations of fish are dependent on the antecedent history of habitat availability. It is also logical to assume that future population levels will be influenced by the time dependent characteristics of habitat availability. In many instances, it is the time dependent characteristics of habitat occurrence that ultimately may limit a particular life stage and, therefore, control the fishery population. This has often been referred to as a limiting life stage or population bottleneck. An instream flow assessment based on PHABSIM can be used to explore these potential limiting conditions for specific species and life stages through the application of habitat time series. This extension of the basic PHABSIM model results (the weighted usable area versus discharge curve) to temporal predictions of habitat can be a crucial step in the examination of habitat availability that may influence long-term changes in fish and invertebrate populations. Use of habitat time series in an IFIM analysis is more extensively covered in Bovee, et al., (1998). Habitat time series may be generated using programs in the TSLIB (Time Series LIBrary) group of programs or through use of spreadsheets.

To conduct a habitat time series analysis, the user needs to derive the basic habitat versus flow relationships for target species and life stages and also obtain a baseline and various alternative time series of flow(s) at the study site. The major premise of habitat time series analysis is that habitat is a function of stream flow and that stream flow varies over time. The basic steps to calculate a habitat time series are illustrated in Figure 5-9, where the habitat versus flow function (i.e., WUA vs. discharge) is integrated with the flow at each time step to derive habitat availability at each time step. The habitat time series can then be analyzed to derive a habitat duration curve similar to flow duration curves derived in hydrologic analyses as illustrated in Figure 5-10 and discussed below.

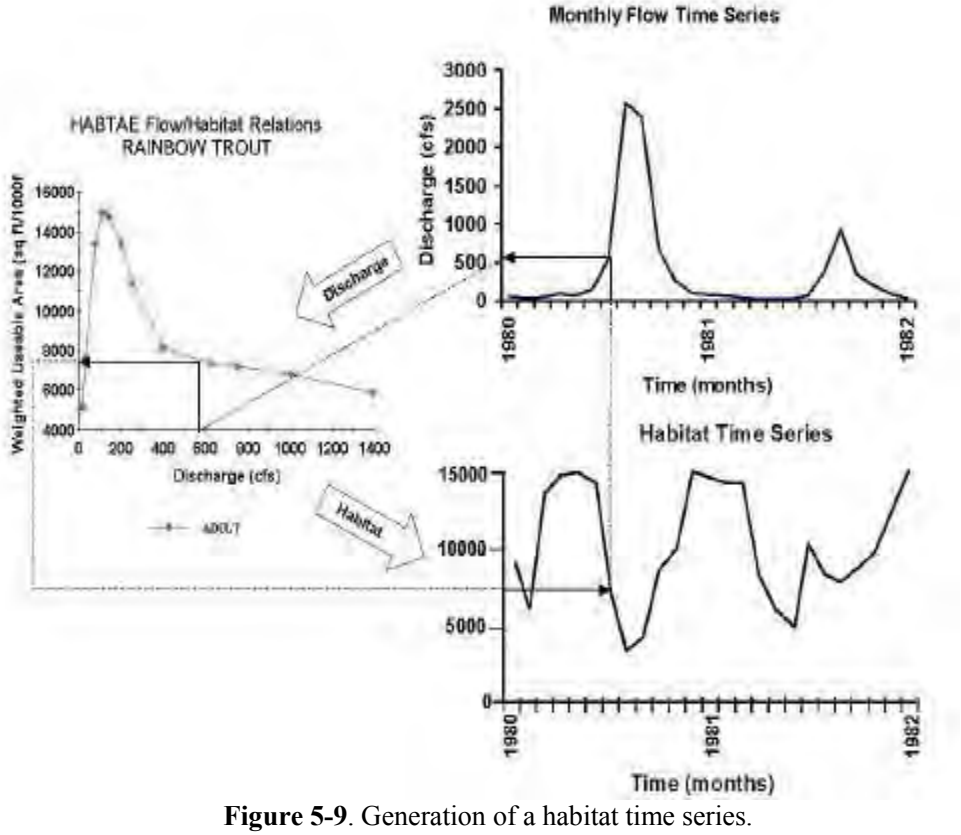


Figure 5-9. Generation of a habitat time series.

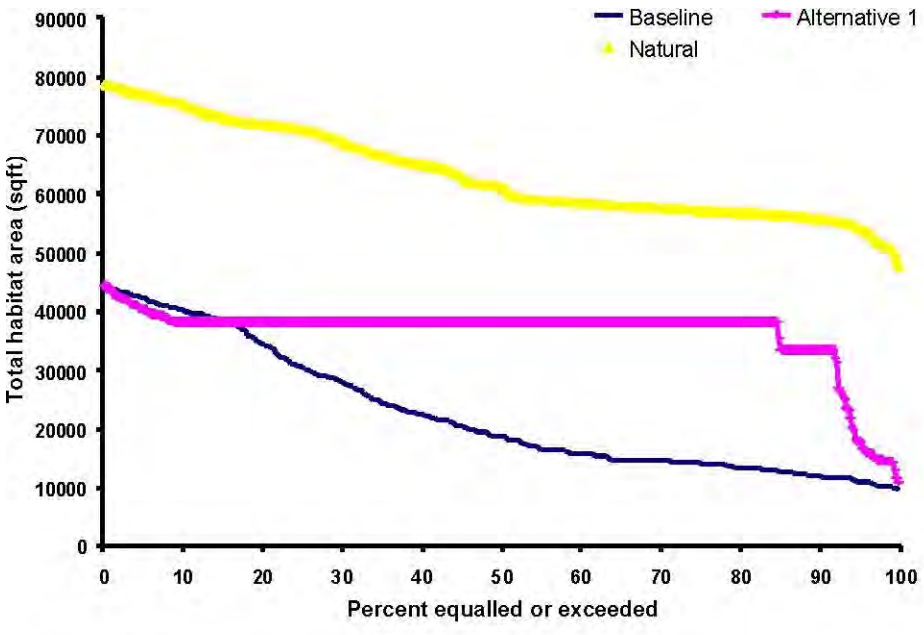


Figure 5-10. Example of habitat duration curves derived from three habitat time series.

In its various forms, time series analysis provides a very valuable method of assessing the impacts of changes in flow regime. The most common approach to this is to generate habitat time series data for a study site both under baseline conditions agreed upon in the analysis scoping phase of IFIM. The flow time series used must incorporate the effects of an abstraction or other alternative flow management regime as illustrated in Figure 5-10. It may also be appropriate to produce habitat time series to show the effects of different levels of human manipulation of the stream. Analysis of these alternatives can take a variety of forms. The following are some of the more common approaches:

1. A simple comparison of the two (or more) sets of habitat time series data can identify periods where the human influence has greater/lesser impacts.

2. Using the above data, the percentage reduction in habitat can be calculated, again to assist in the identification of periods of greater/lesser impacts. (See Bovee, et al., 1998)

3. Mean monthly (or other time interval) habitat levels and mean monthly percentage habitat losses can be calculated to examine more general patterns of habitat change.

4. A combination of these analyses can be used to identify which of the alternative flow regimes being analyzed minimizes potential adverse impacts or provides habitat improvements for critical time periods or life stages to meet habitat management objectives.

Once the habitat time series data sets have been calculated, the user may wish to aggregate values at some appropriate time interval such as using daily time steps aggregated to monthly, seasonal, or even yearly intervals, in order to examine habitat changes on a different time interval basis. Commonly used summary statistics of habitat time series for any interval of time include:

Mean habitat Median habitat Minimum habitat Maximum/optimum habitat Index-A: mean of all the habitats between 50% and 90% exceedence, i.e., the majority of the low flow events Index-B: mean of all habitats between 10% and 90% exceedence An exceedence statistic e.g., 90, 95-percentile habitat Number of days below a habitat quantity threshold, or total threshold deficit

Bovee, et al. (1998) contains a full discussion of these indices and their use in negotiating instream flow regimes.

Habitat Duration Curves

Further analysis of habitat time series may be achieved using a variety of techniques developed for river flow analysis. The first example of this is the habitat duration curve (Figure 5-10). A duration curve, whether for flow, habitat, or another instream variable, displays the relationship between the variable and the percentage of time it is exceeded. Duration curves are constructed by sorting the data (time series of flows or habitat values) from highest to lowest, and expressing each data point as a percentage of the total number of values. These methods are of particular use in the analysis of how alternative flow regimes affect habitat available to individual life stages of a species.

Duration curves are particularly useful for assessing the impacts of alternative flow regimes over the complete range of discharges considered for alternative flow scenarios as shown in Figure 5-10 which gives “baseline” (with habitat reduced by an abstraction), “alternative” (a proposed managed flow regime) and “natural” (with natural levels of habitat) duration curves. They are also useful for examining habitat changes due to artificial influences for the time periods identified as critical in the species/life stage periodicity analysis or on a seasonal basis by simply sampling from the appropriate portions of the time series to build the habitat duration curve. It is important to note that the habitat duration curves can only be interpreted as representing the amount of time that a particular magnitude of habitat is equaled or exceeded. Other forms of analysis discussed below must be used if the investigator is interested in determining the amount of time that habitat is continuously below some threshold. In other words, a monthly habitat duration curve may indicate that a given quantity of habitat is equaled or exceeded 90% of the time, but one cannot determine from the flow duration curve if the lowest 10% of habitat availability occurs once every fifth day or for five continuous days. From a biological perspective, differentiation between these two cases may be of critical importance in understanding limiting habitat conditions such as chronic versus acute episodes.

Habitat Duration Threshold Analyses

This technique has been used to characterize periods of flow below a certain threshold habitat value. In a PHABSIM study, it allows the user to assess not only the number of low habitat events but also the duration (length of time) of each low habitat event. For example, habitat may drop below a threshold level for 20 separate days in a year, or it may drop below the same level for a single continuous period of 20 days within a year. These two scenarios would appear the same when plotted on a duration curve but may have very different implications for the target species/life stage in question. In this type of analysis, within an IFIM study, a habitat threshold level must be set by the investigator and the relative importance of both the number and length (i.e., number of time steps) over which habitat is at or below this threshold must be interpreted using the available knowledge of the target species/life stage in question. An example of this technique illustrating the use of habitat duration threshold analysis is presented in Capra et al. (1995).

Choice of Flow Time Series and Baseline Conditions

In the initial planning stages of an IFIM study using PHABSIM, an important consideration will have been the sources of flow data that are available. When changes in flow regime are to be considered, predictions of historical physical habitat are commonly compared with alternative modeled scenarios that could have occurred over the same historical time period, including the "naturalized" condition. This often requires the development of models to predict the flow regime in the river concerned under the "naturalized" flow conditions, which in itself can form a major part of a study. Some key factors in selecting flow data for use in habitat time series analysis are that the flow data is on a time step appropriate for the issues and target species/life stages in question (e.g., 15 minute flow values may be essential for analysis of the impacts of hydropower schemes), that the flow time series is sufficiently long to allow the production of robust seasonal habitat duration curves and other time-based statistics, and that modeled flow scenarios properly represent anticipated management influences, naturalized flows, or other factors as appropriate.

With regard to periods of record, there are no set guidelines. Each study should be considered on a case-by-case basis. However, if daily flows are available, it is suggested that at least 10 years of flow data be used. If the study is using monthly flow data, then 15 or more years may be required. Shorter or longer time periods may be appropriate, however, given data availability and study objectives.

Some Important Factors in Time Series and Duration Curve Analysis

It is important to note that a habitat duration curve shows exceedence percentiles for values of habitat, ranked from highest to lowest. It does not simply show flow exceedence percentiles mapped to their corresponding habitat values. It is also important to note that there is generally not a continuous increasing relationship between habitat and flow in a habitat versus flow function for a target species/life stage. Instead, habitat often increases with flow up to a maximum at a certain flow, and then habitat values decrease with increasing flow. This phenomenon may result in some portion of the habitat duration curve representing levels of habitat produced under both high and low flow conditions. This is unlike a flow duration curve, where high flows are always associated with low exceedence values. As a result care must be taken when interpreting habitat duration curves a low habitat availability does not always result from a low flow.

While not detracting from the use of habitat duration curves in the evaluation of the impacts of alternate flow regimes, caution should be exercised in their interpretation. It is possible to overcome these issues by plotting values of flow alongside habitat duration curves so that the analyst can see which flows are producing a given habitat exceedence level. Alternatively, the analyst may confine the period of analysis either by restricting it to certain time periods of the year, when flows are lowest, or simply by not calculating habitat exceedence percentiles for flows above the peak in the WUA versus discharge curve. It should also be remembered that duration curves do not give information about the temporal distribution of low flow or habitat events, i.e., whether they occur together or separately. Other techniques such as a habitat/flow threshold analysis, as outlined above, should be considered for this purpose.

Integration of Channel Maintenance and Sediment Transport

One of the more important aspects of an ecologically sound flow regime is the recognition that the long-term ecological function of a stream or river corridor requires that the physical processes that form and maintain a channel must be protected. There are numerous examples where sediment transport has been either severely reduced, such as below a dam, or significantly increased, such as runoff from a watershed that has been intensively mined or burned in a forest fire. In these situations, the channel will react to the change in the sediment dynamics and either degrade or aggrade differentially along its longitudinal gradient. In some instances, a well-defined river channel will become highly braided, in other circumstances the opposite effect has been observed. This problem, of course, is not confined solely to changes in the sediment supply since alterations in the flow regime, such as seasonally maintained low flows or abstraction of the high flow component for reservoir storage, can result in changes to the dynamic equilibrium between the flow and sediment transport. This can, in turn, result in changes to channel structure and habitat composition as well as changes in the dynamics of the streamside or riparian vegetation.

PHABSIM for Windows does not contain models of sediment dynamics. To include sediment issues in an IFIM application, other models and expertise must be brought to the problem. Appendix 4 contains a brief discussion of some of the issues to consider when including channel maintenance in an instream flow analysis.

Summary of Chapter 5

This chapter covered numerous ideas for application of PHABSIM to various analysis situations. These items are intended as thought provoking examples to encourage PHABSIM users to adapt the analysis to the situations they may encounter in practice. This section concludes the PHABSIM for Windows user's manual.

Appendix 1. Glossary of Terms and Program Names

Terminology

The following terms and their definitions are provided to help the reader understand some of the specialized vocabulary utilized throughout PHABSIM in the description of open channel hydraulics, suitability curves, and habitat modeling.

AREA, CONVEYANCE: Cross-sectional area of a stream perpendicular to the flow.

AREA, CROSS-SECTIONAL: The area of the cross section containing water, perpendicular to the direction of flow. (Units: square feet or square meters).

AREA, USABLE: The surface area of a stream that can be used by an aquatic organism. (Units: square feet or square meters).

AREA, WEIGHTED USABLE (WUA): The surface area of a stream weighted by its suitability to an aquatic organism. (Units: square feet or square meters).

AREA, WEIGHTED USABLE BED (WUBA): The bed area of a stream weighted by its suitability to an aquatic organism. (Units: square feet or square meters).

BACKWATER: (1) A region of a stream where the water surface level is governed by a downstream control (Hence the term step-backwater is applied to the WSP model, see below.). (2) An off-shoot from the main channel with little flow and where the water surface elevation is maintained by

conditions in the main channel.

BANKFUL WIDTH: See Width, Bankful.

BETA COEFFICIENT: (1) A coefficient used to represent the change in Manning's roughness with

discharge or hydraulic radius. (2) Ratio of the bed shear stress to the resisting forces of the bed-material (Shield's Parameter).

CELL: As used in PHABSIM, an increment of width of a stream channel weighted for its relative importance by a length to give an area. Defined by verticals.

CELL FACTORS: See Factors, Cell.

CHANNEL INDEX: A suitability index to the channel characteristics, usually substrate or cover.

CHANNEL ROUGHNESS: A coefficient of resistance to flow caused by particle or vegetative friction and channel features such as bends and constrictions.

CHANNEL WIDTH: See Width, Channel.

COMPOSITE SUITABILITY OF USE FACTOR: See Factors, Cell.

CONVEYANCE, FACTOR: See Factor, Conveyance.

COVER: Areas of shelter in a stream channel that provide aquatic organisms protection from predators and/or a place in which to rest and conserve energy due to a reduction in the force of the current or visual isolation, e.g., pools, undercut banks, boulders, water depth, surface turbulence, etc.

CRITICAL FLOW: See Flow, Sub-Critical and Super-Critical.

CROSS SECTION: A section across a stream channel that is perpendicular to the direction of the flow. Sometimes called a transect.

CURVES, PREFERENCE: The criteria used to weight an area as to it worth for a specific aquatic organism. The organism prefers certain conditions.

CURVES, SUITABILITY-OF-USE (SI): Same as Preference Curves except the concept of the suitability of the conditions for a specific organism is stressed.

CURVES, USABILITY: Same as Preference Curves except the concept of usability of the conditions for a specific organism is stressed.

DATUM: Any numerical or geometrical quantity or set of such quantities that may serve as a reference or base for other quantities. An agreed standard point or plane of stated elevation, noted by permanent bench marks on some solid immovable structure, from which elevations are measured, or to which they are referred.

DEPTH: The vertical distance from a point on the bed to the water surface.

DEPTH, HYDRAULIC: Equivalent to mean or average depth.

DEPTH, MEAN: The cross section area divided by the surface width.

DEPTH, THALWEG: The vertical distance of the lowest point of a channel cross section to the water surface, i.e., maximum depth of cross section.

DISCHARGE: The rate of flow, or volume of water flowing in a given stream at a given place and within a given period of time, expressed as cubic feet per second (cfs) in traditional (English) units.

FACTOR, CELL: Also referred to as Composite Suitability of Use Factor. The function of velocity (v), depth (d), and the channel index (CI) used to weight an area of stream for its value as habitat. The term is defined within the context of specific habitat models in Chapter 5.

FACTOR, CONVEYANCE: In uniform flow situations, the area available to transport water is directly proportional to Q. The Conveyance Factor (K) is the relationship between the channel and flow characteristics. The equation in traditional units is:

$$\frac{1.49}{AR^{2/3}}K = n$$

The discharge can then be defined in terms of K by:

$$Q = \sqrt{S}SK$$

where: A = area R = hydraulic radius n = Manning's roughness Q = discharge K = conveyance Factor S = slope

FLOW: The movement of a stream of water and/or other mobile substances from place to place; discharge; total quantity carried by a stream.

FLOW, STEADY and UNSTEADY: Flow in an open channel is said to be steady if the depth of flow does not change or can be assumed constant over a specified time interval. The flow is unsteady if the depth changes with time.

FLOW, SUB-CRITICAL and SUPER-CRITICAL: In any body of moving water both inertial and gravity forces are acting on the water body. The effect of gravity on the state of flow is represented by the ratio between inertial and gravity forces, i.e., Froude Number.

If the Froude Number is less than unity, gravity forces predominate, so the flow has low velocity and is described as tranquil or streaming. If the Froude Number is greater than unity, the effects of inertia are more pronounced, so the flow has high velocity and is described as shooting, rapid, or torrential. When the Froude Number is equal to unity, flow is defined as critical.

Most instream flow studies are concerned primarily with the sub-critical state of flow, although hydraulic simulations for certain recreational activities may deal with super-critical states of flow that are difficult to model.

FLOW, UNIFORM and VARIED: Uniform flow means that the depth of flow is the same at every section of the channel. Thus, the hydraulic, energy, and bottom slopes are parallel. If the flow is varied, the depth of flow changes along the length of the channel. Varied flow is classified as either rapidly or gradually varied, depending on the distance within which the change in depth occurs. Rapidly varied flow is manifest in an abrupt change in depth, resulting in hydraulic jumps, hydraulic drops, and related phenomena. The criterion for uniform or varied flow is change in depth with respect to space.

FROUDE NUMBER: A dimensionless number used as an index to characterize the type of flow in a hydraulic structure that has the force of gravity (as the only force producing motion) in conjunction with the resisting force of inertia. As used in this document the Froude Number is:

$$VF_R = gd$$

where: F_R = Froude Number V = mean column velocity g = acceleration of gravity d = depth of the water

$$\sqrt{gd}$$

GRADIENT: The rate of change of any characteristic per unit of length. See Slope.

HEAD PIN: The terminal points in a cross section. Usually marked by something (a "pin") pounded into the ground. By convention, the first head pin is on the left-bank looking upstream.

HEIGHT OF INSTRUMENT: The elevation of the sight plane through a level. Level measurements are measured downward from this plane.

HYDRAULIC GEOMETRY: The dimensions of certain stream features with respect to both the wetted and unwetted portions of the channel.

HYDRAULIC RADIUS: Ratio of the cross-sectional area to the wetted perimeter, R = A/P. For relatively wide shallow channels, R approximates the hydraulic depth.

IFIM: The Instream Flow Incremental Methodology. (See Bovee, et al., 1998 and Stalnaker, et al., 1995)

LIFE STAGE: An arbitrary classification of the age of an organism into stages related to body morphology and reproductive potential, e.g., "middle age" for man and "fry" for fish.

MACROHABITAT: Habitat conditions in a reach of river controlling longitudinal distribution of aquatic organisms.

MANNING'S EQUATION: An empirical formula for the calculation of velocity in a channel. The equation in traditional units is:

$$V = \frac{1.49}{n} R^{2/3} S^{1/2}$$

MANNING'S ROUGHNESS or MANNING's n: A factor used when computing the average velocity of flow of water in a channel that represents the effect of roughness of the confining material upon the energy losses in the flowing water. Also referred to as "n" or roughness coefficient.

MICROHABITAT: Habitat small area (cell) of a river controlling specific locations or home ranges.

MEAN DEPTH: See Depth, Mean.

PHABSIM: (pronounced P-HAB-SIM) - the Physical Habitat Simulation System. Computes a relationship between streamflow and physical habitat for various life stages of an aquatic organism or a recreational activity. PHABSIM is a component of IFIM; PHABSIM is not IFIM.

PHYSICAL HABITAT: The place where a population lives and its surroundings as defined by physical conditions, most commonly depth, velocity, and channel conditions such as substrate and cover objects.

PROFILE or PROFILE, LONGITUDINAL: (1) In open channel hydraulics, it is a plot of water surface elevation against channel distance and/or bottom elevation. (2) A line of elevations along a river usually following the thalweg. Most often includes the bed and water surface elevations.

PROFILE, TRANSVERSE: Same as a cross section.

RATING CURVE: A curve that expresses graphically the relation between mutually dependent quantities, e.g., a curve showing the relation between gage height (or stage) and discharge of a stream.

REACH: A comparatively short length of a stream, channel, or shore. The actual length is defined by the purpose of the study.

REACH LENGTH: The length of a section or piece of a river.

REYNOLDS' NUMBER - FLUID: A dimensionless number relating to the flowing force of the water to the viscous forces. It is calculated using the equation:

$$V*dRe = ?$$

where: R_e = Reynolds number **L** = Kinematic viscosity of water V = mean velocity d = depth of the water

REYNOLDS' NUMBER - GRAIN (R_*): A dimensionless number used as an index to characterize the relative importance of active forces on the streambed to the viscous forces in the fluid. It is calculated using the equation:

$$\mu*DR* = ?$$

where: **:***= Shear velocity (see Velocity, Shear below) D = is a characteristic particle size **L** = Kinematic viscosity of water

RIFFLE: Shallow rapids in an open stream where the water surface is broken into waves by obstructions wholly or partly submerged.

ROUGHNESS COEFFICIENT: See Manning's Roughness.

SEGMENT: Relatively homogeneous section of a stream composed of two or more reaches.

SHEAR STRESS, BED: The stress on the river bed caused by the flowing water.

SHIELD'S PARAMETER $: Ratio of the Bed Shear Stress to the resisting forces of the bed-material:

$$ß == \frac{tD\ RS}{?s - ?\ (Ss - 1)D}$$

where: **J** = bed shear stress
($_s$ = unit weight of bed material (= unit weight of water D = bed material size S_s = specific gravity of bed material R = hydraulic radius S = slope

The terms K_s, ϑ^* are also used for the Shield's Parameter and D may be the mean size of the surface layer or the D_{65} of the surface area (D_{65} is where 65% of the particles are finer).

SLOPE: The inclination or gradient from the horizontal of a line or surface. The degree of inclination can be expressed as a ratio, such as 1:25, indicating one unit rise in 25 units of horizontal distance or as

0.04 length per length. Sometimes also expressed as feet per mile. **SLOPE, BOTTOM**: The change in the average elevations of the bed between two cross sections, divided by the distance between them. **SLOPE, ENERGY**: Change in total energy (potential and kinetic) available at a point. Usually approximated as the change between the cross section divided by the distance between cross sections. **SLOPE, HYDRAULIC**: The change in elevation of the water surface between two cross sections, divided by the distance between the cross sections. **SLOPE, THALWEG**: The change in the elevation of the bed, measured at the points of maximum depth, divided by the distance between cross sections. **SLOPE, WATER SURFACE**: The slope of the water surface at a point and is usually approximated as the difference in water surface elevations at two points divided by the distance along the flow path between the points. **STAGE**: The elevation, or vertical distance of the water surface above a datum (a plane of known or arbitrary elevation). **STAGE OF ZERO FLOW (SZF)**: The water surface elevation at a cross section when the flow reaches zero. This is either the lowest point of the bed or the pool water surface when no flow occurs (i.e., a

downstream low bed point acts as the pool water surface control). **STEADY FLOW**: See Flow, Steady and Unsteady. **STREAMBED**: The bottom of the stream channel; may be wet or dry. **STREAM WIDTH**: See Width, Stream. **SUB-CRITICAL FLOW**: See Flow, Sub-Critical and Super-Critical. **SUBSTRATE**: The material on the bottom of the stream channel, e.g., rocks, vegetation, etc. **SUPER-CRITICAL FLOW**: See Flow, Sub-Critical and Super-Critical. **THALWEG**: The longitudinal line connecting points of minimum bed elevation along the stream course. **TOE WIDTH**: See Width, Toe **TOP WIDTH**: See Width, Top. **TRANSECT**: Same as cross section. **UNIFORM FLOW**: See Flow, Uniform and Varied.

UNSTEADY FLOW: See Flow, Steady and Unsteady. **USABLE AREA**: See Area, Usable. **VARIED FLOW**: See Flow, Uniform and Varie d. **VELOCITY**: The time rate of motion; the distance traveled divided by the time required to travel that

distance.

VELOCITY, ADJACENT: A velocity in a cell near the cell being considered.

VELOCITY, MEAN: The mean velocity may represent either a cell or a cross section. It is calculated as: V

$$Q = A$$

where: Q = the discharge in the cross section or cell A = the area of the cross section or cell.

VELOCITY, MEAN COLUMN: The velocity averaged from the top to the bottom of a stream. Usually measured at 6/10 depth or an average of values measured at 2/10 and 8/10 of the depth when the depth is greater than 2.5 ft.

$$V = \int_{d_0}^{d} v \, dy$$

where: V = the mean column velocity v = the point velocity dy = small increment of depth dy thick d = total depth

VELOCITY, NOSE: The velocity at the point where a fish is located. This is the point velocity expressed in terms of an organism.

VELOCITY, POINT: The velocity at a depth in the stream.

VELOCITY, SHEAR: The square root of the bed shear stress divided by the density of the water and has the dimension of length/time:

$$\mu_* = \sqrt{\frac{t_*}{?}} = \sqrt{\frac{t_*}{?_*/g}}$$

where: u_* = shear velocity **J** $_*$ = shear stress on the bed ($_*$ = density of water

VELOCITY ADJUSTMENT FACTOR (VAF): The ratio of the discharge for which velocities are being simulated to the sum of simulating cell velocities times cell areas:

$$Q_{target} = \sum_{i=1}^{n} v_i a_i$$

where: Q = target discharge (Discharged to be simulated) v_i = cell velocity a_i = cell area n = number of wet cells

VELOCITY CALIBRATION ERROR (VCE): The error calculated for the relationship $v = aQ^b$ and is calculated as:

$$VCE = \frac{\sum_{i=1}^{n} |v - \hat{v}|}{\sum_{i=1}^{n} v}$$

where: v = estimated velocity
v = measured velocity
n = number of velocity discharge pairs used to determine coefficients a and b.

VERTICAL: As used in PHABSIM, sample locations across a cross section.

WATER SURFACE ELEVATION (WSL): The elevation of the water's surface in relation to an arbitrary datum.

WATER TRANSPORT PARAMETER (WTP): As used in PHABSIM, the Water Transport Parameter is expressed in traditional units by the equation:

$$WTP = \frac{1.49}{n} \sqrt{S}$$

where:

S = the energy slope

n = Manning's roughness **WEIGHTED USABLE AREA (WUA)**: See Area, Weighted Usable. **WEIGHTED USABLE BED AREA (WUBA)**: See Area, Weighted Usable Bed. **WEIGHTED USABLE VOLUME (WUV)**: The volume of a stream weighted for its worth as habitat. **WEIGHTING FACTOR**: The value that weights a surface area or volume area as to its worth as habitat. **WETTED PERIMETER**: The distance along the bottom and sides of a channel cross section in contact

with water. Roughly equal to the width plus two times the mean depth. **WETTED WIDTH**: See Width,

Wetted. **WIDTH**: The distance across a channel at the water surface measured normal to flow.

WIDTH, BANKFUL: The width of the stream just before the flow overtops the channel.

WIDTH, CHANNEL: An arbitrary width based on what the observer sees as a channel.

WIDTH, STREAM: Either the same as the channel width or the width of the wetted stream.

WIDTH, TOE: The width of the base of a trapezoidal channel.

WIDTH, TOP: The width of the wetted area of flow across a stream channel.

WIDTH, WETTED: The width of the stream with water in it.

Program Names

STGQ: The STGQ model uses a stage-discharge relationship (rating curve) to calculate water surface elevations at each cross section. In the stage-discharge relationship and its simulation, each cross section is independent of all others in the data set. The basic computational procedure is conducted by performing a log-log regression between observed stage and discharge pairs at each cross section. The resulting regression equation is then used to estimate water surface elevations at all flows of interest.

MANSQ: The MANSQ program utilizes Manning's equation to calculate water surface elevations on a cross section by cross section basis and therefore treats each cross section as independent. Model calibration is accomplished by a trial and error procedure to select a β coefficient that minimizes the error between observed and simulated water surface elevations at all measured discharges.

WSP: The Water Surface Profile (WSP) program uses a standard step-backwater method to determine water surface elevations on a cross section by cross section basis. The WSP program requires that all cross sections being analyzed in a given model run be related to each other in terms of survey controls and sequence upstream. That is, each cross section's hydraulic characteristics in terms of bed geometry and water surface elevations are measured from a common datum. The model is initially calibrated to a measured longitudinal profile of water surface elevations by adjusting Manning's roughness, first for the entire study site and then at each cross section. Manning's roughness is then adjusted for subsequent measured longitudinal water surface profiles at other discharges by setting the roughness modifiers used within the model. This approach requires all hydraulic controls within the modeled study site are represented by cross sections.

VELSIM: The VELSIM program is the principal tool used to simulate the velocity distributions within a cross section over the required range of discharges (i.e., the mean column velocity in each wetted cell in a study cross section at each simulation discharge). The technique relies on an empirical set of velocity observations (i.e., measured velocities) that act as a template to distribute velocities across a channel by solving for the „n' in Manning's equation (in this context „n' acts as a roughness distribution factor across the channel). The channel is divided into cells and the velocity calculated for each of these cells. The usual practice is to use one set of velocities as a template for simulating velocities for a particular range of discharges. When more than one set of empirical velocity measurements is available, a commensurate number of flow ranges can be simulated with different velocity templates. The program can be used when no velocity measurements are available . In this situation, velocity will be distributed across the cross section as a function of flow depth.

HABTAE: The primary habitat simulation program in PHABSIM. Options within **HABTAE** allow the user to select habitat calculation assuming the condition within a cell establishes the worth of the habitat in the cell. Adjacent cell conditions (for example a "feeding station") are also included in **HABTAE.** Assuming the condition in a cell simulates conditional velocity considerations plus the velocity in adjacent cells or at another location nearby establishes the worth of the habitat in the cell. The **HABTAE** program also allows habitat to be determined in terms of volume (instead of the surface area), and provides a method for determining the habitat conditions at each cross section as well as the aggregate for a study site.

HABEF: Effective habitat analysis in PHABSIM is used to determine availability of physical habitat considering two flows; in other words, the HABitat that remains EFfective when two flows are of importance. This situation often arises, for example, in the evaluation of reducing flows during the spawning period and subsequent incubation period or in hydro-peaking operations that have a daily minimum and maximum flow. In the case of spawning and incubation analyses, the spawning area at a cross section is not „effective' unless the incubation period flow regime maintains the habitat in a suitable condition for the eggs to hatch.

HABTAM: The second effective habitat model is the **HABTAM** program. In **HABTAM** the species can move from cell to cell cross each transect over a range of starting and ending discharges. In this model, effective habitat is defined as the habitat that remains usable when the species is forced to move due to flow fluctuations.

AVDEPTH/AVPERM: The average parameter model, **AVDEPTH /AVPERM**, calculates a variety of hydraulic characteristics for each cross section in addition to a study site average view. These include wetted width, wetted perimeter, and wetted surface area, cross sectional area, mean channel velocity, and average depths. They can also be utilized to determine the width of a stream with water that is over some arbitrary depth(s) specified by the user. These programs provide a wealth of information at a cross section or a study site level aggregate and should be examined in most applications.

CALCF4: This utility program calculates a water transport (or conveyance) parameter (WTP) for each cross section. The program uses Manning's equation at each cross section to calculate the WTP for each water surface elevation, develops power relationships between WTP's, area and maximum depth, discharge and width, velocity, and average depth. The exponent (B) in the WTP regression equation between discharge and the channel conveyance factor or WTP for each cross section is an excellent initial estimate for the β coefficient for each transect in the MANSQ program.

SLOP34: A utility program that provides thalweg values, water surface elevations, and slopes in the following four tables: water surface elevation, water surface slope, energy grade line elevation and energy grade line slope.

LSTWLF: Utility program that calculates and displays the Froude number and mean channel velocities for each cross section and each flow.

Appendix 2. References

Bain, M. B., J. T. Finn, and H. E. Booke. 1988. Streamflow regulation and fish community structure. Ecology 69(2):382–392.

Bovee, K. D. 1986. Development and evaluation of habitat suitability criteria for use in the instream flow incremental methodology. U.S. Fish and Wildlife Service Biological Report 86(7). 235 pp.

Bovee, K. D. 2000. Data collection procedures for the Physical Habitat Simulation System. 114 pp. Available on the Internet at http://www.mesc.usgs.gov

Bovee, K. D., B. L. Lamb, J. M. Bartholow, C. B. Stalnaker, J. Taylor, and J. Henriksen. 1998. Stream habitat analysis using the instream flow incremental methodology. U.S. Geological Survey, Biological Resources Division Information and Technology Report USGS/BRD-1998-0004. viii + 131 pp.

Bovee, K. D., T. J. Newcomb, and T. G. Coon. 1994. Relations between habitat variability and population dynamics of bass in the Huron River, Michigan. National Biological Survey Biological Report 21. 63 pp.

Bowen, Z. H. 1996. Relations between fishes and habitat in the Tallapoosa River system, Alabama. Ph.D. dissertation, Auburn University, Alabama. 109 pp.

Capra H., H. Breil, and Y. Souchon. 1995. A new tool to interpret magnitude and duration of fish habitat variations. Regulated Rivers: Research and Management 10:281–289.

Chow, V. T. 1959. Open channel hydraulics. McGraw-Hill Publishing Co., New York.

Collings, M. R., R. W. Smith, and G. T. Higgins. 1972. The hydrology of four streams in western Washington as related to several Pacific salmon species. U.S. Geological Survey Water Supply Paper 1968. 109 pp.

Conover, W. J. 1980. Practical nonparametric statistics. 2nd Edition. John Wiley & Sons, New York. 493 pp.

Doerksen, H. 1991. Two Decades of Instream Flow, A Memoir. Rivers 2(2):99–104.

Felley, J. D., and L. G. Hill. 1983. Multivariate assessment of environmental preference of cyprinid fishes of the Illinois River, Oklahoma. American Midland Naturalist 109:209–221.

Hawkins, P. H., and ten coauthors. 1993. A hierarchical approach to classifying stream habitat features. Fisheries 18:(6).

Henderson, F. M. 1966. Open channel flow. Macmillan Publishing Co., Inc., New York. 522 pp. See List of Symbols, Chapter 1: Basic Concepts of Fluid Flow, Chapter 2: the Energy Principle in Open Channel Flow, Chapter 3: the Momentum Principle in Open Channel Flow, Chapter 4: Flow Resistance, Chapter 5: Flow Resistance – Nonuniform Flow Computations, Chapter 10: Sediment Transport.

Johnson, D. H. 1980. The comparison of usage and availability measurements for evaluating resource preference. Ecology 69:125–134.

Jowett, I. G. 1992. Models of the abundance of large brown trout in New Zealand rivers. North American Journal of Fisheries Management 12:417–432.

Karr, J. R. and D. R. Dudley. 1981. Ecological perspectives on water quality goals. Environmental Management 5(1):55–68

Knight, J. G., M. B. Bain, and K. J. Scheidegger. 1991. A habitat framework for assessing the effects of streamflow regulation on fish. Completion Report #14-16-0009-1550. Alabama Cooperative Fish and Wildlife Research Unit, Auburn. 161 pp.

Manly, B. F. J., L. L. McDonald, and D. L. Thomas. 1993. Resource selection by animals: statistical design and analysis for field studies. Chapman and Hall, London, United Kingdom. 175 pp.

Milhous, R. T., M. A. Updike, and D. M. Schneider. 1989. Physical Habitat Simulation System Reference Manual – Version II. Instream Flow Information Paper No. 26. U.S. Fish and Wildlife Service Biological Report 89(16). v.p.

Morhardt, J. E., D. F. Hanson, and P. J. Coulston. 1983. Instream flow: Increased accuracy using habitat mapping In Proceedings of Water Power „83. International Conference on Hydropower 3:1294–1304.

Morhardt, J. E., and C. F. Mesick. 1988. Behavioral carrying capacity as a possible short-term response variable. Hydro Review 7(2):32–40.

Nehring, R. B., and R. M. Anderson. 1993. Determination of population-limiting critical salmonid habitats in Colorado streams using IFIM/PHABSIM. Rivers 4(1):1–19.

Railsback, S.F., R.E. Blackett, and N. D. Pottinger. 1993. Evaluation of the fisheries impact assessment and monitoring program for the Terror Lake hydroelectric project. Rivers 4(4):312–327.

Rantz, S. E., and others. 1982. Measurement and computation of streamflow: Volume 1: Measurement of stage and discharge. U.S. Geological Survey Water Supply Paper 2175. 284 pp.

Scheidegger, K. J., and M. B. Bain. 1995. Larval fish distribution and microhabitat use in free-flowing and regulated rivers. Copeia 1995(1):125–135.

Stalnaker, C., B. L. Lamb, J. Henriksen, K. Bovee, and J. Bartholow. 1995. The Instream Flow Incremental Methodology – A Primer for IFIM. Biological Report 29, March 1995, U.S. Department of the Interior, National Biological Service, Fort Collins, Colo.

Thomas, J. A., and K. D. Bovee. 1993. Application and testing of a procedure to evaluate transferability of habitat suitability criteria. Regulated Rivers: Research & Management 8:285–294.

U.S. Bureau of Reclamation. 1968. “Guide to the Application of the Water Surface Profile Computer Program”.

Waters, B. F. 1976. A methodology for evaluating the effects of different stream flows on salmonid habitat. Pages 254–266 *in* J. F. Orsborn and C. H. Allman, editors. Instream flow needs. Special Publication of the American Fisheries Society, Bethesda, Md.

Appendix 3. ProjView

ProjView is a utility program included with the PHABSIM for Windows installation that allows the user to export the binary project files to a text format. It is intended that ProjView aid the user in recovery from software/hardware errors with the minimal amount of lost data as possible.

Output from ProjView is either a set of text files that can be viewed and edited, or a set of PHABSIM for Windows project files. Exported text files and their contents are:

Project.txt -General project information Xsec.txt -Cross section specific data Point.txt -Point specific data Index.txt -Indexes points to cross sections Cal.txt -Calibration data Options.txt -PHABSIM option selections Curves.txt -Suitability index curves

The exported text format files have, for the most part, a very specific format in order for the "build" options to function properly. Any editing of text files MUST follow the formats listed below.

There are two "build" options, Build and Build/Clean. The Build option builds new project files for only those checked in the selection box. The Build/Clean option performs a complete project build. As such, it requires an export of all files, with the exception of the Options file. In addition, the Build/Clean option rebuilds the Options file with default settings. This option should be used if errors to the options file would take longer to edit than it would take to reset options in PHABSIM for Windows.

Some Conventions and Comments

Lines indicated by {Note: }, {Format: }, or underlining are informational lines on format and are not part of the actual file.

Lines ending in \ are longer than the paper width and are continued on the next line. These form a single line in the text file.

Lines followed by a vertical ". . ." indicate lines missing to conserve space. Missing lines are of the same format, and the total number of lines for the section will be included in a {Note: }.

Where there are multiple data values on a single line, the positioning is important. Single data values on a line do not require specific spacing, except that when following text, there should be a space between the text and the data. Blank lines in a file should not be removed.

Where appropriate, comments are added on how errors have been repaired. Please note that, during the PHABSIM development process, it was only necessary to edit the Options file to fix corrupt datasets. Generally, it best to edit the existing file, using correct data lines as a template. When unsure about format, run ProjView on a good project and use the resulting files as templates.

Note: ProjView exports data in the order that it is stored in the project files. This is not necessarily the order in which it is displayed by PHABSIM for Windows.

Project File

The Project File contains general information about the project; name, units, discharges, etc., plus some information specific to the velocity model (N limits and beta). Discharges listed in Options File data records should match the discharges in the Project File. Likewise,

Sample File

Project: wintest Units : English N MIN: 0.000 N MAX: 0.000 BETA: 0.000 Number of calibration sets: 3 XSEC ID LIST 4
0.000 60.000 135.000 201.000 CALIBRATIONS FLOWS 3
75.200
139.000
250.000 SIMULATIONS FLOWS 4
15.000
30.100
625.000 1250.000

Point File

The Point File contains information related to each coordinate point. There is a single coordinate point per line and point IDs should match those listed in the Point Index File. Velocity values for calibration sets not used should be entered as –99.990.

Sample File

{Format: Values are ID, X, Y, Z, CI, N, units, and velocities for nine calibration sets. Note that –99.99 is used for no data.

```
1234567123456678.123123456678.123123456678.12312.1231.12345123123.123\
\1234.123123.1231234.123123.1231234.123123.1231234.123123.123}
 .      1 2.000 0.000 94.800 6.0000.00000 0 -99.990\ \ -99.990 -99.990 -99.990 -99.990 -99.990
-99.990 -99.990 -99.990
 .      2 4.000 0.000 94.000 6.0000.00000 0 -99.990\ \ -99.990 -99.990 -99.990 -99.990 -99.990
-99.990 -99.990 -99.990
 .      3 6.000 0.000 93.000 6.0000.00000 0 -99.990\ \ -99.990 -99.990 -99.990 -99.990 -99.990
-99.990 -99.990 -99.990
 .     4 8.000 0.000 92.700 6.0000.00000 0 -99.990\ \ -99.990 -99.990 -99.990 -99.990 -99.990
-99.990 -99.990 -99.990
```

Windows		DOS	Difference	% difference
Cell bed elevation	91.65	91.65	0	0.00
Water surface elevation	92.456	92.47	0.014	0.02
Depth	0.806	0.82	0.014	1.71

{Note: There is a line for each coordinate point.} .

```
     154 68.000 201.000 96.000 7.0000.00000 0 -99.990\ \ -99.990 -99.990 -99.990
-99.990 -99.990 -99.990 -99.990 -99.990
```

Index File

The Index File lists which coordinate points belong to specific cross section. Coordinate Ids in the list should match coordinate Ids in the Point File.

Sample File

{Format: There are 10 indices/line at 5 spaces allocated for each point index.}

```
XSEC: 0.000 NUMBER OF POINTS: 44
     1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32
   33 34 35 36 37 38 39 40 41 42 43 44
. .
```

{Note: There is a block for each cross section. There should be a blank line between each block.} .

```
XSEC: 201.000 NUMBER OF POINTS: 32 123 124 125 126 127 128 129 130 131 132 133 134 135 136
  137 138 139 140 141 142 143 144 145 146 147 148 149 150 151 152 153 154
```

Xsec File

The Xsec File contains information specific to each cross section. Cross section Ids should match those in the Project File and the number of points should match the Index File.

Sample File

{Format: Values are, in order ID, distance, upstream weight, left bank weight, right bank weight, SZF, thalweg, N, beta, slope, and number of points.

```
123456.123 123456.123 123456.123 12.123 12.123 1234.123 1234.123 / /123.123
1.123 12.12345 1234}
      0.000 0.000 0.500 1.000 1.000 90.600  90.600 / / 0.000 0.000 0.00400 44
     60.000 60.000 0.500 1.000 1.000 90.600 90.600 / / 0.000 0.000 0.00320 41
    135.000 75.000 0.500 1.000 1.000 90.600 90.500 / / 0.000 0.000 0.00230 37
    201.000 66.000  0.500 1.000 1.000 90.600 89.800 / / 0.000 0.000 0.00230 32
```

Cal File

The Cal File lists information specific to calibration data sets. There is one record for each cross section/calibration set pair. Cross section Ids should match Ids in previous files, and the number of calibration sets is given in the Project File.

Sample File

{Format: Values are Cross section, cal set ID, best estimate discharge, local discharge, left bank WSL, right bank

Windows		DOS	Difference	% difference
Cell bed elevation	91.65	91.65	0	0.00
Water surface elevation	92.456	92.47	0.014	0.02
Depth	0.806	0.82	0.014	1.71
Depth Suitability Index	0.0708	0.096	0.025	26.25
Combined Suitability Index	0.0644	0.087	0.023	26.25
Weighted Usable Area	8.698	11.79	3.096	26.25

Acknowledgements **i**
PREFACE **ii**
A Brief History of PHABSIM
Use of this Document
Changes Between PHABSIM Version 2 and PHABSIM for Windows

WSL, user supplied WSL.

```
12345.123 1234 12345.123 12345.123 1234.123 1234.123 1234.123}
```

Curves File

The Curve File contains the suitability index curve information. The number of curves in the file should match the number of curves listed in the Options File.

Each curve has an ID line, a species line, and a stage line. The next line is a header line followed by the number of coordinate pairs for velocity, depth, channel index, and temperature, respectively. Note that PHABSIM for Windows does not use temperature data.

Following the suitability curve point counts are the data points. Points are listed as X/Y pairs with each value using 8 spaces with 3 decimal points (8.3 format.) There are 6 X/Y pairs per line with each curve (i.e., velocity, depth, etc.) starting on a new line. Thus, a curve with 7 coordinate pairs would have 6 on the first line, 1 on the second, and the next curve would start on the third.

Sample File

```
Number of curves: 3 ID: 21112 Species: RAINBOW TROUT Stage: FRY
 VEL DEP CI TEM
 4 8 8 0
 0.000 1.000 0.100 1.000 0.500 0.000 100.000 0.000
    0.000 0.000 0.100 0.100 0.200 1.000 0.500 1.000 / / 1.000 0.500 1.250 0.300
 3.000 0.000 100.000 0.000
 0.000 0.000 1.000 1.000 2.000 1.000 4.000 1.000 / / 6.000 1.000 8.000 1.000
```

```
    9.000 1.000 100.000 0.000 ID: 21114 Species: RAINBOW TROUT Stage: JUVENILE
   VEL DEP CI TEM 5 4 8 0
                0.000 1.000 1.200 1.000 1.600 0.250 2.600 0.000 / /100.000
0.000
    0.000 0.000 0.400 0.000 0.700 1.000 100.000 1.000
    0.000 0.000 1.000 1.000 2.000 0.500 6.000 0.500 / / 7.000 1.000 8.000 1.000
    9.000 0.000 100.000 0.000 ID: 21115 Species: RAINBOW TROUT Stage: ADULT
   VEL DEP CI TEM 4 4 8 0
    0.000 1.000 1.500 1.000 3.000 0.000 100.000 0.000
    0.000 0.000 1.000 0.200 1.600 1.000 100.000 1.000
    0.000 0.000 1.000 1.000 2.000 0.700 6.000 0.700 / / 7.000 1.000 8.000 1.000
   9.000 0.000 100.000 0.000
```

Options File

The Options File stores all user selections from the PHABSIM for Windows dialogs. All cross section IDs, discharges, calibration set IDs, and suitability curve IDs listed in the various sections of the Options File must match the respective value in the other files.

Example Problem Fixes

General: Often, a quick scan of the file will reveal problems. They usually appear as values of 0 or something like 128723746109238787654. Check the category and edit for the appropriate data.

Problem: The WSL method grid shows error cells (colored red) that appear whenever the project is reopened.

Solution: Check the section titled “Selected WSL Models:” and make sure every cross section/discharge combination is there and has correct method value (1 through 7 based on the dialog radio button) and a correct WSL, if needed.

Problem: Velocity calibration set assignments appear as zero when that is not the desired assignment.

Solution: Check the “VELOCITY XSEC/Q Calibration Set Assignments:” section for the appropriate cross section/discharge combinations. With the correct records, the use flag should be no less than 0 and no greater than the number of calibration sets.

Note: This problem can occur with the “WSL XSEC/Q Calibration Set Assignments” also; however, the use flag is not as straight forward. Once the correct records are in place it is best to set the use flag to 0 (all off) or 65535 (all on), and adjust the settings in PHABSIM.

Problem: Selected life stages for the habitat programs do not stay selected when reopening a saved project.

Solution: Check that the "NUMBER OF CURVES:" is correct.

Sample File

```
NUMBER OF CROSS SECTIONS: 4 NUMBER OF CALIBRATION SETS: 3 NUMBER OF DISCHARGES: 7 NUMBER OF
CURVES: 8 WSP option values:
   0  0  1  0 MANSQ option
values: 1  0  0  0  0  0  0
0 STGQ option values: 4  3
1 VELOCITY option values: 1
1  0  0  1  0  0  0 HABTAE
option values:
   1  0  0  0  0  0  0  0  0  1  0  0  0  0 Near Shore Distance: 0.000000 HABTAM option
values:
   0  0  0  0  0  0  0  0  0  0  0  0  0  0
AVDEPTH/AVPERM Depths: 5
    0.100 0.250 0.500 0.750 1.000 {Note: If there are no depths, the preceding line is blank.}
HABTAM Migration Flow Pairs:
     0.000 0.000
    0.0 0.000
{Note: There are 25 total lines here.} . .
      .
     0.000 0.000
     0.000 0.000 HABTAM Factors for Nose Velocity Calculation Dn: 0.0000 A: 0.0000 B: 0.0000
D65: 0.0000 STGQ Cross Section Option Flags:
   xsec ID cID QT WT SZF
      0.000 1 2 4 1
      0.000 2 2 4 1
      0.000 3 2 4 1
     60.000 1 2 4 1
     60.000 2 2 4 1
     60.000 3 2 4 1
    135.000 1 2 4 1
    135.000 2 2 4 1
    135.000 3 2 4 1
    201.000 1 2 4 1
    201.000 2 2 4 1
    201.000 3 2 4 1
MANSQ Cross Section Options: xsec ID
  cID QT beta
      0.000 0 0 0.0000
     60.000 0 0 0.0000
```

135.000 0 0 0.0000

201.000 0 0 0.0000 Selected WSL Models: XSEC: 0.000 Q: 15.000 Method: 1 User WSL: 0.000 XSEC: 0.000 Q: 30.100 Method: 1 User WSL: 0.000 XSEC: 0.000 Q: 75.200 Method: 1 User WSL: 0.000 XSEC: 0.000 Q: 139.000 Method: 1 User WSL: 0.000 XSEC: 0.000 Q: 250.000 Method: 1 User WSL: 0.000 XSEC: 0.000 Q: 625.000 Method: 1 User WSL: 0.000 XSEC: 0.000 Q: 1250.000 Method: 1 User WSL: 0.000 . . {Note: One line for each cross section/discharge pair.} . XSEC: 201.000 Q: 1250.000 Method: 1 User WSL: 0.000 WSL XSEC/Q Calibration Set Assignments: XSEC: 0.000 Q: 15.000 Use: 65535 XSEC: 0.000 Q: 30.100 Use: 65535 XSEC: 0.000 Q: 75.200 Use: 65535 XSEC: 0.000 Q: 139.000 Use: 65535 XSEC: 0.000 Q: 250.000 Use: 65535 XSEC: 0.000 Q: 625.000 Use: 65535 XSEC: 0.000 Q: 1250.000 Use: 65535 . . {Note: One line for each cross section/discharge pair.}

. XSEC: 201.000 Q: 1250.000 Use: 65535 VELOCITY XSEC/Q Calibration Set Assignments: XSEC: 0.000 Q: 15.000 Use: 1 XSEC: 0.000 Q: 30.100 Use: 1 XSEC: 0.000 Q: 75.200 Use: 1 XSEC: 0.000 Q: 139.000 Use: 2 XSEC: 0.000 Q: 250.000 Use: 3 XSEC: 0.000 Q: 625.000 Use: 3 XSEC: 0.000 Q: 1250.000 Use: 3 . . {Note: One line for each cross section/discharge pair.} . XSEC: 201.000 Q: 1250.000 Use: 3 VELOCITY Calculation options for Habitat Analysis

sprintf(line,"%8d %2d %2d %2d %2d %8.3f %8.3f %8.3f %8.3f %8.3f %8.3f %8.3f %8.3f %8.3f\n", l.ID,l.selected,l.velcalc,l.nosevel,l.velrepl,l.wmin,l.cfmin,l.Dn, l.A,l.B,l.N,l.D65,l.spg,l.CELL);

ID s v n r wmin cfmin Dn A B / / N D65 SPG CELL 12345678 12 12 12 12 1234.123 1234.123 1234.123 1234.123 1234.123/ /1234.123 1234.123 1234.123 1234.123

11300 1 0 0 0 0.000 0.000 0.000 0.000 0.000/ / 0.000 0.000 2.650 0.000

11301 1 0 0 0 0.000 0.000 0.000 0.000 0.000/ / 0.000 0.000 2.650 0.000 . .{Note: One line for each curve ID.} .

21115 1 0 0 0 0.000 0.000 0.000 0.000 0.000/

```
/ 0.000 0.000 2.650 0.000 ID dist vlim vo 11300   0.000 0.000 0.000 11301 0.000 0.000 0.000
   11302 0.000 0.000 0.000 11303 0.000 0.000 0.000 11304 0.000 0.000 0.000 21112 0.000 0.000
   0.000 21114 0.000 0.000 0.000 21115 0.000 0.000 0.000
Maximum Migration Distances
11300 5.000
11301 5.000
11302 10.000
11303 0.000
11304 0.000
21112 0.000
21114 0.000
21115 0.000
Additional migration distance cards: 2
11301 10.000
11302 15.000
Velocity regression records: 12
     0.000 1 1
     0.000 2 1
     0.000 3 1
    60.000 1 1
    60.000 2 1
    60.000 3 1
   135.000 1 1
   135.000 2 1
   135.000 3 1
   201.000 1 1
   201.000 2 1
   201.000 3 1
```

Appendix 4. Integration of Channel Maintenance and Sediment Transport

One of the more important aspects of an ecologically sound flow regime is the recognition that the long-term ecological function of a stream or river corridor requires that the physical processes that form and maintain a channel must be protected. There are numerous examples where sediment transport has been either severely reduced, such as below a dam, or significantly increased, such as runoff from a watershed that has been intensively mined or burned in a forest fire. In these situations, the channel will react to the change in the sediment dynamics and either degrade or aggrade differentially along its longitudinal gradient. In some instances, a well-defined river channel will become highly braided, in other circumstances the opposite effect has been observed. This problem, of course, is not confined solely to changes in the sediment supply since alterations in the flow regime, such as seasonally maintained low flows or abstraction of the high flow component for reservoir storage, can result in changes to the dynamic equilibrium between the flow and sediment transport. This can, in turn, result in changes to channel structure and habitat composition as well as changes in the dynamics of the streamside or riparian vegetation.

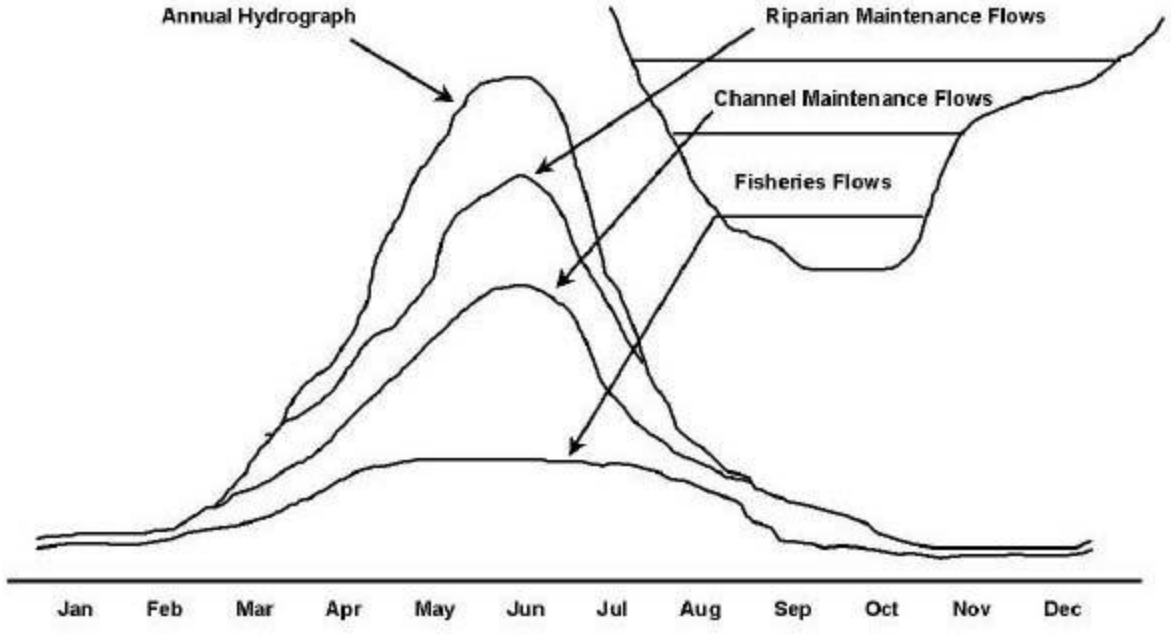
It has only been in the last decade that the importance of the physical and biological processes that maintain the interconnection between a channel and the adjacent floodplain has come into focus as a critical element of ecologically sound flows. Unfortunately, no consistent methodology has yet to be put forward dealing with what is now recognized as the three critical elements of ecologically sound flows: fishery flows, channel maintenance flows, and riparian maintenance flows. These different flow regimes are illustrated in Figure A4-1. It is important to understand that the latter two types of flow are basically related to the ability of the channel to process sediment loads and to provide adequate hydrologic connections between the stream course and the dependent riparian vegetation over some meaningful temporal domain.

We have already dealt with the use of PHABSIM as a tool to assist in the determination of the fisheries flow component of ecologically sound flows. PHABSIM analyses are well suited to examine the changes in physical habitat over flow ranges where the habitat mosaic is relatively static (i.e., after the physical and biological processes associated with channel or riparian flows have done their work within the channel). We now recognize that PHABSIM typically provides only a partial picture of the ecological flow needs and that during the higher flow periods we must turn to other methods for determination of appropriate flows during these periods (i.e., use the IFIM framework). This includes conducting analyses to determine flow regimes that maintain the channel characteristics from a physical perspective, independent of microhabitat. Identifying channel maintenance flow regimes helps to ensure that those microhabitats upon which the fish are dependent for their existence are formed or maintained during short high flow events.

In order to examine which flow patterns are needed to maintain an ecologically functioning stream system, the analyst needs to recognize that flowing water (timing, duration and magnitude) erodes, transports, and deposits sediment as well as controls the types and growth patterns of vegetation species in generally predictable ways. The temporal distribution of the magnitude and duration of flows interacts with the resident geology, topography, and vegetation to ultimately determine to form and condition of the mesoscale and microhabitat distribution of habitat upon which fish and other aquatic organisms are dependent for their living space. Alteration of the flood flow regime in a river can ultimately result in loss of side channel habitats, changes in riparian species and distribution, and alteration of the ratio of pools to riffles. Therefore, these factors need to be carefully considered in any analysis of altered flow regimes and are not restricted to the high flow component. Seasonal reductions in flow at artificially low sustained levels can also result in the accumulation of fine sediments that are deleterious to successful spawning and egg incubation of many species.

Figure A4-1. Elements of the hydrograph to consider when describing an ecologically sound flow regime.

In order to examine which flow patterns are needed to maintain an ecologically functioning stream system, the



analyst needs to recognize that flowing water (timing, duration and magnitude) erodes, transports, and deposits sediment as well as controls the types and growth patterns of vegetation species in generally predictable ways. The temporal distribution of the magnitude and duration of flows interacts with the resident geology, topography, and vegetation to ultimately determine to form and condition of the mesoscale and microhabitat distribution of habitat upon which fish and other aquatic organisms are dependent for their living space. Alteration of the flood flow regime in a river can ultimately result in loss of side channel habitats, changes in riparian species and distribution, and alteration of the ratio of pools to riffles. Therefore, these factors need to be carefully considered in any analysis of altered flow regimes and are not restricted to the high flow component. Seasonal reductions in flow at artificially low sustained levels can also result in the accumulation of fine sediments that are deleterious to successful spawning and egg incubation of many species.

Maintenance of stream and river ecosystems hinges on the determination of flow regimes that protect the physical processes, which in turn influence the biological processes within the stream or river. This results in the concept of multiple flow regimes that target specific elements of the flow such as fisheries, channel maintenance, and riparian maintenance flows.

Channel Maintenance Flows

Channel maintenance (or fish habitat maintenance) flows represent that portion of the hydrograph that is high enough to prevent vegetation growth within the active channel and remove sediment. The active channel can be characterized as that elevation within the channel associated with bank-full flows and is typically indicated by flat areas of alluvial deposits and the line of perennial vegetation that makes a well-defined margin along a stream or river corridor. Although a fairly wide range of flows are associated with bank-full discharges across different river systems, flows associated with a return period of approximately
1.5 years have been identified as an average value for these types of flows. Some investigators have also determined that the bulk of sediment transport on an annual budget occurs at intermediate flow ranges and that the most effective discharge in terms of long-term sediment budgets is nearly equivalent to the discharge at bank-full. These studies indicate bank-full flows are an important hydrological benchmark that is related to the flows, which are critical to maintaining the shape of alluvial channels and therefore, the mesohabitats upon which they are dependent.

Site-specific studies that measure the bank full discharge directly or are modeled from observations of the elevations of riparian and sediment deposition areas can be undertaken as an integral part of an IFIM application. Once the magnitude of the bank full flow has been determined, it can be used in conjunction with other information to determine this part of an ecologically acceptable flow regime. Other considerations of these higher flows relate to how the timing of the reduction of the high flows may be impacted by a project. For example, a rapid reduction in high flows has been observed to result in an increased sediment flow to rivers from bank failure due to rapid loss of hydrostatic pressure in the banks.

In some instream flow studies, the anthropogenic reduction in the high flows have been constrained to no more than a 10% reduction from the previous peak daily flow in order to minimize these types of secondary effects. Although not developed from a rigorous analytical procedure, these flow reduction criteria were derived from an examination of the long-term historical daily hydrographs for a number of similar river types and selecting a flow reduction range at the upper limit of observed natural processes. Most natural high flows do not decrease this rapidly and a more stringent requirement may be warranted. Reducing the duration of the peak flows may in fact impair some channel forming processes as well as impacting riparian species seeding and growth dynamics that are tied to these characteristic patterns in flow reductions. It should also be apparent that a careful examination of the flow reduction pattern should be considered in light of not only the riparian vegetation needs but also to minimize potential impacts associated with fish stranding if appropriate. Utilization of the PHABSIM cross section geometries in association with water surface elevation modeling can provide some insights to appropriate flow reductions over specific flow magnitude ranges.

Riparian Maintenance Flows

As with most conceptual tenants of instream flows, to date no universally accepted or recognized methods have been developed for the determination of flow quantity or duration needed to maintain riparian habitats and associated flood plains. In this context we take riparian flows as those not only necessary for the riparian vegetation immediately adjacent to the active channel but also side channels, oxbow lakes, wetlands, swamps, and ponds. Often these types of habitats are only seasonally connected to the main river channel but in turn may represent critical breeding or rearing areas for many fish species and in fact are necessary for successful completion of their life cycles. In addition, the overall importance of these types of habitats in terms of the general ecological diversity and function of a river corridor cannot be overstated.

Existing methods concentrate on modeling flows at which the water surface elevations inundate the flood plain where these riparian features are present within the affected study reaches. As with the channel maintenance flows, these site-specific issues and features can be identified during the scoping, fieldwork, and analysis phases of an IFIM application by making the appropriate cross section geometry measurements and extending them as necessary to pick up critical elevation features. The investigator is still left with determining the seasonal and duration aspects of these flows and inclusion of a riparian and terrestrial wildlife biologist when planning the analysis is strongly recommended for studies in which these types of issues are deemed important.

Including Sediment Analysis for Medium to Low Flow Issues

As a final note, we strongly encourage investigators to consider sediment transport as part of the overall instream flow assessment. Characterization of the various sediment size distributions within the study stream can permit simple calculations of the flow at which various size fractions can be moved. This would permit the investigator to determine, for example, in a stream where a significant proportion of the sediment load during medium to low flows is sand or silt, whether or not a proposed flow reduction would be expected to result in conditions in which these size fractions would no longer be transported. This would imply that deposition of these materials in slower water areas of the reach would occur and allow the investigator to evaluate the potential impacts on egg incubation and potential changes in invertebrate community structure associated with the changes in channel substrate characteristics.

Laboratory 1. Using the PHABSIM for Windows Interface

Introduction

The PHABSIM Windows interface considers all hydraulic and habitat simulation work planned for a study site to be one "project". All data entry, selection of simulation options, output option selection, and viewing of results takes place within the project. The purpose of Laboratory 1 is to familiarize the user with use of the interface to build a PHABSIM project data set.

Using the Menu System

The general steps to use the interface consist of creating a new project or opening an existing project; importing, entering, or changing data; entering or changing run options; running programs; viewing intermediate and final results; saving the project files; and capturing results in a format for creating reports. In the laboratory exercises, each of those steps is presented in the following format:

\Main Menu\Next Menu\Next Menu or Tab: followed by instructions.

For example, to enter cross section coordinate data for the second cross section, the user clicks on Edit, followed by clicking Cross Sections, followed by selecting the second cross section, followed by clicking the Coordinate Data tab, and then entering data in the spreadsheet-like interface. That sequence of operations is noted in the documentation as:

\Edit\Cross Sections *Number*\Coordinate Data: Enter x, z, channel index, n (if known), VelSet1, VelSet2, ...

The actions are:

Move mouse to **Edit** item in the main menu, click. Move mouse to **Cross Sections** tab, click. Move mouse to the gray **box showing *number* 2** in the left column, click. Move mouse to **Coordinate Data** tab, click. Enter data in the spreadsheet-like interface as described below.

Abbreviated notation, for example **..\Coordinate Data,** is used in some places to abbreviate **\Edit\Cross Sections *Number*\Coordinate Data** when moving within the same set of tabs or menus.

This notation convention is used through out the Laboratory exercises. If you find the notation is too terse or confusing, click on the first item that comes to mind and see what happens. Until the data entries or option selections are changed, you are merely viewing different portions of the interface so you can click on each successive item in this notation and follow where it leads.

To gain familiarity with the interface, we will begin by loading an existing project and navigating through the interface to get a feel of the process. First open the project:

Step 1. Open a Project

\File\Open Project: Navigate the Windows File Menu to \If310\Newlabs\Lab01 and double click on the file Lab1.phb

Step 2. Enter and Edit Cross Section Data

Data can be entered and viewed in the Edit area. Look at the cross section data in the Sampl1 project by:

\Edit\Cross Sections \Cross Section Data

Note that the data set contains four cross sections. For each cross section, the following information has been entered.

ID – The cross section identifier. *In PHABSIM for Windows we always use the distance from the downstream cross section as the identifier. This allows a cumulative upstream distance to be calculated and displayed as the Y ordinate in the coordinate data tab.*

Length – the cross section length or the distance from the downstream cross section. Length is used to calculate the y (cumulative distance) value. Cross sections are sorted by the cross section ID in ascending order.

Upstream WF – the weight assigned to this cross section. That is, the faction of distance upstream it represents. **L Bank WF** – the left bank weight for a bend. **R Bank WF** – the right bank weight for a bend. If these are equal, there is no bend. **SZF** – stage of zero flow.

N – Manning's n value for the cross section. **Beta/D50** – beta exponent for use in the MANSQ program, if applicable, or median substrate particle size in mm.

Slope – energy slope at the cross section. Typically estimated as the water surface slope. To edit or view individual cross sections use:

\Edit\Cross Sections\Coordinate Data

Under this tab, the cross section currently highlighted under **Edit\Cross Sections \Cross Section Data** will be displayed. Cross section ID is shown above the table and the number of points on the cross section is also displayed. To view the cross section profile, click the **Graph** button. You may drag the graph and Cross Section Data windows by their top bars so both can be viewed simultaneously. To view a different cross section, return to the **Cross Section Data** tab and click on a different cross section. The highlighted region will change. Return to the **Coordinate Data** tab and the graph will update.

The **\Edit\Cross Sections \Calibration Data** tab allows entry of data for left and right bank water surface elevations, the user-determined (or "given") water surface elevation, the "best estimate" discharge for the site, and the discharge measured at that cross section. As with the coordinate data, cross sections are selected in the **Cross Section Data** tab prior to viewing the **Calibration Data** tab for that cross section.

Entering and Editing Suitability Curves

Now that you have seen how to navigate around the cross section editing menu, take a look at the **\Edit\Suitability Curves** menu. You will find a similar set of menus and tabs there. Look at the data entry and display area for habitat suitability curves using:

\Edit\Suitability Curves

The\ **Edit\Suitability Curves\File** menu item allows you to create a new curve, import an existing curve file from another project, copy curve files, and save curve files. The **\Edit\Suitability Curves\Curve** menu item allows you to choose which curve in a suitability curve set is displayed in the data entry box. For example: by selecting **..\Curve\Select by ID** you can view a list of all HSC curve sets currently entered into this project and select a particular curve for viewing. Individual curves for depth, velocity, channel index, or temperature are selected using the **Curve Type** buttons to the right. **\Edit\Suitability Curves\Graph** allows you to display a graph of the selected curve values displayed in the SI curve-editing box. These graphs can be scaled for a better view. See Chapter 1 for use of the mouse button graphing features in PHABSIM for Windows.

The **\Edit\Suitability Curves\Curve\Display All Curves** menu item displays the four HSC curves in one window.

Entering and Editing Simulation Discharges

This simple dialog allows you to start with a small number of simulated discharges to be used in calibrating the hydraulic models, then add additional discharges for final simulation runs. For calibration when comparing observed with simulated conditions, the calibration discharges have been entered as simulation discharges by default. They cannot be removed and will appear in all simulations you run. The calibration discharges are shown in gray and any other discharges you enter will be shown with a white background.

To add discharges to this list, either place the cursor on the next highest discharge and press the Insert key on the keyboard or, to add a discharge higher than the highest shown, place the cursor on the last discharge and press the down arrow. Either of these actions will provide a new row with a discharge of 0. You simply type the desired discharge value in the highlighted cell.

Step 3. Running the Models

The **\Models** menu is where you set-up and run the various models. Here hydraulic simulation is divided into water surface and velocity simulation and habitat simulation includes the Habtae, Habtam, and Habef models. Also included here is a combined Avdepth\Avperm model. Each model contains a **Run** button that is clicked after all of the model input parameters are selected.

Further instructions in running the models are contained in the remainder of the laboratory exercises.

Step 4. Close and Save the Project

To prepare for the next laboratory exercises, please close this project using:

\File\Close Project

If you had made any changes to your project, they would be saved now. The system will prompt you to save your project if changes have been made. In general it is a good idea to frequently use:

\File\Save Project

You may wish to save the project periodically to ensure you can recover from a mistake or a computer glitch.

Step 5. Manipulating PHABSIM for Windows Graphics

PHABSIM for Windows uses a third-party graphics package that allows the graphs displayed by clicking the various graphics buttons described in the labs and manual to be scaled, translated, zoomed and, in some cases, rotated. The following examples illustrate each of those functions.

Scaling (Figures L1-1 and L1-2):

- Press Ctrl and hold down both mouse buttons
- Move mouse down to increase the chart's size
- Move mouse up to decrease the chart's size

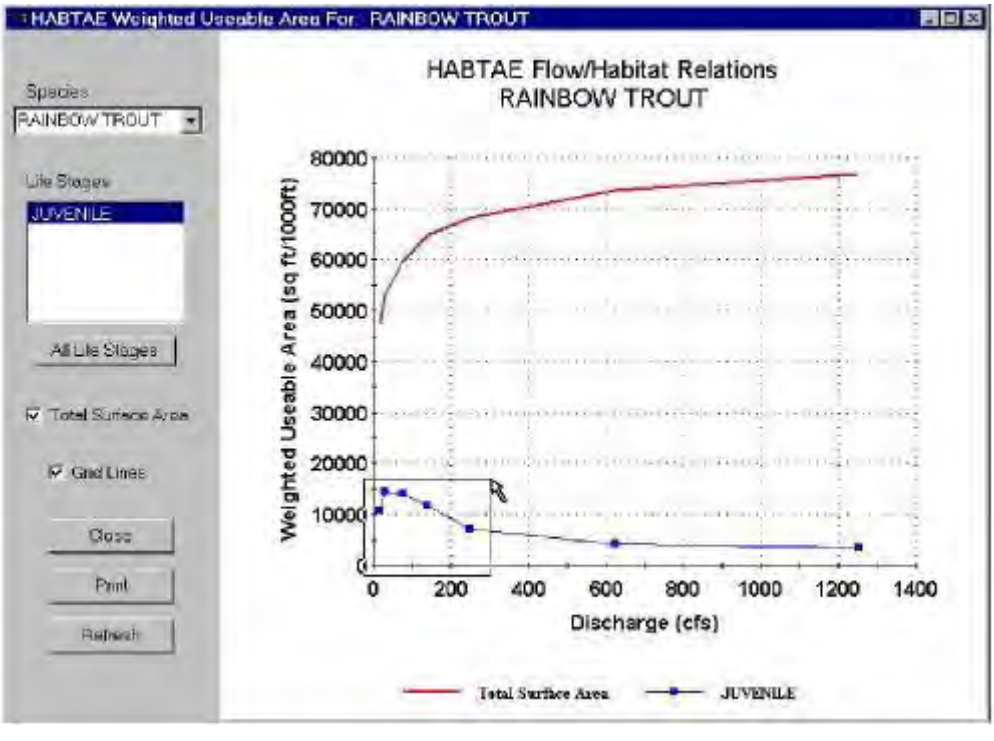
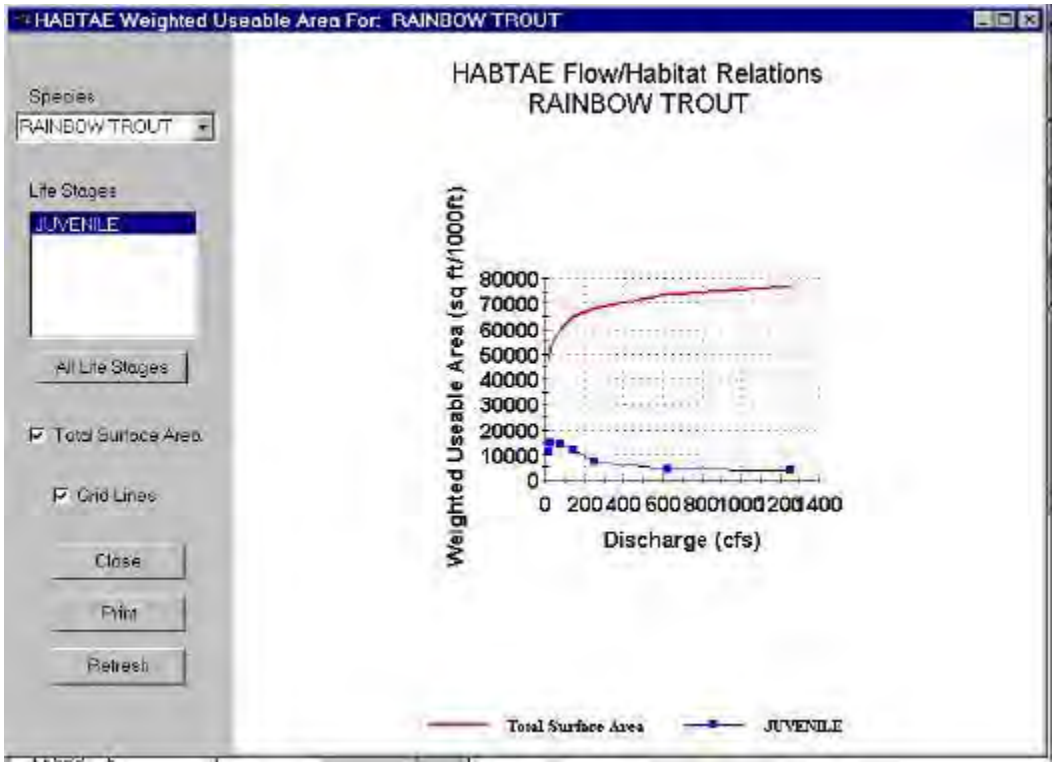


Figure L1-1. Original image. **Figure L1-2**. Scaled view.



Translation (Figure L1-3)

- Press Shift and hold down both mouse buttons
- Move mouse to shift the chart

Zooming

Axis Zoom

- Press Shift and hold down the left mouse button
- Move mouse to select the area to Zoom into (a box will be drawn around the area) then release the button

- Axis zoom is illustrated in Figures L1-4 and L1-5. Graphics Zoom does not retain axes, otherwise, same as Axis Zoom

- Press Ctrl and hold down the left mouse button

- Move mouse to select the area to Zoom into and release button

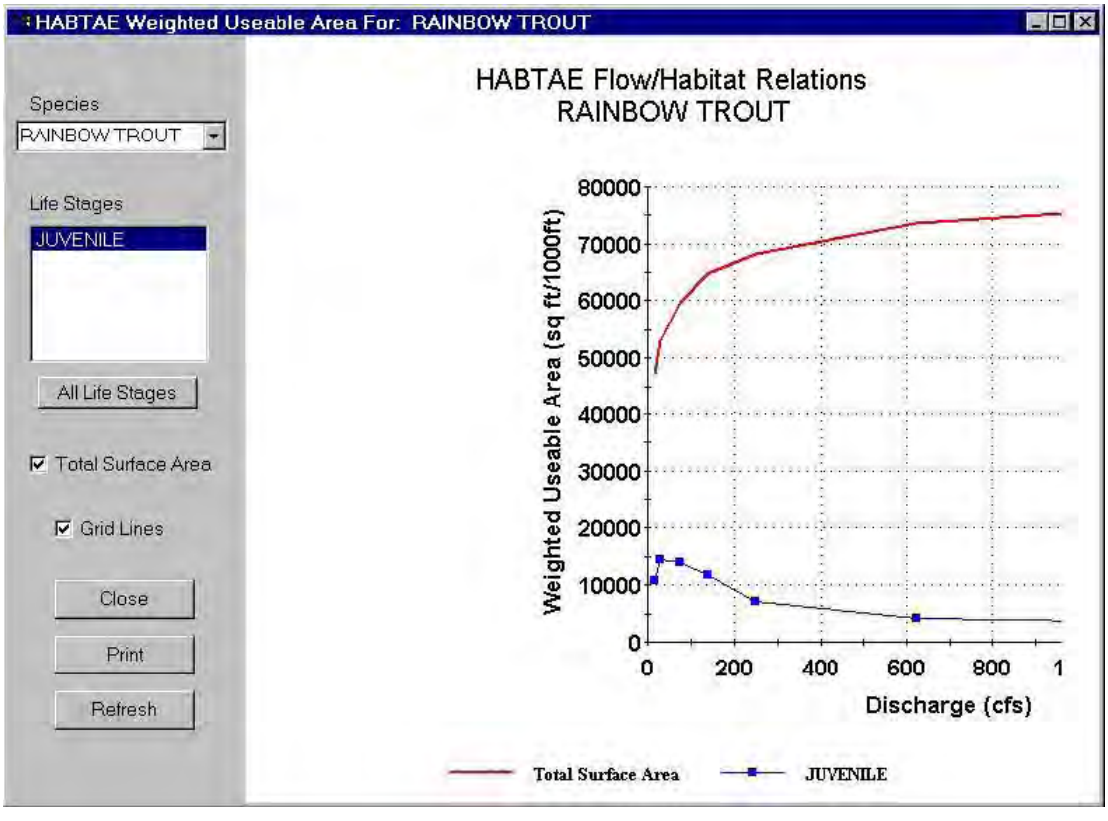


Figure L1-3. Translated image.

Rotation (3-D charts only, Figures L-6 and L-7)

- Hold down both mouse buttons
- Move mouse left and right to change the rotation angle
- Move mouse up and down to change the inclination angle

Return to Default Position (Fig. L1-8)

- Press "r"
- All interactive scaling, translation, and zooming is removed

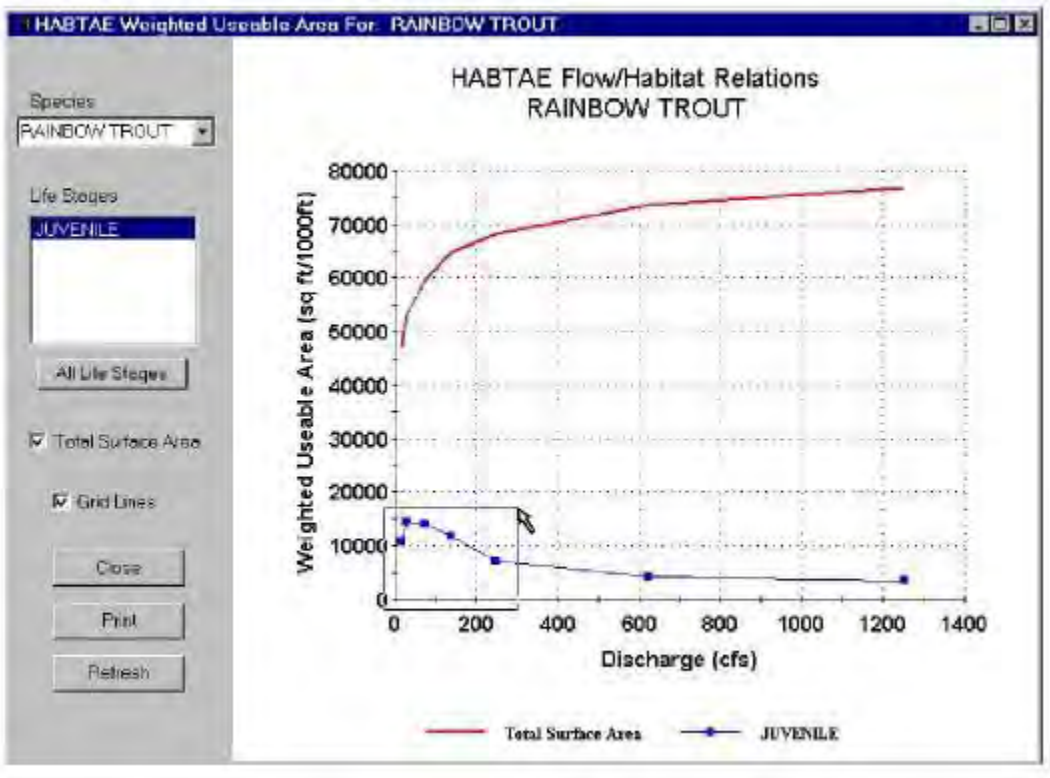
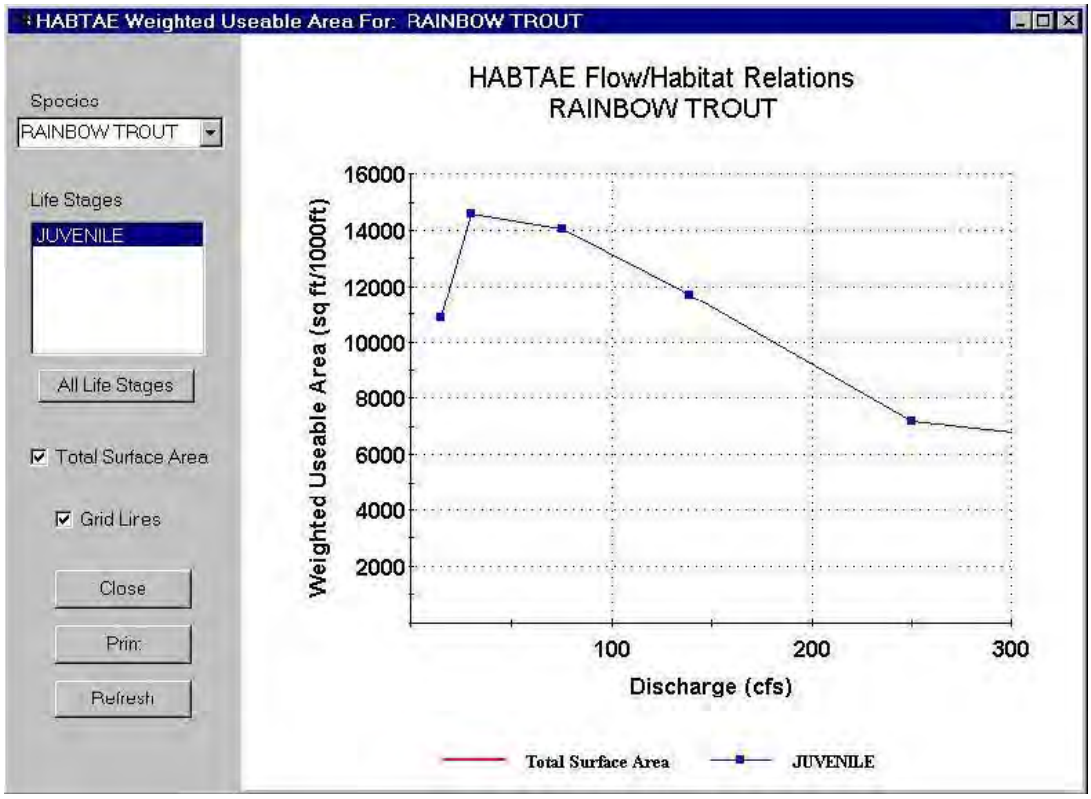
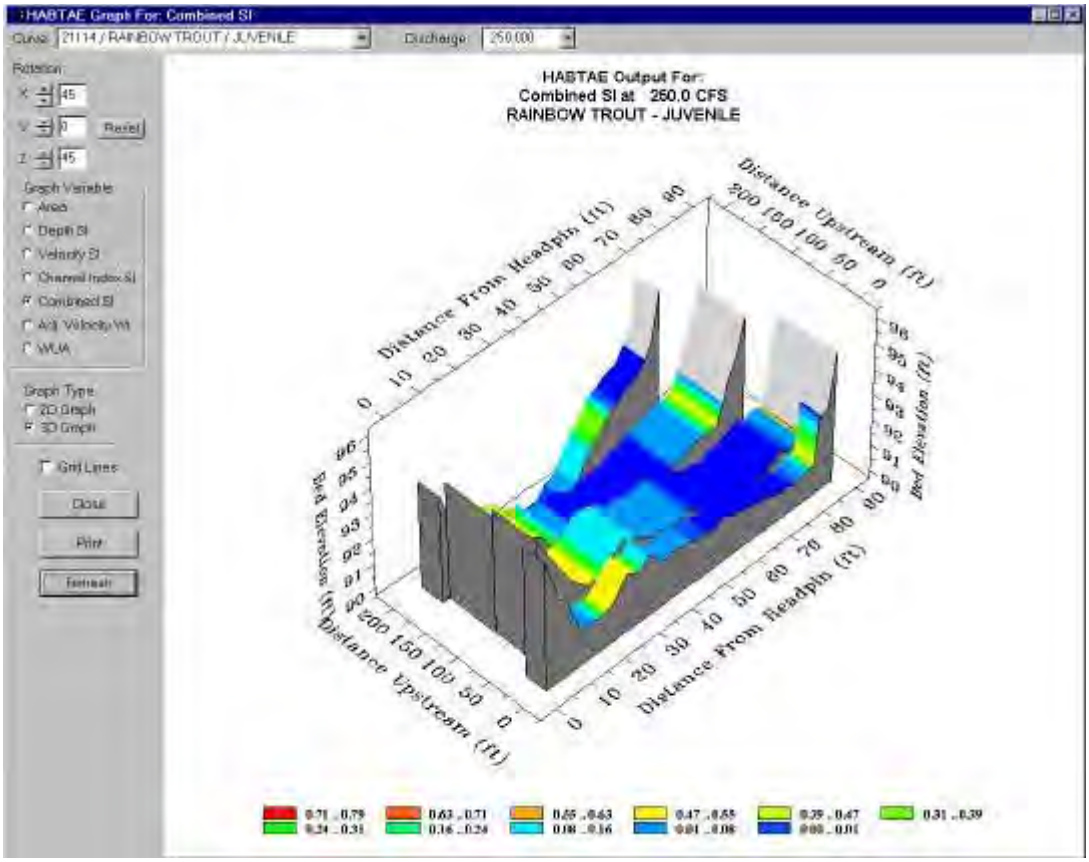
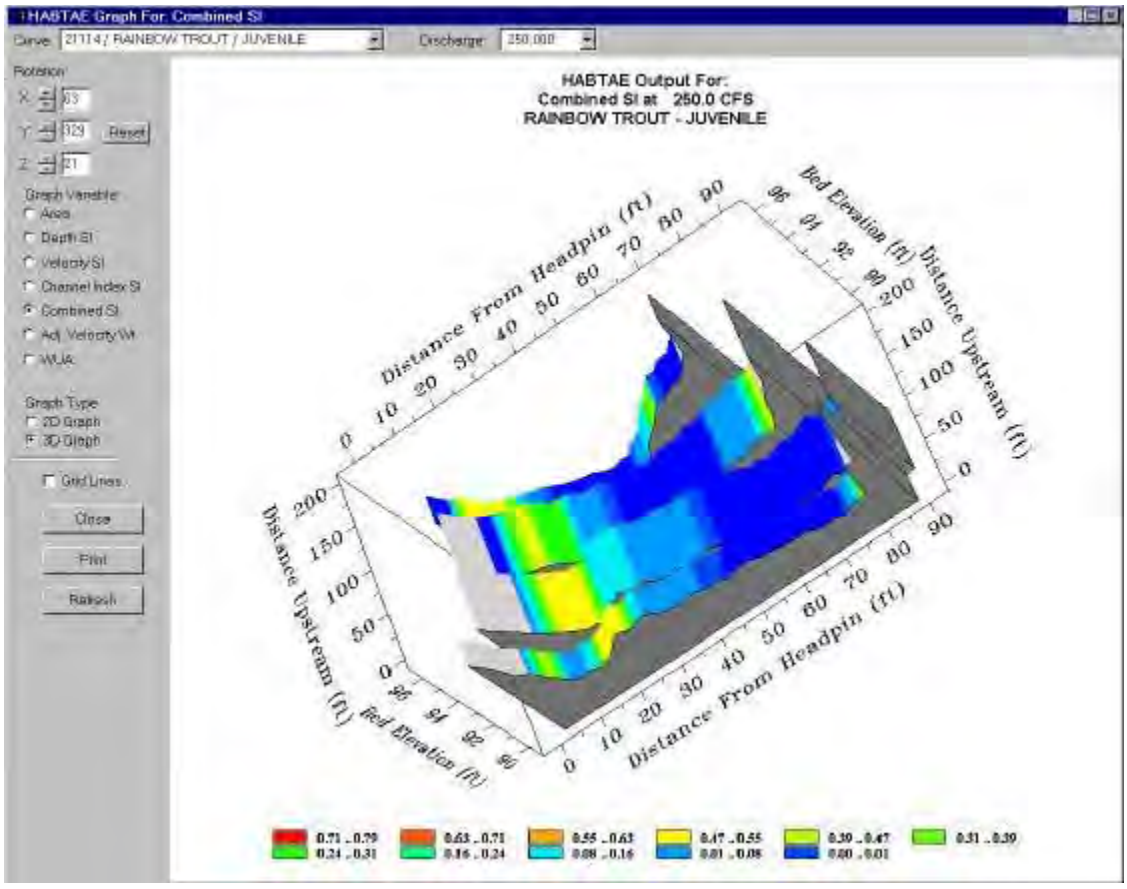
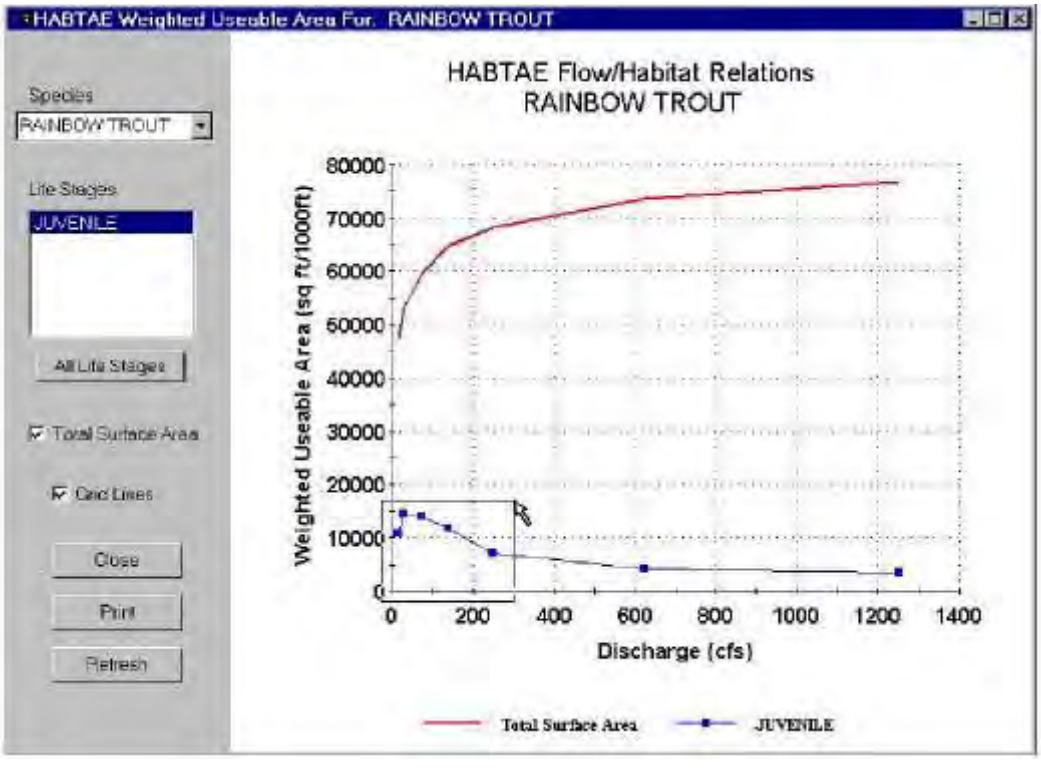


Figure L1-4. Selecting a region to enlarge. Hold Shift and Left Mouse button, drag box to desired area. **Figure L1-5**. Zoomed view appears when mouse button is released. **Figure L1-6**. Default position of 3-D chart. **Figure L1-7**. Rotated 3-D chart. **Figure L1-8**. Press “r” o keyboard to return to original view.


HABTAE Weighted Useable Area For: RAINBOW TROUT
Species
RAINBOW TROUT
Life Stages
JUVENILE
All Life Stages
Total Surface Area
Grid Lines
Close
Print
Refresh
HABTAE Flow/Habitat Relations
RAINBOW TROUT
Weighted Useable Area (sq ft/1000ft)
16000
14000
12000
10000
8000
6000
4000
2000
100
200
300
Discharge (cfs)
Total Surface Area
JUVENILE


HABTAE Graph For: Combined SI
Curve: 21114 / RAINBOW TROUT / JUVENILE
Discharge: 250.000
Rotation
X: 45
Y: 0
Reset
Z: 45
Graph Variable
Area
Depth SI
Velocity SI
Channel Index SI
Combined SI
Adj. Velocity WA
WUA
Graph Type
2D Graph
3D Graph
Grid Lines
Close
Print
Refresh
HABTAE Output For:
Combined SI at 250.0 CFS
RAINBOW TROUT - JUVENILE
Distance From Headpin (ft)
Distance Upstream (ft)
Bed Elevation (ft)
Wet Elevation (ft)
0.71 - 0.79
0.63 - 0.71
0.55 - 0.63
0.47 - 0.55
0.39 - 0.47
0.31 - 0.39
0.24 - 0.31
0.16 - 0.24
0.08 - 0.16
0.01 - 0.08
0.00 - 0.01


HABTAE Graph For: Combined SI
Curve: 21114 / RAINBOW TROUT / JUVENILE
Discharge: 250.000
Rotation
X: 63
Y: 329
Reset
Z: 21
Graph Variable
Area
Depth SI
Velocity SI
Channel Index SI
Combined SI
Adj. Velocity SI
WUA
Graph Type
2D Graph
3D Graph
Grid Lines
Close
Print
Refresh
HABTAE Output For:
Combined SI at 250.0 CFS
RAINBOW TROUT - JUVENILE
Distance From Headpin (ft)
Bed Elevation (ft)
Distance Upstream (ft)
0.71 - 0.79
0.24 - 0.31
0.63 - 0.71
0.16 - 0.24
0.55 - 0.63
0.08 - 0.16
0.47 - 0.55
0.01 - 0.08
0.39 - 0.47
0.00 - 0.01
0.31 - 0.39



A Strategy for Using PHABSIM for Windows

PHABSIM for Windows was designed to be used in combination with other Windows features to allow a large degree of flexibility in the PHABSIM analysis. The following suggestions constitute a strategy for using Windows to the maximum advantage while doing a PHABSIM analysis.

Monitor Adjustments

We have found it is most convenient to adjust your monitor to display the maximum number of pixels that can comfortably viewed. Current generation 17- inch monitors can reliably display 1024 x 768 pixels with font sizes in the range of normal printed text. If you can comfortably use 1280 x 1024 pixels you will find additional utility in being able to position various windows on the desktop for convenient use. The minimum resolution monitor that can be used with PHABSIM for Windows is 800 x 600 pixels. You may find that a 19-inch monitor operating at 1280 by 1024 pixels facilitates the analysis by allowing multiple windows to be open simultaneously.

Location of the Working Directory

PHABSIM for Windows places the sample files in **C:\My Documents\Phabsim\Sample1** and **..\Sample2.** This location was chosen solely because most computers using Microsoft Windows will have

a My Documents directory on the C: drive. You may place your working directory for any project in the desired location at project creation. This may be accomplished by creating the directory using the **Browse** feature in the **\File\Open Project** dialog or by creating the directory prior to running PHABSIM for Windows using Windows Explorer. Place the working directory in a location that is relevant to your project and easy to remember.

The PHABSIM Window

The main program window need not be maintained at its full size. The primary purpose of the main window is to provide the top-level menu items in the menu bar. Thus, after a project is opened, the main PHABSIM window may be sized so only the menu bar or the text in the project description is displayed. This opens up space on the desktop without losing any of the main menu functionality. Drag the lower right corner of the window to resize it.

Displaying Graphs

Many of the plots of input data or model results display values that are either entered or displayed using various interactive tables in the PHABSIM for Windows interface. It is often convenient to drag the graph window to the lower right of the screen and drag the data entry or program option window to the upper right so at least portions of the data table may be viewed at the same time as the graph. Graph windows may be resized by dragging their corners.

The Desktop

We have found that it is very convenient to place icons on the desktop for PHABSIM, Projview (a PHABSIM file translation utility), Notepad, and Wordpad (also called Write). It is also convenient to have an icon for your spreadsheet program to provide ease of starting the spreadsheet by simply double clicking the icon.

A convenient way to capture PHABSIM for Windows graphics (other than printing them) for use in other documents is to use the Print Screen feature of Windows and paste the graphic into Microsoft Paint. Thus, placing an icon for Paint on the desktop may also be convenient.

PHABSIM for Windows produces numerous files that can provide ancillary information during the course of the analysis. It is convenient to have Windows Explorer running while using PHABSIM so those files may be accessed by simple drag and drop actions from Windows Explorer to the other programs noted here that are placed on the desktop.

Auxiliary Programs

Spreadsheet Program

Though PHABSIM for Windows contains numerous automatically generated plots that can be used to display both input data and the results produced by the various models within the program, the plotting package can only display results from the current analysis. Thus, when the user wishes to compare results of different analyses, it is necessary to export those results to a different medium using cut and paste operations. We have found it very convenient to create spreadsheets for this purpose. Later lab exercises use spreadsheets to calculate differences between model results based on different model options and to display those different results graphically. When spreadsheets are used in conjunction with PHABSIM for Windows, the spreadsheet files should be saved with the PHABSIM files and should become part of the analysis record.

Notepad

While applying PHABSIM to a study site, numerous decisions are made regarding program options, data issues, and alternative approaches to describing habitat for the site. It is very difficult to recall each decision after the study is done. Thus, we suggest that the user create a Notepad file with a name like "Projectlog.txt" and keep a diary of the progress of the analysis including any problems encountered, the program options selected, and especially why they were selected, and any other pertinent information that will allow later defense of the study. For example, such a log file would be a good place to keep track of calibration error statistics and notes as to why a particular calibration was deemed satisfactory.

Windows Explorer and Wordpad

In addition to the results tables provided in the PHABSIM for Windows interface, the program produces numbered *projectname.ZOUTxx* files that contain computational details and other numerical results from running the models. Viewing these files facilitates some portions of the analysis. It is convenient to be able to "drag and drop" the numbered ZOUTxx files from Windows Explorer to Notepad for viewing. Some of the files will be too large for Notepad, but Wordpad will be able to display them. Further, Wordpad provides more formatting control, when portions of the ZOUT files are to be inserted in reports, than Notepad.

Use Strategy

When doing a PHABSIM analysis, the strategy we have found most convenient is to open and minimize the following programs and files:

- Notepad, open the log file
- Spreadsheet, open data comparison or error tracking file(s)
- Windows Explorer, move to the working directory so you can drag and drop conveniently

The minimized programs will show as buttons on the task bar at the bottom of the screen. Click on the appropriate button to access them. Remember to save your log, PHABSIM and spreadsheet files often during the course of the analysis. Such a strategy will prevent data loss due to the occasional inevitable mistake.

Laboratory 2. Building a PHABSIM Project

Objective

The objective of this laboratory is to cover the use of PHABSIM for Windows to create a PHABSIM project file. PHABSIM for Windows will be used to create an example project file and the project will be reviewed for errors.

Data Files Used: Data.xls

Introduction

In typical PHABSIM applications, the user will likely have a number of cross sections where the hydraulic characteristics of the river channel have been measured at one or more discharges. In this laboratory, we have provided data collected at four cross sections from the Fryingpan River, where water surface elevations and velocities have been measured at three calibration discharges. All the hydraulic data necessary to create a complete PHABSIM project file have been summarized in tabular form by cross section and provided in Tables L1-1 to L14 at the end of this lab. Information about reach lengths, Stage of Zero Flow (SZF), upstream weighting factors, reach length, slope, best estimate of the discharge, and measured discharge at each calibration flow is located at the top of each tabular summary. The remaining data in the table lists the x-distance, bed elevation, channel index, and observed velocities at each of the calibration flows.

The laboratory illustrates use of **Edit\Cross sections** to enter the data for the four cross sections. Two complete PHABSIM project data files containing these calibration data have already been created (SAMPLE1.PRJ and SAMPLE2.PRJ) as example data files. SAMPLE1.PRJ contains data entry only, while SAMPLE2.PRJ has been run through the habitat simulation stage. Both projects are included on the PHABSIM distribution disks. Proceed through the steps in order. If you run out of time to enter all the data described below, you can use SAMPLE1 to navigate the various menus and view diagnostic plots. A separate set of worked laboratory exercise project files is provided for each lab. The location of those files will vary depending on the computer system used for class instruction.

Step 1. Create a New Data Set

Now that you understand the basic PHABSIM for Windows navigation process from Lab 01, you are ready to open a new project and enter data.

For ease of reference these instructions will use the Project name MYLAB02.

\File\Open Project: Enter a project name in the **Project folder name** box. Then type a description of the project in the **Project Description** box. (The description is limited to 256 characters.) Next use the **Browse** button to navigate the Windows file tree to where you want the new folder to be stored. PHABSIM for Windows will create a directory and a set of files with the project name. For this lab, enter the new project name (i.e., MYLAB02) in the file name box, enter an appropriate description in the project description box, then click **Browse** and navigate to \IF310\Laboratories, and click **OK**. (See Figures L2-1, L2-1, and L2-3.)

Figure L2-1. Opening a new project.

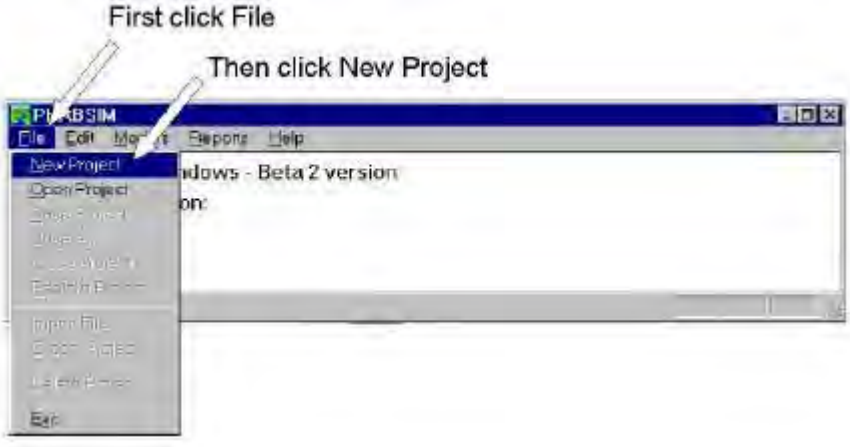
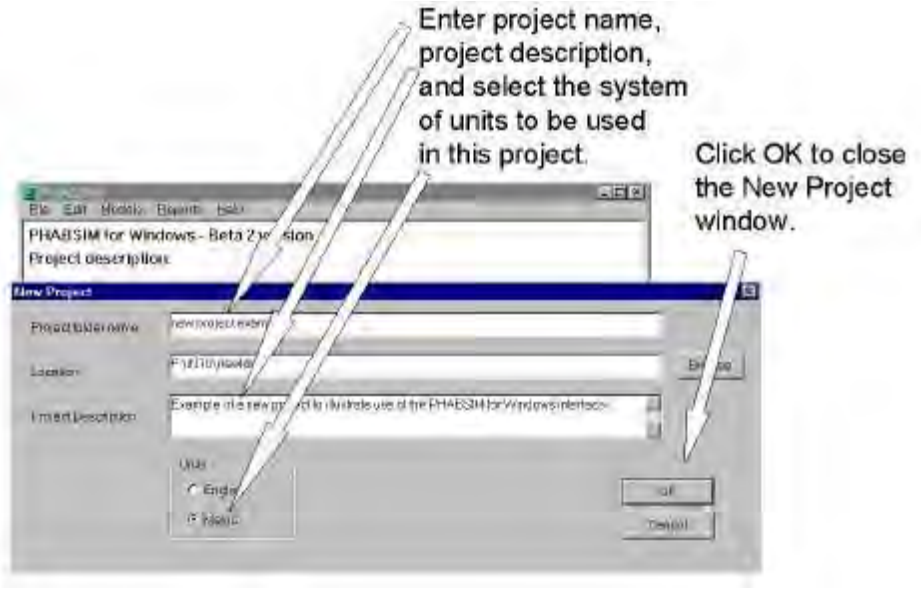


Figure L2-2. Assigning a folder location.

Figure L2-3. Entering project name and description.





An example of a project description might be:

> "Fryingpan River 3 miles downstream from Reudi Reservoir. High flow data collected May 10, 1999, mid flow data collected July 10, 1999, and low flow data collected Aug. 23, 1999. By name, name, and name."

You can revise the project description from the Edit menu using **\Edit\Project Data**. This allows adding short notes on the status of the analysis as the process progresses.

Step 2. Enter Project Hydraulic D**ata for Lab02**

To build a project's data set, click the **Edit** menu item. You are presented with choices of **Cross Sections**, **Suitability Curves**, and **Discharges**. You can enter and change data for each of these categories by selecting the corresponding menu item. However, you must begin with **Edit\Cross Sections\Cross Section Data** and enter the cross section data for at least one transect (cross section) prior to entering calibration data or coordinate data as shown in Figure L2-4. The Edit\Cross Sections dialog contains three tabs for **Cross Section Data, Calibration Data,** and **Coordinate Data**. The **Cross Section Data** tab is displayed by default.

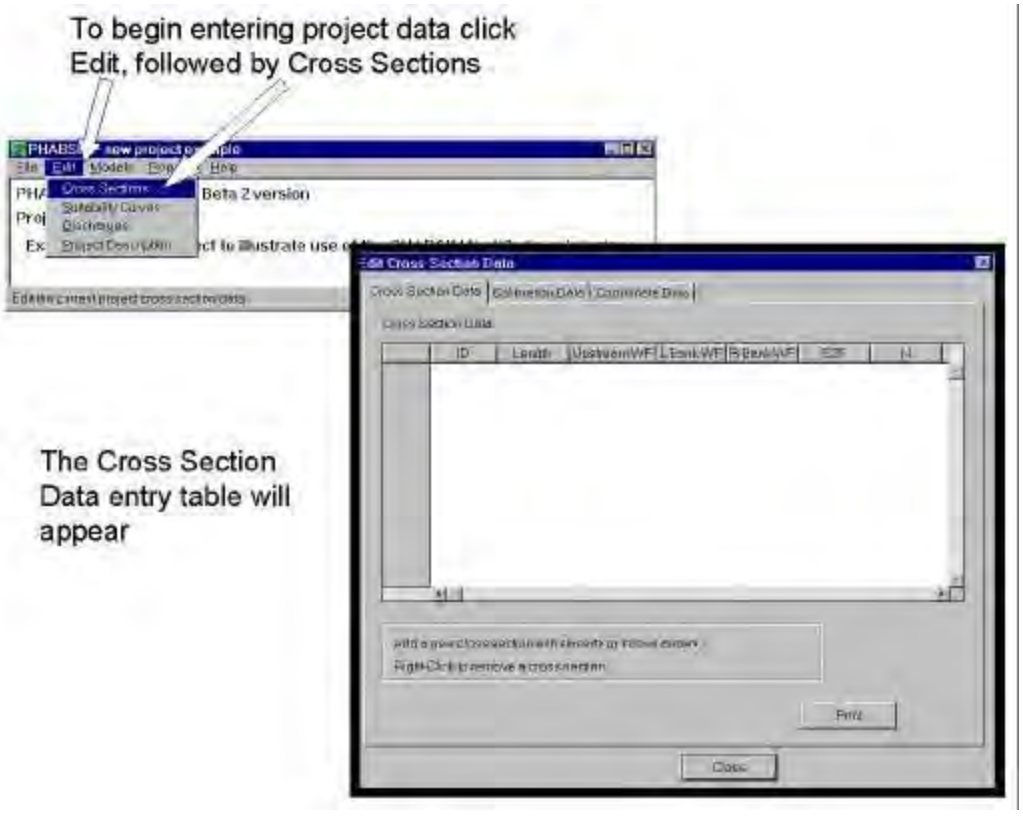


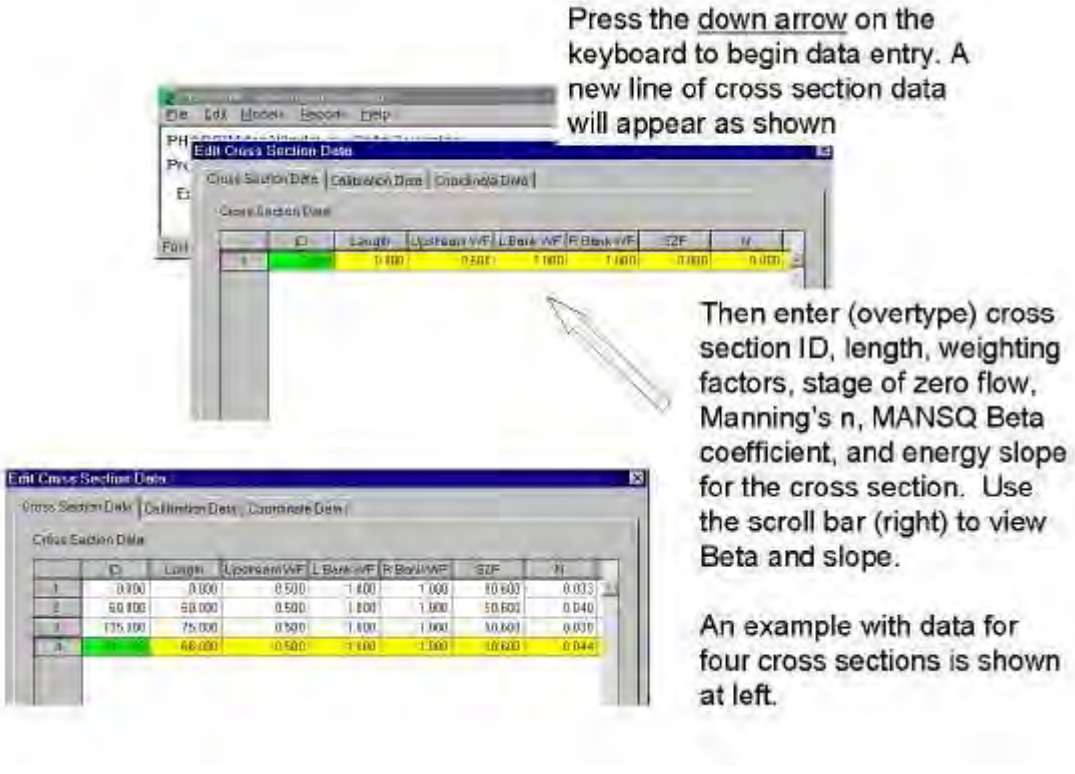
Figure L2-4. Preparing to enter cross section data.

To create a new cross section, in the ..**Cross Section Data** tab, use the down arrow. A row of cells appears with a cross section ID number of "–1.00". For each cross section, enter the id for the cross section by typing the cross section ID from Table L2-1 over the –1.00 entry. Move the highlight cursor to the right with the right arrow and enter the reach length. Continue moving to the right and enter the upstream weighting factor, the bend weights for the Left Bank and Right Bank, the stage of zero flow (SZF), Manning's n value (if known), Beta coefficient for MANSQ (if known), and the energy slope. Values for Manning's n and beta can be left unchanged for now. You would enter those values when using the WSP or MANSQ models later in the analysis. Your data for the first transect should now contain the

Windows		DOS	Difference	% difference
Cell bed elevation	91.65	91.65	0	0.00
Water surface elevation	92.456	92.47	0.014	0.02
Depth	0.806	0.82	0.014	1.71
Depth Suitability Index	0.0708	0.096	0.025	26.25
Combined Suitability Index	0.0644	0.087	0.023	26.25
Weighted Usable Area	8.698	11.79	3.096	26.25
Acknowledgements				**i**
PREFACE				**ii**
A Brief History of PHABSIM				

following values.

Complete the cross section data table as shown in Figure L2-5. Scroll right to include beta and slope values. **Figure L2-5**. Entering cross section data.



Next, click on the cross section ID 0.00 line and proceed to the **Calibration Data** tab (Fig. L2-6). Enter data for either left and right bank water surface elevations, *or* a single "user" selected water surface elevation, the user-determined or "given" discharge for the study site, and the measured discharge for the current transect. Enter these items for each calibration discharge (matching each VEL set) for this study. Return to **..\Cross Section** tab to change to the next cross section ID.

Note that the best estimate discharge must be a unique value (duplicates are not allowed). After you enter calibration data and exit the calibration data tab, the table sorts in ascending order on the **Best Estimate Q** values.

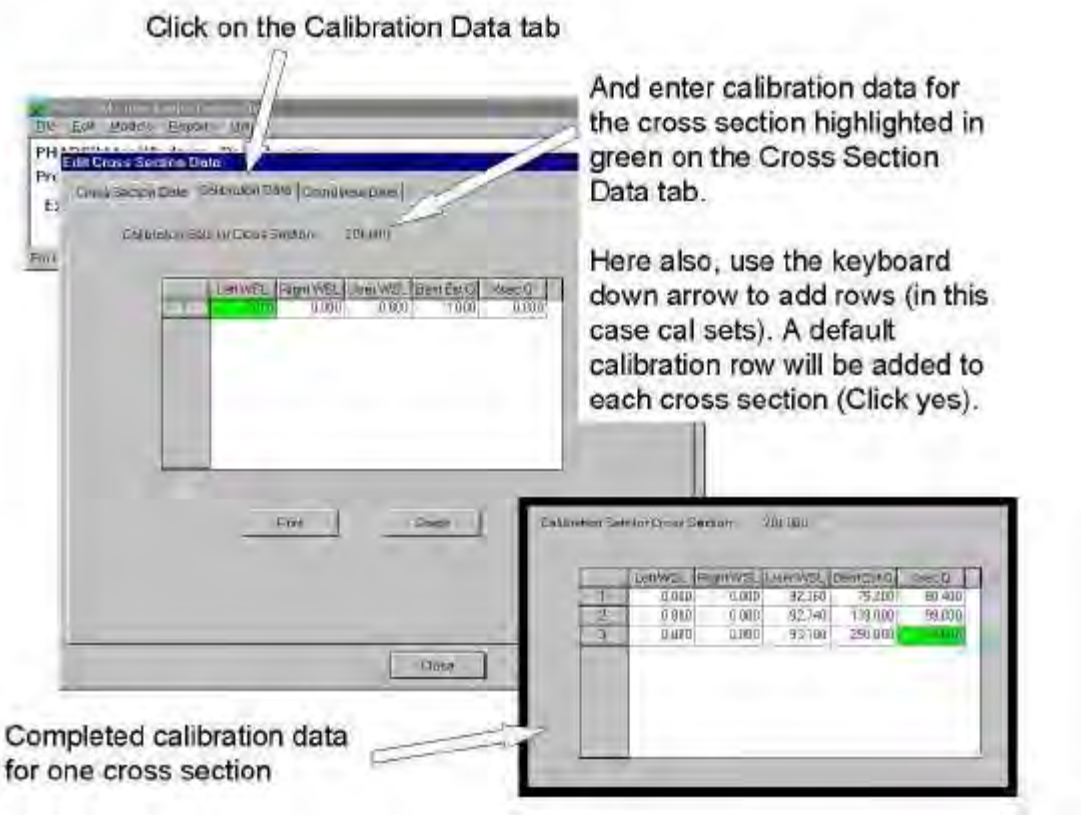


Figure L2-6. Entering calibration data.

Coordinate Data tab. Here you will find a difference from historical PHABSIM data entry in that there are values for X, Y, and Z. The inclusion of three dimensions is in anticipation of the ability to import GIS or spatially referenced data in the future. For now, enter the total distance upstream from the first transect as Y. Thus, X represents distance across the transect from the head pin, Y represents the distance upstream from the first transect (also referred to as Stationing), and Z represents the vertical distance above the datum selected for the study site. The program calculates Y values and those cells have a gray background.

From the data in sheet xsec01 enter the x-distance in column X, the distance upstream from the first transect in column Y, and the elevation in column Z. Channel index and individual Manning's n values for each cell are entered in the columns labeled CI and N. Calibration velocity sets are entered in the **Vel @discharge** columns. Enter the coordinate and velocity data from Table L2-1. The coordinate data entry process is shown in Figure L2

7. When you have finished, proceed to the **..\Cross Section Data** tab, select the next cross section and repeat the Calibration Data and Coordinate Data entry steps.

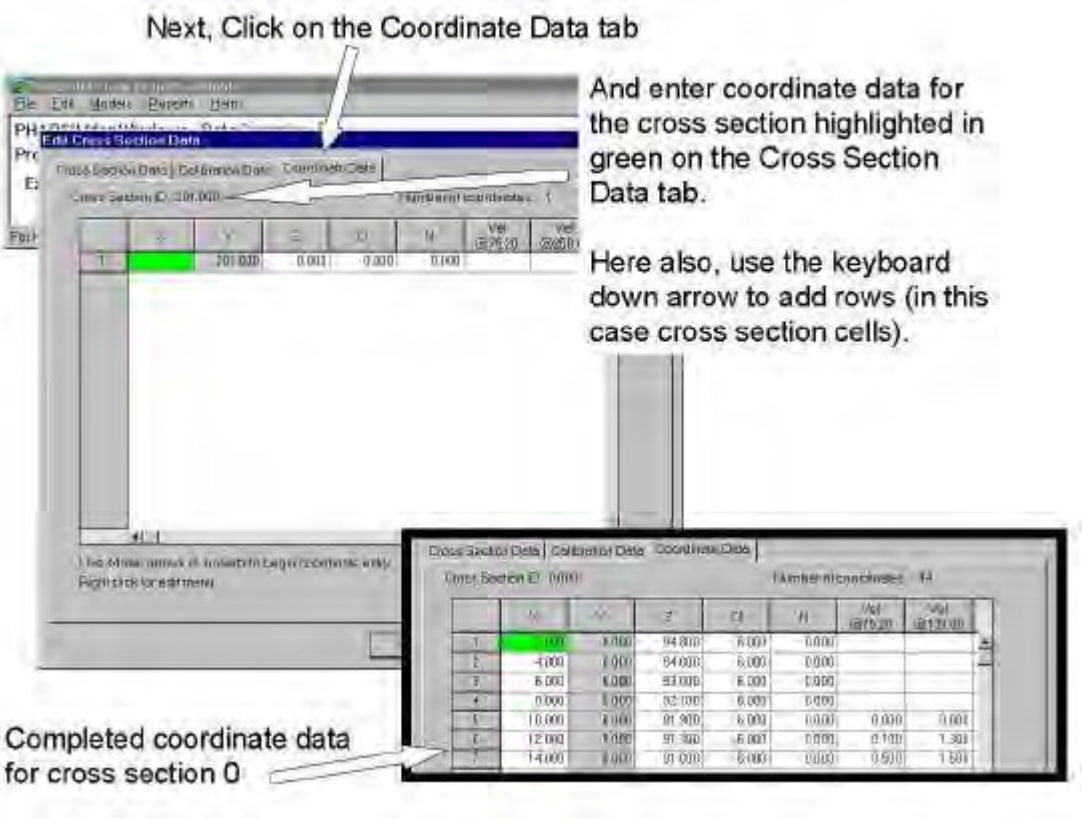


Figure L2-7. Coordinate data entry.

These steps would normally be repeated for all transects in the study. At that point, you have entered the basic hydraulic data for the study site. In this lab, we will also learn how to input coordinate data from a spreadsheet using Windows copy and paste functions for the third and fourth cross sections in this project.

Entering Coordinate Data by Copy and Paste from a Spreadsheet

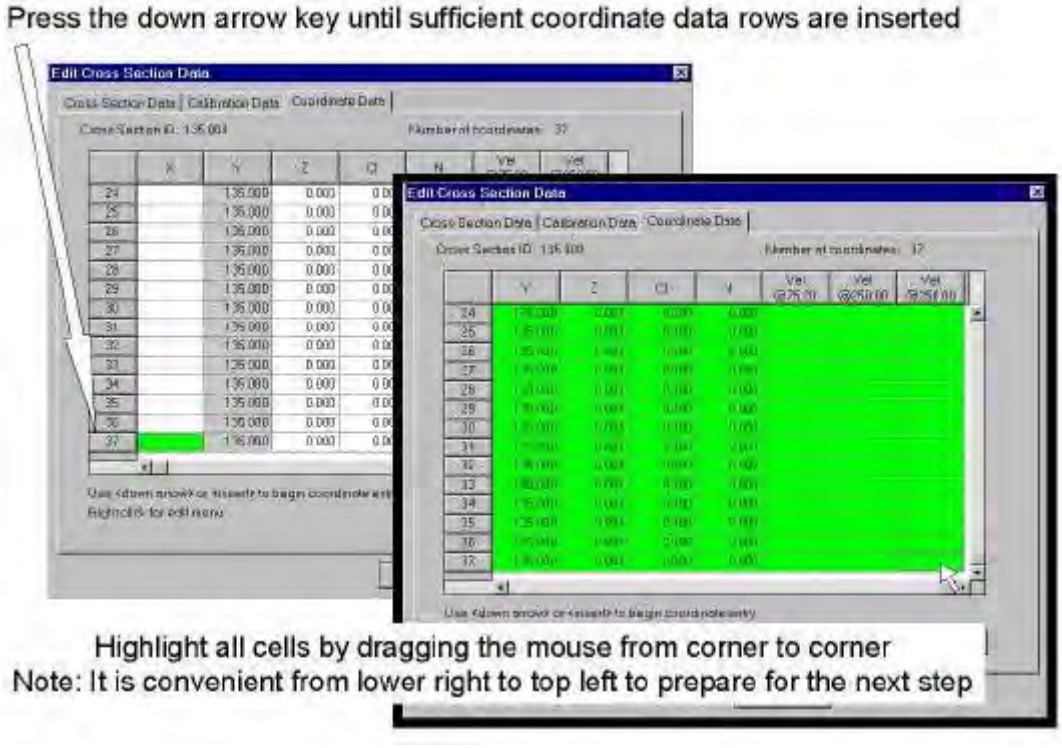
PHABSIM for Windows allows entry of certain parts of the project data using Windows copy and paste operations. The third party data entry software has some quirks that must be accommodated to enable the copy and paste features. The next steps demonstrate how to paste coordinate data from a spreadsheet into PHABSIM for Windows.

Move to the ..**Calibration Data** tab for cross section 135. Enter (type) the calibration data contained in Table L2-1. Now move to the **..\Coordinate Data** tab for cross section 135.

Start your spreadsheet software and open the spreadsheet named Mylab02.xls. Move to the worksheet labeled XSEC135. There you will find a block of cells containing the X, Y, Z, channel index, Manning's n, and calibration velocity data for this cross section. Using the row index at the left, determine the number of rows of data in the transect. Highlight this block of cells and execute the Windows Copy command to copy those values into the Windows clipboard.

Return to PHABSIM for Windows using a mouse click in that window.

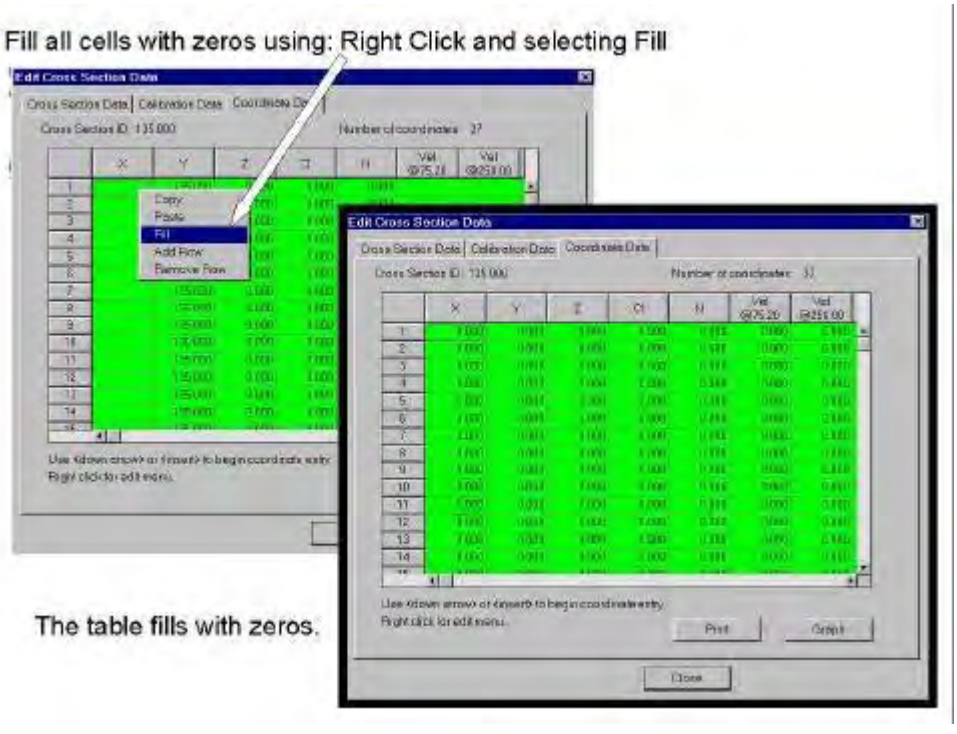
Using the **Insert** or **Down Arrow** key, insert the number of rows of data (not row numbers) found in the **Coordinate Data** tab worksheet. (If you insert too many rows, right click and select **Remove Row** as many times as needed. Then, using the left mouse button, **Drag** the cursor from the lower left (last X, last vel) corner of the worksheet to the upper left, being sure to include the calibration velocity set columns. That entire area should now be highlighted. Next, **Right Click** and select **Fill** from the pop-up menu. The entire area will be filled with 0.00. Finally, move to the upper left corner of the coordinate data entry area again. **Right Click**, and select **Paste** from the pop-up menu. The highlighted coordinate data area will be filled with the data from the spreadsheet. This process is shown in Figures L2-8 through



L2-10.

Figure L2-8. Opening and blocking coordinate data tab rows.

Due to the nature of the data entry grid software, calibration velocity cells that were blank in the spreadsheet now have zeros. Delete those zeros using the **Delete** key so the data set follows the convention that a blank velocity means the cell was dry and a velocity of 0.0 means the cell had standing water. Compare the PHABSIM for Windows data entry sheet with Mylab02.xls to ensure all of the required velocity cells are changed to blank. Column Y may change during this cut and paste operation, but it will revert to the calculated value the next time you open this tab.



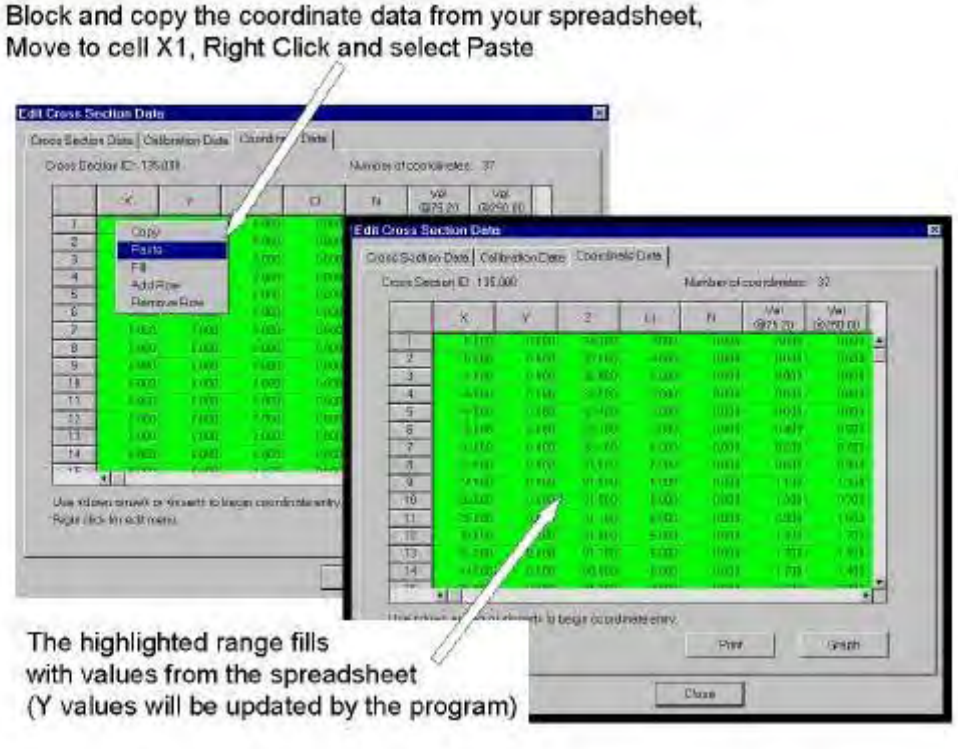


Figure L2-9. Filling the coordinate data table with zeros.

Figure L2-10. Pasting coordinate data from a spreadsheet.

Repeat these operations (Calibration and Coordinate Data) for cross section 201.

Step 3. Enter Suitability Data for Lab02

Click **Edit\Suitability Curves** and you are presented with a dialog box where habitat suitability of use curve (HSC) data can be entered for all species of interest for the study. Begin by using **..\Suitability Curves\Edit\Add Curve** and entering the curve ID number and the species and life stage descriptions from the HSC sheet in the Mylab02 spreadsheet in the boxes provided. Note that curve ID numbers should be five or more digits to capture species and life stage coding. Then click **OK**. A table for entry of the Velocity curve information is displayed by default.

The same **Insert** key convention to create a new line used with coordinate data entry applies. You may also copy and paste HSC curves into PHABSIM for Windows using the conventions described for coordinate data above. You must type the species, life stage, and HSC number, but the coordinate data can be entered using copy/paste operations.

Enter the HSC data for velocity by copy and paste or by typing.

To switch to the Depth, Channel Index, or Temperature HSC curves, click the appropriate button in the Curve Type box at the upper right and enter the HSC data by paste or typing as above.

Repeat this process beginning with **..\Add Curve** for all HSC curve sets in the HSC sheet.

Enter Simulation Discharges for Lab01

This step may be performed now or after the hydraulic models have been calibrated. To avoid excessive output during the calibration process, the user would typically select to run the full range of simulation discharges toward the end of the hydraulic model calibration process. Those selections will be made in the WSL and Velsim windows in later lab exercises. We will enter a small number of additional discharges here to illustrate the process.

Select **Edit\Discharges** to display the Simulation Discharges window. The user-defined calibration best estimated discharges (75.2, 139.0, and 250.0 cfs) are shaded in gray. They are automatically entered in the Discharge column. Note that they are marked "cal" in the Type column. Click on the first of these discharges and press the **Insert** key. A new cell with a value of 0.00 will appear. Enter a value of 15.0. Repeat this process with Insert (before the calibration discharges) or the Down arrow (after one or more calibration discharges) to enter the values of 60.0, 625.0, and 1250.0. Click the Close button to end discharge data entry.

You have now finished the basic data entry process. Save your project using **File\Save Project**.

One more key data entry step remains, that of entering Suitability-of-use criteria (SI curves). This topic will be covered in Laboratory 7.

Step 4. Evaluate Diagnostic Plots

The quality of any modeling exercise begins with correct data entry. PHABSIM for Windows contains several means of viewing plots of the entered data for quality control. A longitudinal plot of the observed water surface elevations can be obtained using **Reports\Graphs\Longitudinal Profile** and checking the Observed WSL box. Selecting \Edit\Cross Sections\Coordinate Data and clicking the graph button can view cross section geometry plots. The cross section profile is displayed for the cross section currently selected in **Edit\Cross Sections\Cross Section Data.** To view different cross sections, return to the **..\Cross Section Data** tab and select the desired cross section, then return to the **..\Coordinate Data** tab. Combined plots of velocities, water surface elevations and bed geometry can be obtained using **Reports\Graphs\Bed Profile with WSL\Velocities** and checking the Observed WSL and Observed Velocity boxes. You may wish to toggle on or off various calibration discharges for clarity.

Step 5. Quality Assurance

As noted earlier, a longitudinal plot of the observed water surface elevations can be obtained using **\Reports\Graphs\Longitudinal Profile** and checking the Observed WSL box. Cross section geometry plots can be obtained by selecting **\Reports\Graphs\Bed Profile with WSL\Velocities** and checking the Observed WSL and Observed Velocity boxes.

First, look at the longitudinal profile using **\Reports\Graphs\Longitudinal Profile**, and then the cross section profiles for each transect using **\Reports\Graphs\Bed Profile with WSL\Velocities**. In the cross section profile plots, select the cross section and discharge to be viewed in the tables to the left of the plot and click **Refresh**. Examining the longitudinal profile of the water surface elevations and thalweg depths in conjunction with the cross section profiles for these data should indicate cross section 0.0 is a riffle (or channel control) and that cross section 201 is in a pool. This is shown by the increased depths at cross section 201 (see longitudinal profile) as well as the more parabolic shape of the cross section profile at station 201.

Note in Table L2-1, the velocity values at verticals from 1.0 to 4.0 and vertical 44 have been left blank, since these verticals were out of the water at each of the calibration discharges.

In general it is a good idea to examine the longitudinal and cross section plots and note any areas that appear unusual. Are there any characteristics of this data set that merit further attention? **Hint**: look at the three velocity profiles for cross section 201. Look carefully at the shape of the velocity profiles and at the stream margins. Do you see anything that does not make sense? Are the longitudinal water surface profiles (look at longitudinal plot) consistent? If there are any questions, you can refer to the original field notes, consult with the crew members or look for other means (assistance of a hydraulic engineer or hydrologist, for example) to resolve inconsistencies.

Table L2-1. Data for cross section 0.0. **Table L2-1**. Concluded. **Table L2-2**. Data for cross section 60.0.

Windows		DOS	Difference	% difference
Cell bed elevation	91.65	91.65	0	0.00
Water surface elevation	92.456	92.47	0.014	0.02
Depth	0.806	0.82	0.014	1.71
Depth Suitability Index	0.0708	0.096	0.025	26.25
Combined Suitability Index	0.0644	0.087	0.023	26.25
Weighted Usable Area	8.698	11.79	3.096	26.25

Acknowledgements **i**

PREFACE **ii**

A Brief History of PHABSIM

Use of this Document

Changes Between PHABSIM Version 2 and PHABSIM for Windows

Conventions Used in this Document

Chapter 1, Introduction to the Physical Habitat Simulation System **1**

Objectives

Associated Laboratory Exercises

An Overview of IFIM

The Purpose of PHABSIM

The Structure of PHABSIM

Application of PHABSIM

Scoping

Selection of Target Species and Suitability Curves

Selection of Target Species

Types of Suitability Curves

Transferability of Suitability Curves

Segmenting the Study Area and Study Site Location

Critical Reach

Mesohabitat Study Site Selection

Cross Section Selection and Field Data Collection

Cross Section Selection

Field Data Collection

Hydraulic Modeling

Water Surface Elevation Modeling

Velocity Modeling

Habitat Modeling

The Average Parameter Model

Distributed Parameter Models

Effective Habitat Analysis in PHABSIM

Interpreting PHABSIM and Completing the IFIM Process

Use of the PHABSIM for Windows Menu System

PHABSIM for Windows File Structure

Analysis Limits in PHABSIM for Windows

Summary of Chapter 1

Chapter 2, Hydraulic Modeling in PHABSIM **25**

Objectives

Laboratories

Introduction

Terms and Definitions of Open-Channel Flow

Equations Used for the Description of Open-Channel Flow

Continuity and Mass Balance

Union Analysis

Table L-2. Concluded.

Windows		DOS	Difference	% difference
Weighted elevation	91.65	91.65	0	0.00
Wetted perimeter	92.456	92.47	0.014	0.02
Water surface elevation	92.456	92.47	0.014	0.02
Depth Suitability Index	0.8068	0.826	0.019	2.35
Depth Suitability Index	0.806	0.82	0.014	1.71
Combined Suitability Index	0.0648	0.087	0.023	26.25
Depth Suitability Index	0.0708	0.096	0.025	26.25
Weighted Usable Area	8.698	11.79	3.096	26.25
Combined Suitability Index	0.0644	0.087	0.023	26.25
Weighted Usable Area	8.698	11.79	3.096	26.25

Acknowledgements i
PREFACE ii
A Brief History of PHABSIM
Changes Between PHABSIM Version 2 and PHABSIM for Windows
Use of this Document
Conventions Used in this Document
Chapter 1, Introduction to the Physical Habitat Simulation System 1
Objectives
Associated Laboratory Exercises
An Overview of IFIM
The Purpose of PHABSIM
The Structure of PHABSIM
Application of PHABSIM
Selection of Target Species and Suitability Curves
Types of Suitability Curves
Transferability of Suitability Curves
Segmenting the Study Area and Study Site Location
Critical Reach
Mesohabitat Study Site Selection
Cross Section Selection and Field Data Collection
Cross Section Selection
Field Data Collection
Hydraulic Modeling
Water Surface Elevation Modeling
Velocity Modeling
Habitat Modeling
The Average Parameter Model
Distributed Parameter Models
Effective Habitat Analysis in PHABSIM
Interpreting PHABSIM and Completing the IFIM Process
Use of the PHABSIM for Windows Menu System
PHABSIM for Windows File Structure
Analysis Limits in PHABSIM for Windows
Summary of Chapter 1
Chapter 2, Hydraulic Modeling in PHABSIM 25
Objectives
Laboratories
Introduction
Terms and Definitions of Open-Channel Flow
Equations Used for the Description of Open-Channel Flow
Continuity and Mass Balance
Union Analysis

Table L2-3. Data for cross section 135.0.

Windows		DOS	Difference	% difference
Cell bed elevation	91.65	91.65	0	0.00
Water surface elevation	92.456	92.47	0.014	0.02
Depth	0.806	0.82	0.014	1.71
Depth Suitability Index	0.0708	0.096	0.025	26.25
Combined Suitability Index	0.0644	0.087	0.023	26.25
Weighted Usable Area	8.698	11.79	3.096	26.25

Acknowledgements **i**

PREFACE **ii**

A Brief History of PHABSIM

Use of this Document

Changes Between PHABSIM Version 2 and PHABSIM for Windows

Conventions Used in this Document

Chapter 1, Introduction to the Physical Habitat Simulation System **1**

Objectives

Associated Laboratory Exercises

An Overview of IFIM

The Purpose of PHABSIM

The Structure of PHABSIM

Application of PHABSIM

Scoping

Selection of Target Species and Suitability Curves

Selection of Target Species

Types of Suitability Curves

Transferability of Suitability Curves

Segmenting the Study Area and Study Site Location

Critical Reach

Mesohabitat Study Site Selection

Cross Section Selection and Field Data Collection

Cross Section Selection

Field Data Collection

Hydraulic Modeling

Water Surface Elevation Modeling

Velocity Modeling

Habitat Modeling

The Average Parameter Model

Distributed Parameter Models

Effective Habitat Analysis in PHABSIM

Interpreting PHABSIM and Completing the IFIM Process

Use of the PHABSIM for Windows Menu System

PHABSIM for Windows File Structure

Analysis Limits in PHABSIM for Windows

Summary of Chapter 1

Chapter 2, Hydraulic Modeling in PHABSIM **25**

Objectives

Laboratories

Introduction

Terms and Definitions of Open-Channel Flow

Equations Used for the Description of Open-Channel Flow

Continuity and Mass Balance

Table L-3. Concluded.

Windows		DOS	Difference	% difference
Cell bed elevation	91.65	91.65	0	0.00
Water surface elevation	92.456	92.47	0.014	0.02
Depth	0.806	0.82	0.014	1.71
Depth Suitability Index	0.0708	0.096	0.025	26.25
Combined Suitability Index	0.0644	0.087	0.023	26.25
Weighted Usable Area	8.698	11.79	3.096	26.25

Acknowledgements **i**
PREFACE **ii**
A Brief History of PHABSIM
Use of this Document
Changes Between PHABSIM Version 2 and PHABSIM for Windows
Conventions Used in this Document
Chapter 1, Introduction to the Physical Habitat Simulation System **1**
Objectives
Associated Laboratory Exercises
An Overview of IFIM

Table L2-4. Data for cross section 201.0. **Table L2-4**. Concluded.

Windows		DOS	Difference	% difference
Windows		DOS	Difference	% difference
Cell bed elevation	91.65	91.65	0	0.00
Cell bed elevation	91.65	91.65	0	0.00
Water surface elevation	92.456	92.47	0.014	0.02
Water surface elevation	92.456	92.47	0.014	0.02
Depth	0.806	0.82	0.014	1.71
Depth	0.806	0.82	0.014	1.71
Depth Suitability Index	0.0708	0.096	0.025	26.25
Depth Suitability Index	0.0708	0.096	0.025	26.25
Combined Suitability Index	0.0644	0.087	0.023	26.25
Combined Suitability Index	0.0644	0.087	0.023	26.25
Weighted Usable Area	8.698	11.79	3.096	26.25
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Acknowledgements **i**
Acknowledgements **ii**
PREFACE **ii**
PREFACE **ii**
A Brief History of PHABSIM
A Brief History of PHABSIM
Use of this Document
Changes Between PHABSIM Version 2 and PHABSIM for Windows
Conventions Used in this Document
Chapter 1, Introduction to the Physical Habitat Simulation System **1**
Objectives
Associated Laboratory Exercises
An Overview of IFIM
The Purpose of PHABSIM
The Structure of PHABSIM
Application of PHABSIM
Scoping
Selection of Target Species and Suitability Curves
Selection of Target Species
Types of Suitability Curves
Transferability of Suitability Curves
Segmenting the Study Area and Study Site Location
Critical Reach
Mesohabitat Study Site Selection
Cross Section Selection and Field Data Collection
Cross Section Selection
Field Data Collection
Hydraulic Modeling
Water Surface Elevation Modeling
Velocity Modeling
Habitat Modeling
The Average Parameter Model
Distributed Parameter Models
Effective Habitat Analysis in PHABSIM
Interpreting PHABSIM and Completing the IFIM Process
Use of the PHABSIM for Windows Menu System
PHABSIM for Windows File Structure
Analysis Limits in PHABSIM for Windows
Summary of Chapter 1
Chapter 2, Hydraulic Modeling in PHABSIM **25**
Objectives
Laboratories
Introduction
Terms and Definitions of Open-Channel Flow
Equations Used for the Description of Open-Channel Flow

Laboratory 3. Water Surface Modeling Using A Stage-Discharge Approach

Objective

The objective of this laboratory is to demonstrate modeling water surface elevations based on a stage-discharge regression approach. The reader will be introduced to the use of the STGQ program within PHABSIM for this purpose. The general theory of stage-discharge modeling using a regression approach is covered in the manual in Chapter 3.

Program Used: STGQ

Project File Used: C:\My Documents\Phabsim\Laboratories\Lab3.phb

Introduction

The purpose of this laboratory is to introduce stage-discharge regression modeling in PHABSIM using the STGQ model. Recall from the lecture material that under most circumstances an investigator will obtain measured water surface elevations at a specific cross section at three or more flows, which is illustrated in Figure L3-1 for cross section 0.0 for the Fryingpan River (see Laboratory 1 or access **\Models\WSL\STGQ Options\Stage Discharge Graph** in the Lab3 project).

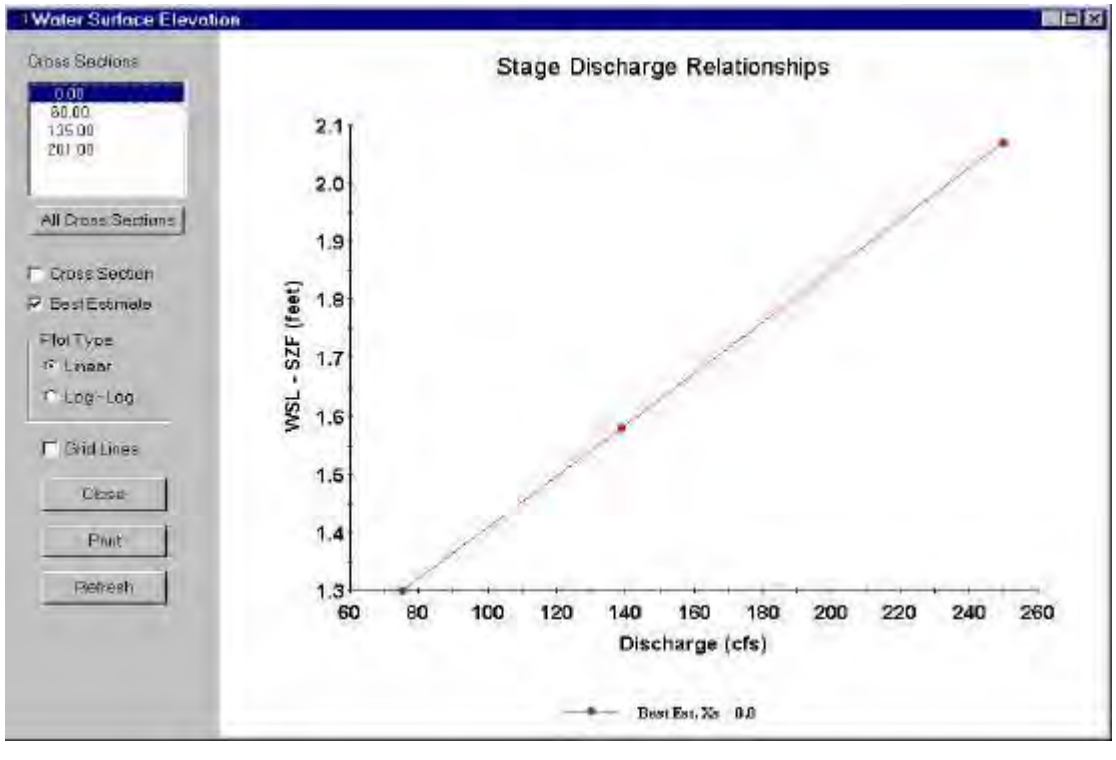


Figure L3-1. A stage-discharge relationship.

As discussed in Chapter 3, the relationship between stage (i.e. water surface elevation) and discharge can often be represented at a cross section in a channel by the following equation:

$$(WSL - SZF) = a\,Q^{b} \quad \text{(L3-1)}$$

where: Q = discharge
WSL = stage or water surface elevation
SZF = stage of zero flow
a = constant derived from measured values of discharge and stage
b = coefficient derived from measured values of discharge and stage

Note that the SZF is included in Equation L3-1 since the stage-discharge relationship at a channel cross section is a function of the SZF at that specific location as discussed in Chapter 3. The SZF is used within the STGQ program and should be included whenever using alternative stage-discharge regressions. Equation L3-1 can be transformed to a linear relationship between stage and discharge by taking the $\log_{10}$ of the equation, which yields:

$$\log_{10}(WSL - SZF) = \log_{10}(a) + b * \log_{10}(Q) \quad \text{(L3-2)}$$

Given at least three sets of measured stage-discharge data at a cross section, a simple linear regression can then be performed using Equation L3-2 to determine the constant and coefficient and the resulting regression equation can be used to predict stage over a desired range of discharges. The effectiveness of this modeling approach for the simulation of water surface elevations is not only a function of the observed data, but also the channel geometry and relative difference in the slopes of the regression lines between adjacent cross sections (see Chapter 3 of the manual).

In regression-based modeling, the primary modeling choices involve the selection of the appropriate calibration discharges (i.e., best estimate of discharge versus cross section specific [or "local"] discharges), determination of an appropriate SZF, and selection of the calibration water surface elevations. In this laboratory, the best estimate of the discharge and average water surface elevations will be used in the regressions. The SZF has also been determined based on the thalweg bed elevations at each cross section following the procedure outlined in Chapter 3 of the Manual.

Figure L3-2 contains the log of the water surface elevations (minus SZF) versus the log of the discharges (best estimate) for all four of the cross sections for the Fryingpan River. This figure is provided to assist in an understanding of the laboratory data and in the interpretation of the laboratory results.

Now proceed through the laboratory steps in the given order.

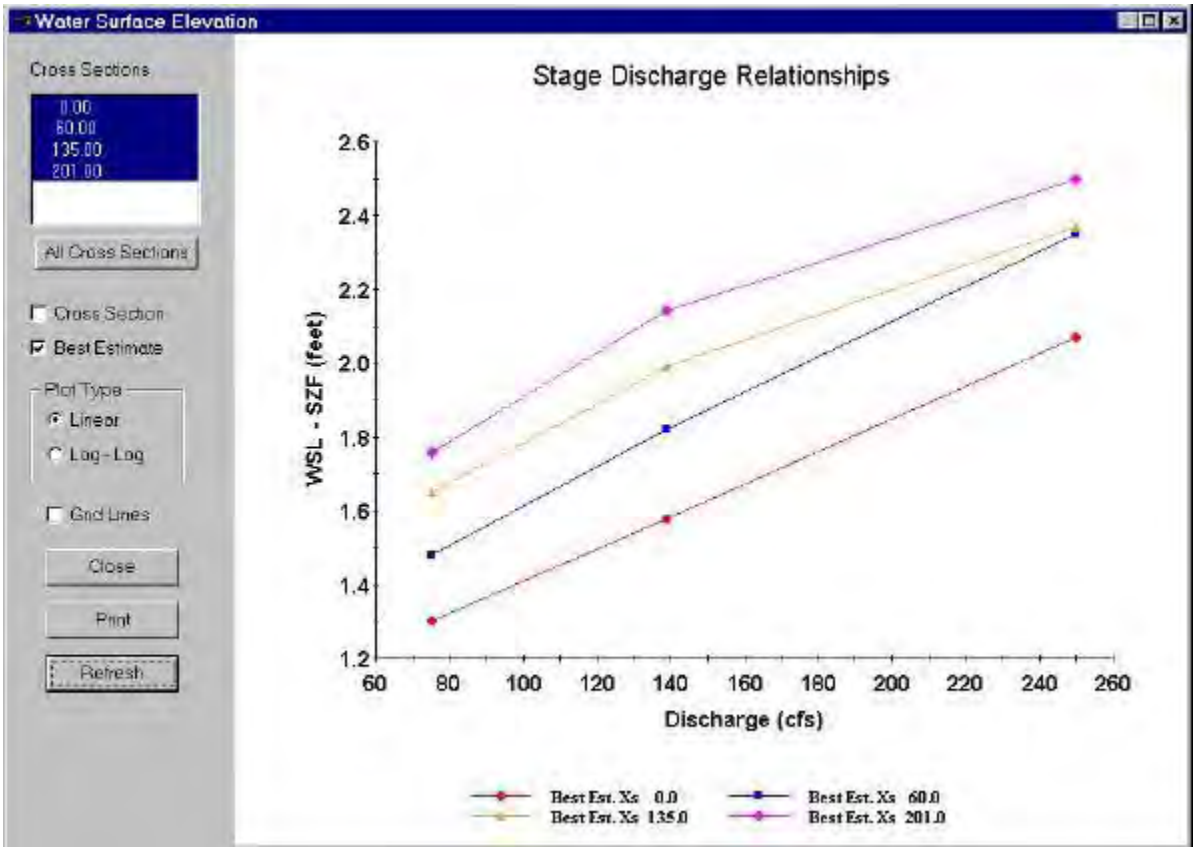


Figure L3-2. Stage-discharge relationship for four cross sections.

Step 1. Selection and Setup of STGQ Water Surface Simulation Model

The complete project data set for the Fryingpan River is supplied with the PHABSIM distribution disks and is named SAMPLE1.phb.

Begin by starting PHABSIM and opening the SAMPLE1 project. Select **Models\WSL.** The **Water Surface Elevation Simulation** window opens and the **Output Options** tab is displayed by default. In this window the user can select which of the discharges supplied earlier are to be used at the current stage of the simulation process. For example, while calibrating the hydraulic models, it is suggested to use only the calibration discharges. Thus, the check boxes in the **Use** column should be toggled so only the "cal" discharges are checked. When doing a final production run, all discharges would be checked. In this lab, we are running a small number of discharges, so leave this set at **Use All**.

In this window, you may also choose to overwrite the ZOUT (results output) files. If you chose not to overwrite ZOUT, successive runs of the models in PHABSIM append their results to ZOUT. This can result in a very large file, but may be necessary when working on a particularly difficult simulation. You may select Overwrite ZOUT File for this lab by clicking on the box or the **Overwrite ZOUT File** text so a check mark appears.

Next, click on the **STGQ Options** tab. Examine the options (see Chapter 3) and make sure that you understand which options are being used. In particular, note the Discharge (IOC Option 5) has been set to "Best Est Q" for all calibration sets for all transects. This instructs STGQ to use the first "best-estimate" discharge in the stage-discharge regressions. Setting the items in the Discharge column to **Xsec Q** will use the discharge measured at that cross section in the stage-discharge regression. This is not necessarily equivalent to the best estimated discharge for the reach at that calibration flow, but may provide a better fit to the observed water surface elevation for individual cross sections under some conditions.

Also note that the project has seven simulation flows ranging from 15.0 to 1250.0 cfs, which represent a range of discharges both lower and higher than the three calibration, flows of 75.2, 139.0, and 250.0 (see Laboratory 1). The higher and lower discharges allow an evaluation of model performance over a simulated range of discharges that is needed for the final habitat-discharge relation.

Step 2. Obtain the Calibration Water Surface Elevation and Discharge Data

Select **\Edit\Cross Sections\Calibration Data** to find the calibration data sets for the first cross section (i.e., cross section 0.0) and note the three calibration flows and their observed water surface elevations.

The three calibration flows (best estimate of discharge as well as the actual measured discharge at this cross section for each calibration set) and the corresponding water surface elevations from the CAL lines are:

Find and record the water surface elevations, discharges, and SZF for all cross sections in Table L3-1 by first clicking on the **Cross Section Data** tab, and on the next desired cross section, then the **Calibration Data** tab. Once you have recorded the data in Table L3-1, choose cancel and return to the **Models\WSL\STGQ Options** tab.

Windows		DOS	Difference	% difference
Cell bed elevation	91.65	91.65	0	0.00
Water surface elevation	92.456	92.47	0.014	0.02
Depth	0.806	0.82	0.014	1.71

Table L3-1. Calibration information for the Fryingpan River.

In this example, the best estimate of the discharge was determined from an examination of the measured

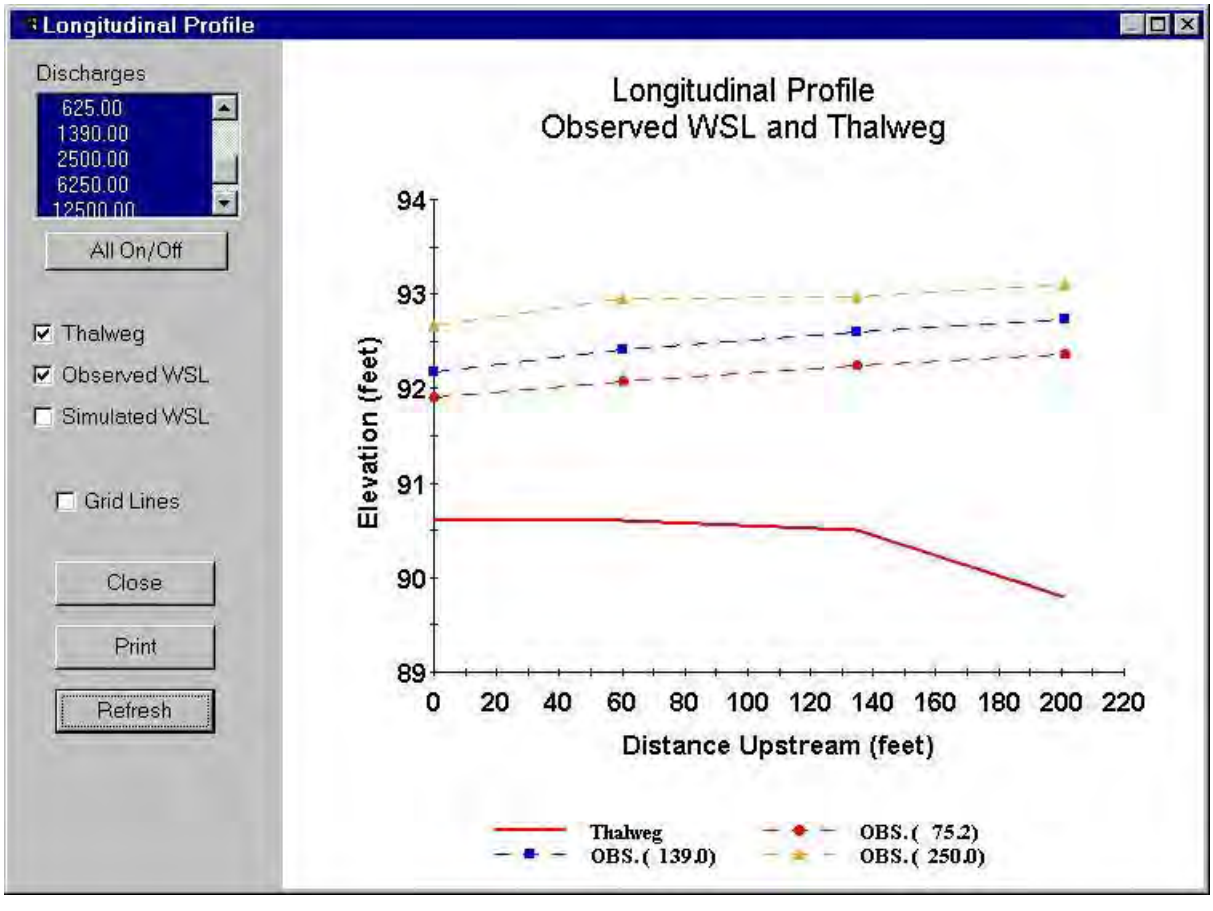
Windows		DOS	Difference	% difference
Cell bed elevation	91.65	91.65	0	0.00
Water surface elevation	92.456	92.47	0.014	0.02
Depth	0.806	0.82	0.014	1.71
Depth Suitability Index	0.0708	0.096	0.025	26.25
Combined Suitability Index	0.0644	0.087	0.023	26.25
Weighted Usable Area	8.698	11.79	3.096	26.25

Acknowledgements **i**
PREFACE **ii**
A Brief History of PHABSIM
Use of this Document
Changes Between PHABSIM Version 2 and PHABSIM for Windows
Conventions Used in this Document
Chapter 1, Introduction to the Physical Habitat Simulation System **1**
Objectives
Associated Laboratory Exercises

discharges at each cross section. In some applications, the best estimate of the discharge could have been derived from a gage within the reach or from the average of a selected number of the measured transects where conditions for obtaining good flow estimates was possible.

Step 3. Examination of the Stage-Discharge Relationships

The summary data in Table L3-1 was used to create a plot of the observed longitudinal water surface elevations versus discharge for the calibration data and a plot of the log of the discharge versus the log of the (WSL-SZF) (see Figures



L3-1 and L3-2).

Figure L3-3. Observed water surface profiles.

First, it should be apparent from the plot of the longitudinal profile of the calibration data (Figure L3-3) that at the high calibration flow, a flattening of the water surface elevation is apparent at the middle two cross sections. This may be indicative of a backwater effect at this discharge. Although backwater effects can be pronounced more often at low flows due to riffle type habitats, channel constrictions can produce this effect at higher discharges. We do not know (since we did not collect this data) what is actually occurring.

Examining the plot of the log-log relationship between WSL-SZF and discharge shows that the observed data for cross sections 60 and 135 have almost identical WSL values at the high calibration discharge (see Figure L3-2). This should

indicate that using a regression approach (i.e., stage-discharge with STGQ may be problematic at high simulated discharges since the regression lines will likely >cross over= each other. This will be explored in more detail in this laboratory.

Step 4. Running the Stage-Discharge Regression

Running the STGQ model to perform stage-discharge regression modeling is basically an automated process once the appropriate data have been entered and model options have been selected.

Select **\Models\WSL\STGQ Options** and ensure that the SZF box is checked for each cal set for each transect (the default). In rare instances removing the check mark can be used to set the SZF used in the calculations to zero. You will not encounter such a situation in this class. Click the **Write Computational Details** check box so the program produces a file called ZOUT containing the computational results. Once you have experience with PHABSIM, this file can be omitted during the calibration process. It is often a good idea to turn on this option when doing production runs in case an "at the time" record is needed for documenting or defending the study.

Next click the **Assign Cal Sets** button. Select each transect using the dialog box in the upper left and ensure that there is a check for each cal set for each applicable discharge. Selecting **All On** means that the WSL for all discharges will be simulated using all cal sets in the regression model. Under various circumstances of data quality or channel configuration it may be desirable to use only a portion of the available cal sets for a given discharge at a particular cross section. Note: you may have more than three Cal sets, but only certain ones may apply to specific cross sections. That selection is made in the **Assign Cal Sets** table.

In PHABSIM for Windows it is possible to use different water surface elevation models for different transects at different discharges. Therefore, you must specify which model is being used for each transect/discharge combination. Clicking the Method tab and selecting a method from the list on the right and clicking the appropriate position in the cross section discharge table accomplish this. For this laboratory exercise, click **STGQ** and then click **Set All**. This tells PHABSIM for Windows that the STGQ model will be applied to all combinations.

Now you are ready to run the STGQ program. Simply click the **Run** button at the bottom right. When the model has finished running a "WSL Simulation Completed" message will be displayed. To view the results, click **OK**and then click the **Results** tab.

In the **Results** tab window you will see a table of water surface elevations for each transect – discharge combination. Plots of the water surface elevation results can be viewed by clicking either the **Cross Section** or **Longitudinal** buttons at the bottom.

Step 5. Evaluation of the Stage-Discharge Model Results

At this point, we are interested in determining how well the regression approach is working as a model for use in simulations of water surface elevations. Figure L3-4 contains simulated water surface profiles derived from the stage-discharge relations for the four cross sections.

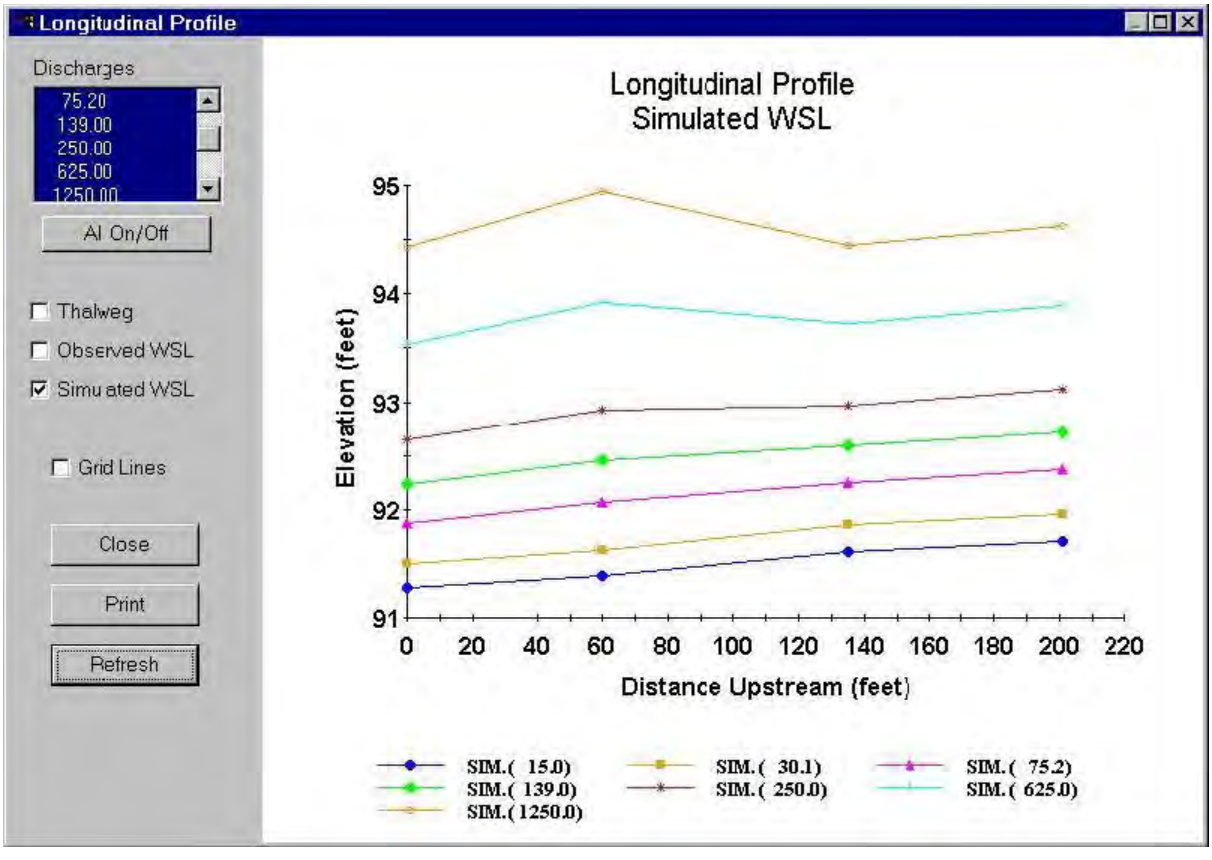


Figure L3-4. Water surface profiles simulated with STGQ.

Click the **Longitudinal** button to view a plot of the water surface profiles for each discharge as simulated by STGQ. Remove checks from the Thalweg and Observed WSL boxes to arrive at Figure L3-4. The top line in this graph (i.e., labeled SIM.(1250.0)) represents the predicted water surface elevation at a discharge of 1,250 cfs. The predicted water surface elevations at each cross section are derived from each cross section's regression equation based on the three sets of calibration data. At this discharge, water appears to be flowing downhill from right to left in this figure. Note that at 1,250 and 625 cfs, water is >flowing uphill= from cross section 135 to 60. These results are irrational from a physical standpoint and indicate that the regression models are not appropriate at higher discharges for this data set. In reviewing the simulation results for **1250.0** cfs, it should be apparent that the >water flowing uphill= between cross section 135 and 60 is >worse= than that observed at 625 cfs. This suggests that the further you extrapolate above the highest observed discharge (250 cfs) the more error in estimated water surface elevation you will have.

At this point, we only know that somewhere between 250 and 625 cfs, the stage-discharge regression approach >breaks down=. If we wanted to better define where the model no longer works properly, we could add additional QARD flows to our data set, such as 275, 300, 325, etc., up to 625 and rerun the STGQ model. Examination of the output would show the specific flow range at which water begins to >run uphill=.

Based on our examination of the plotted longitudinal profiles and the previous examination of the observed calibration data we can more easily understand how these irrational results can be generated by the regression modeling approach.

The STGQ program performs the regression analysis at each cross section independently. Although the r^2 for the regressions at each cross section are > 0.99, the difference in slope for each regression equation results in predicted water surface elevations which **cross** at simulated discharges just above the highest calibration flow. This should be expected given the observed relationships between discharge and water surface elevations shown in Figure L3-2, where the observed water surface elevations at cross sections 60.0 and 135.0 are very close and tend to >converge= over the range of observed discharges.

The modeling results would indicate that the stage-discharge modeling approach may be valid at simulated discharges up to our highest measured data (i.e., 250 cfs) but that an alternative modeling approach for higher simulated flows will be needed. In Laboratory 4, the MANSQ model will be used, while Laboratory 5 will employ the WSP model to deal with this phenomena.

Step 6. Explore STGQ Regression Modeling Options

This section of the laboratory is optional and intended to be completed at your convenience.

As indicated previously in the laboratory, the user can select which of the cal set discharges to use in the regression modeling with STGQ. In the previous laboratory steps, the stage-discharge regressions were conducted using the best estimate of the discharge by setting the **Discharge (IOC 5)** column to >Best Est Q' for all cross sections and cal sets. This forced STGQ to use the best estimate of the discharge in the regression computations. In this step of the laboratory, we will set these values to “Xsec Q” so that the regressions are performed using the calculated discharges at each cross section at each calibration flow.

If you are not in the **Models\WSL** window, move there now. Click the **STGQ Options** tab and click on the first entry “Best Est Q”. Next, click on the small wedge arrow ◔ to the right of the cell and then click “Xsec Q”. Repeat this for all cal sets for all transects.

To ensure the PHABSIM for Windows interface recognized the change, go to the **Methods** tab and then click **STGQ** and click any one of the transect – discharge cells to ensure the **Apply** button becomes active. Then click the **Apply** button and view results as before.

What you should find is that the >error= values in the regression equations have remained the same or increased and that regression modeling of these data with discharges measured at each cross section instead of a best estimate of discharge does not eliminate the irrational results of simulated water surface elevations at flows higher than our high flow calibration data set. Using the computed discharges for each cross section can, and often will, result in poorer linear relationships using Equation L3-2. This type of variability between cross sections using computed discharges is not atypical when field data has been collected in a variety of fisheries habitats whic h are poor in terms of obtaining a >best estimate= of the discharge for hydraulic modeling.

As a final wrap-up to this laboratory, go to the **STGQ** tab and reset all of the discharges to Best Est Q. Then go to the **Methods** tab, ensure that **STGQ** is marked and click **Select All**. Click **Run**, go to results, and view the longitudinal plot. Zoom on the calibration discharges (hold Shift and drag a box with the mouse and release the mouse button) and print the plot for later reference.

Laboratory 4. Water Surface Modeling Using the MANSQ Model

Objective

The objective of this laboratory is to demonstrate the technique of modeling water surface elevations based on using Manning's equation (i.e., the MANSQ model). The general theory for the MANSQ program is covered in the manual within Chapter 2.

Programs Used: MANSQ

Project Files Used: Lab4.phb

Introduction

The MANSQ model can be used to simulate the stage-discharge relationship for individual cross sections. The model assumes that flow variations caused by changes in channel configuration are negligible (i.e., minimal backwater effects). The application of the MANSQ model in pools can be problematic since pools are generally created by backwater effects of a downstream hydraulic control. The MANSQ model assumes that each cross section is independent of all other cross sections during calibration and simulations. Therefore, the longitudinal profile of the simulated water surface elevations should always be checked to assess overall model performance.

At a computational level, the MANSQ model uses Manning's equation in the form:

$$\neg 1.49 \; {}^{1/2}\!) \; {}^{2/3}$$

$$Q = {}^{*}S \; {}^{*}A^{*} \; R \quad \text{(L4-1)}$$

□□

$$\equiv n \Downarrow$$

which is simplified to:

$$Q = KAR^{2/3} \quad \text{(L4-2)}$$

The value of K is determined from a single measured discharge-water surface elevation data set and the measured channel geometry at a cross section. The program then uses additional calibration data sets (i.e. discharges and water surface elevations) to solve one of the following two equations selected by the user:

$$\} Q \}^{ß}$$
$$K = K_o \; \} \; \} \quad \text{(L4-3)} \; Q_o$$

$$\leq \geq$$
$$\} R \}^{ß}$$
$$K = K_o \} \} \quad \text{(L4-4)} \leq R_o \geq$$

where: subscript >o= refers to calibration values **b** is a coefficient supplied by the user for each cross section

LABORATORY 4 – WATER SURFACE MODELING USING THE MANSQ MODEL

Calibration of the model is accomplished by selecting an initial calibration discharge to compute K_o, and then employing a trial and error procedure for selecting a value of **b** that minimizes the error between observed and predicted water surface elevations for the remaining calibration data sets. Typical values of **b** range from 0.0 to 0.6 in most channels and as noted in Chapter 2. The steps in this laboratory represent a suggested order for MANSQ analysis.

Step 1. Obtain an Initial Estimate of b

Begin by initially setting that the **b** value for each transect in **\Edit\Cross Sections\Cross Section Data** to 0.2. This is an arbitrary default value derived from taking the median value for a large number of study sites. Final **b** values will be determined by observing the results of simulating water surface elevations with MANSQ.

In this step, the CALCF4 program will be used to obtain an initial estimate of **b**. Run the CALCF4 program by clicking **\Models\CALCF4**. The results will be automatically displayed to the screen. Scroll down the file and locate the conveyance factor (CFAC) regression equation for cross section 0.0. Alternatively, use the Notepad editor to search for "CFAC" in the current ZOUTx file.

The exponent of the CFAC regression equation represents an excellent initial estimate for **b** and is -0.003 for cross section 0.0. Continue through the output listing to locate and record the CFAC regression exponents at the three remaining cross sections. Record these values in Table L4-1.

Note that the CFAC regression exponent at cross section 0.0 is negative. Under most circumstances, the use of negative **b** values is not expected since this would imply that roughness would be increasing with discharge. In typical applications of MANSQ, a negative **b** would be rounded up to 0.0 for use in the model.

Table L4-1. CFAC regression exponents for each cross section.

Windows	
Cell bed elevation	91.65
Water surface elevation	92.456
Depth	0.806
Depth Suitability Index	0.0708
Combined Suitability Index	0.0644
Weighted Usable Area	8.698

Once the remaining CFAC exponents have been entered in Table L4-1, exit Notepad if you have been using it to find the CFAC exponents and return to **\Models\WSL\MANSQ** in PHABSIM for Windows.

The MANSQ program requires a calibration flow and water surface elevation at each cross section in addition to the initial estimate of **b**. These data are derived from the calibration data sets entered in **\Edit\Cross Sections\Calibration Data** for each cross section. For this laboratory, the high flow calibration data at each cross section will be used as our initial calibration flow for MANSQ.

Table L4-2. Calibration discharges and water surface elevations for the Fryingpan River from MANSQ using 250 cfs (Cal Set 3) as the calibration discharge.

Calibration Q	Cross section 0	Cross section 60	Cross section 135	Cross section 201
75.2	91.90	92.08	92.25	92.36
139	92.18	92.42	92.59	92.74
250	92.67	95.95	92.97	93.10

NOTE: You may choose either the high, medium or low flow calibration data sets (or any combination for specific cross sections). However, selection of the calibration discharge should be considered of the flow ranges most critical to the study. Remember, MANSQ will >return= the observed water surface elevation at the calibration flow and the >error= between predicted and observed water surface elevations at the other calibration discharges will be a function of the field data and selection of appropriate **b**=s. We will select **b**=s to minimize the error between observed and predicted WSL at each transect.

Step 2. Running the MANSQ Model and Evaluating Results

Select the **Models\WSL\MANSQ** tab and note the options available in the MANSQ program and review the options that have be set. For this laboratory exercise, the default options will suffice. However, advanced users may wish to consider the alternative ratios of flow conditions given in equations L4-3 and L4-4, and other MANSQ options.

Next, click on the **Methods** tab and click **MANSQ** followed by **Set All**. This assigns MANSQ as the model to be applied to all cross sections at all discharges. Now click **Run**.

Since we have chosen the high calibration flow (i.e., 250 cfs) MANSQ will always return the observed water surface elevations for this flow at each cross section. We need to evaluate the predicted water surface elevation at each cross section for the medium (139 cfs) and low (75.2) calibration flows.

The **Results** tab contains a table of predicted water surface at each of the simulated discharges for each cross section. Click the **Print** button to obtain a copy of this table for later use. Click the **Longitudinal** button to view a plot of the longitudinal profile for all discharges. Click the check boxes for **Observed WSL** and **Simulated WSL**. Note the wild divergence of the WSLs at transects 135 and 201. The steep water surface elevation at high flows is unrealistic for a pool. In addition, the water surface elevation at the lowest discharges runs uphill. Our initial **b** values are not working too well.

Compare the predicted water surface elevations at 139 cfs and 75.2 cfs for each cross section against the observed water surface elevations for these calibration flows. It is apparent that an initial estimate of **b** of 0.2 results in a prediction of the water surface elevations at cross sections 0 and 60 that are too low, while this same **b** results in a prediction of water surface elevations at cross sections 135 and 201 which are too high at the high discharges and too low at the low discharges.

This means that **b** coefficients at all cross sections need to be adjusted in order to obtain better agreement

between observed and predicted water surface elevations. **Table**

Windows		DOS	Difference	% difference
Cell bed elevation	91.65	91.65	0	0.00
Water surface elevation	92.456	92.47	0.014	0.02
Depth	0.806	0.82	0.014	1.71
Depth Suitability Index	0.0708	0.096	0.025	26.25
Combined Suitability Index	0.0644	0.087	0.023	26.25
Weighted Usable Area	8.698	11.79	3.096	26.25

Acknowledgements **i**
PREFACE **ii**
A Brief History of PHABSIM
Use of this Document
Changes Between PHABSIM Version 2 and PHABSIM for Windows
Conventions Used in this Document
Chapter 1, Introduction to the Physical Habitat Simulation System **1**
Objectives
Associated Laboratory Exercises
An Overview of IFIM
The Purpose of PHABSIM
The Structure of PHABSIM
Application of PHABSIM
Scoping
Selection of Target Species and Suitability Curves
Selection of Target Species
Types of Suitability Curves
Transferability of Suitability Curves
Segmenting the Study Area and Study Site Location
Critical Reach
Mesohabitat Study Site Selection
Cross Section Selection and Field Data Collection
Cross Section Selection
Field Data Collection
Hydraulic Modeling

L4-3. MANSQ calibration table.

Step 3. Trial and Error Calibration of MANSQ by Adjusting b at Each Cross Section

You have now obtained an initial solution of the water surface profile using MANSQ but some adjustment is needed. Return to **\Edit\Cross Sections** and change the **b** coefficient from 0.20 to 0.02. Make this same change to the **b** value at cross sections 60 to 201. Note that these new estimates of **b** have been entered in Table L4-3.

Click OK to exit Edit\Cross Sections and save the file changes. Return to **\Models\WSL\Methods,** check that the MANSQ method is selected, and click **Set All** again. When the program has finished, click **OK** and **Results** as before.

LABORATORY 4 – WATER SURFACE MODELING USING THE MANSQ MODEL

Compare the Results table displayed on the screen to the one you printed earlier. What happened to the predictions for the water surface elevations when we increased or decreased **b** at the cross sections?

You should find that increasing **b** will result in predicted water surface elevations which increase for discharges above the calibration discharge, while decreasing **b** results in the predicted water surface elevations decreasing. The opposite will be true below the calibration discharge.

Return to **\Edit\Cross Sections** and change the **b** values for each cross section to induce the needed change in WSL at each transect to match the calibration discharges. Record these values in Table L4-3. Remember to use a **b** value of 0.00 instead of negative values for any cross section. Save these changes and re-run the MANSQ program and record the new predictions for the water surface elevations at each cross section for the medium and low calibration flows in Table L4-3. How close are the predictions of water surface elevations?

Based on these results, make adjustments to the **b** values as necessary. Your strategy should be to minimize the error between predicted and observed WSLs at both the 139 cfs and 75.2 cfs calibration flows for each cross section (you cannot get them both to be exact) by selecting the 'best' **b** for each cross section. Remember, MANSQ treats each cross section independently, so if you get a particular cross section to work, you no longer have to adjust the **b** value at the cross section while continuing your calibration efforts at other cross sections. You should make several trial runs during the lab in your quest for the best fit; however, due to class time limitations, the final calibration **b** values are provided in Table L4-3.

Step 4. MANSQ Final Calibration Run and Hydraulic Diagnostics

Up to this point we have focused on the calibration discharges and have not dealt with the WSL for the other discharges in the data set. The particular **b** values entered at the far right in Table L4-3 generally result in a maximum error between observed and predicted water surface elevations at the calibration flows, which range between 0.00 and 0.06 feet. This magnitude of difference is on par with the results obtained from the stage-discharge regression approach covered in Laboratory 3. However, we still need to check the effectiveness of the hydraulic simulations further by looking at the longitudinal profile of the water surface elevations at all simulated discharges.

View the longitudinal plot in **\Models\WSL\Results** again. Expand to full screen using the Windows maximize button for the graph window. It is useful to print this graph and label it MANSQ final for later reference.

The thalweg depths for each cross section are displayed as the bottom line with the x-axis indicating the distance between each cross section moving in an upstream direction. The top line in this graph represents the water surface elevation at a discharge of 1250 cfs. Us ing the key at the bottom of the plot, the other discharges can be identified by their line and symbol combinations. To aid in viewing simulated water surface profiles only, the **Observed WSL** check box can be left blank (click to remove check).

The predicted water surface elevations at each cross section are derived from the MANSQ model based on the calibrated **b**'s. At this discharge, water appears to be flowing downhill for some cross sections and uphill for others.

Note that at the simulated discharge of 625 cfs, water is 'flowing uphill' between cross sections 3 and 2. Although excellent agreement can be obtained with MANSQ for the calibration data, the simulated water surface elevations at discharges greater than 250 cfs are irrational.

At this point, we know that somewhere between 250 and 625 cfs, the MANSQ model 'breaks down' in a similar fashion to the results obtained using the IFG4 model in Laboratory 3. The reason behind the production of

irrational results with MANSQ for this data is basically similar to the reasons discussed in Laboratory 3 using IFG4. In MANSQ, the **b** value represents the exponent in a power law relationship (see Equations L4-3 and L4-4) that approximately tracks the changes in Manning's n over a range of discharges. Therefore, **b** acts as the 'slope' factor for the relationship between water surface elevation and discharge. Since the measured water surface elevations at cross sections 60.and 135 are very similar at the high calibration flows (see Table L4-2), the >best fit= relationship derived from matching the water surface elevations at the two lower calibration flows >causes= the predicted water surface elevations to >cross over= at simulated discharges above 250 cfs.

At this point, an alternative modeling approach for the simulation of discharges greater than our high flow calibration (i.e., 250 cfs) should be considered. Given the nature of these data, modeling options within MANSQ are not likely to improve the simulation results (i.e., use of Equation L4-4 rather than Equation L4-3). Given the results already examined in Laboratory 3 using IFG4, the WSP model would be the next step and is examined in Laboratory 5.

Laboratory 5. Water Surface Modeling Using the WSP Model

Objective

The objective of this laboratory is to demonstrate the technique of modeling water surface elevations based on the step-back water method as implemented in the WSP model. We will cover the steps of finding an overall

Windows		DOS	Difference	% difference
Cell bed elevation	91.65	91.65	0	0.00
Water surface elevation	92.456	92.47	0.014	0.02
Depth	0.806	0.82	0.014	1.71
Depth Suitability Index	0.0708	0.096	0.025	26.25
Combined Suitability Index	0.0644	0.087	0.023	26.25

Manning's n value that is a "best fit" for the study site, adjusting n values to capture localized roughness differences at each transect, and specifying roughness modifiers to accommodate the change in n value as a function of discharge. The general theory for the WSP program is covered in the

Introduction

The WSP model is a water surface profile program that is used to predict how the longitudinal profile of the water surface elevation changes over a range of simulated discharges. The initial objective in the calibration of the model is to use a trial-and-error procedure to select Manning's n coefficients at each cross section, which will replicate the longitudinal profile of the water surface elevations at this single calibration flow. This requires that the bed geometry elevations and water surface elevations have been measured to a common benchmark or elevation datum (i.e., the cross sections are 'dependent' and connected). We first attempt to find a global value (or overall channel roughness value) for n that is applied at each cross section to produce a "least error fit" of the water surface elevation profile to the observed data for one discharge. We then vary Manning's n for each cross section (within reasonable limits) to achieve a reasonably close fit between observed and predicted water surface elevations. Finally, we use a trial-and-error procedure to select main channel and overbank roughness modifiers that produce the best fit between observed and predicted water surface profiles for all remaining calibration flows. The relationship between the calibrated roughness modifiers and discharge is then used to develop either a regression equation or a good linear approximation, from which we can estimate the appropriate roughness modifiers for all simulation discharges of interest.

WSP requires a starting water surface elevation or energy slope as an initial condition. We have already found stage-discharge relationships using a regression approach (i.e., STGQ) and by calibrating MANSQ for the downstream cross section. To provide WSP with the needed initial condition, the user selects the combination of starting conditions based on using the water surface elevation derived from STGQ or MANSQ in the **\Models\WSL\Methods** tab by clicking on **..\WSP\STGQ supplies initial WSL** or **..\WSP\MANSQ supplies initial WSL** or **..\WSP\User supplies initial WSL**. The two combined WSP\XX options take the starting water surface elevation from one of those models and supplies it to WSP. The WSP\User option allows the user to set this value manually. The **..\User supplies WSL (no model run)** option allows users to import WSL values for the entire study area and discharge range from an outside source.

In this laboratory, we will select the high flow calibration data as the starting point in the calibration of the WSP model. In particular, we are interested in determining if this modeling approach can overcome the problem with simulated water surface elevations at higher discharges encountered when using a stage-discharge regression (i.e., STGQ in Laboratory 3) or the MANSQ model (Laboratory 4). The laboratory also provides a discussion of the implications of using a different initial calibration flow and resulting impacts to simulated water surface elevations. The given steps represent a suggested order for WSP analysis.

Step 1. Prepare Data and Select Options to Run the WSP Program

We begin by setting the same initial Manning's n roughness value for all cross sections. Start PHABSIM for Windows and load Lab5.phb. Select **\Models\WSL\WSP Options** and note that a Manning's n value of 0.030 has been entered for all cross sections.

WSP requires that the water surface elevations at the down stream cross section for each discharge are supplied to the model as boundary conditions. For discharges of 75.2, 139, and 250 cfs we know the actual observed water surface elevations at the down stream most cross section (i.e., cross section 0.0). However, the water surface elevations for the remaining four discharges are not known. To resolve this issue, we use STGQ or MANSQ to obtain water surface elevations for the downstream cross section. From Labs 2 and 3 we know that STGQ produces a slightly better fit between observed and simulated water surface elevations at cross section 0. Thus, we will use STGQ as the source of starting water surface elevations.

Move to **\Models\WSL\Methods** and first select **WSP** (click the radio button) followed by **Set All**. This saves clicking on each element of the table separately. Now select the **..\WSP\STGQ** radio button and click in the cross section 0.0 row for each discharge. (Be sure and scroll the table so all cross section 0.0 entries for all cross sections are filled with WSP-S. This sets all initial conditions to use the WSL from STGQ and applies WSP to all cross sections at all discharges.

We have the measured water surface elevations for the three calibration discharges. Will they be different than those predicted by STGQ? To ensure the best precision in calibrating WSP, it is wise to use the known values as the initial conditions. For the three calibration discharges, select **..\WSP\User supplies initial WSL** and click the cross section 0.0 entry for each discharge and enter the starting WSL from the data. You have already entered this data as part of the calibration data sets, but to allow for improved estimates of the starting WSL, you must enter it here also.

In the **\Models\WSL\WSP Options** tab, there is a table for entering roughness modifiers (RMODs) for each discharge. The RMODs are used by WSP to adjust the Manning's n values derived in the initial calibration of the longitudinal water surface profiles to account for changes in roughness as a function of discharge. The default value for the RMODs is „1', so initially there is no variation in Manning's n with discharge. These values are modified by the user as needed to obtain a reasonable fit between observed and simulated water surface profiles.

For this exercise, we will use the high discharge as our reference discharge. This is generally a good practice when using WSP as calibration residual errors tend to compress (get smaller) as one simulates downward using backwater type models. As trial values, set the roughness modifiers for 139 cfs and 75.2 cfs to 1.1 and 1.2, respectively. These are strictly trial values so you can start by leaving them at 1.0 if you wish.

Step 2. Run the WSP Program and Determine the Initial Water Surface Elevation Predictions

Click the **Run** button now to run the combined STGQ (at cross section 0.0) and WSP (at all cross sections) model. A message window will indicate when the WSL simulation is completed. Click **OK** to clear this window.

Select the **\Models\WSL\Results** tab or **\Reports** and click on the longitudinal plot option. Select **Observed** and **Simulated WSL** followed by **Refresh**. Zoom on the three calibration discharges by holding down the **Shift** key, moving the mouse to the lower left corner of the region you wish to zoom, holding the **left** mouse button and dragging to the upper right corner of the zoom area. Then release the mouse button and the plot will zoom to that area. Note that **\Models\WSL\Results** contains a table of water surface elevation information for all cross sections and all discharges. In this case, it has seven entries in each row corresponding to the seven discharges we have directed the model to simulate. Note, for example, that the predicted water surface elevation associated with the 250 cfs calibration flow at cross section 201 is 92.936.

How do the simulated values compare with the observed values? Note from the plot that at all three calibration discharges the simulated water surface profile falls considerably below the observed profile. An adjustment to Manning's n is needed. The table in the **\Models\WSL\Results** tab can display the observed, simulated, and difference in water surface elevation at the calibration flows by clicking the **Cal Comparison** radio button. This is useful to display numerical values for the differences seen in the plot.

Step 3. Calibrate WSP for the Longitudinal Water Surface Profile at 250 cfs

For the calibration process it is useful to prepare a table such as Table L5-1 to record successive iterations of the Manning's n adjustment process. The first estimate of the water surface elevation at cross section 60 at 250 cfs recorded in Table L5-1 shows that the predicted WSL is low by 0.185 feet. The calibration strategy will be first to change the Manning's n values at all cross sections simultaneously to get the predicted water surface elevation at all cross sections for our chosen discharge of 250 cfs to fit through the observed values for all cross sections in a reasonable manner. Generally, we would like the simulated values to fit the observed values as closely as possible. We expect some values to be high and some to be low at this stage. Go back to **\Models\WSL\WSP Options** and raise the Manning's n to a new, higher value for all cross sections (.045 is suggested). Remember, raising n increases roughness will thus raise the simulated water surface profile.

Return to **Models\WSL\WSP Options** and make sure the roughness modifier for a discharge of 250 cfs has a value of 1.0. Then click the **Run** button to run the model. Repeat this process of setting Manning's n, running the model, and viewing results until you have achieved a satisfactory fit between the simulated and observed water surface profile for the 250 cfs discharge.

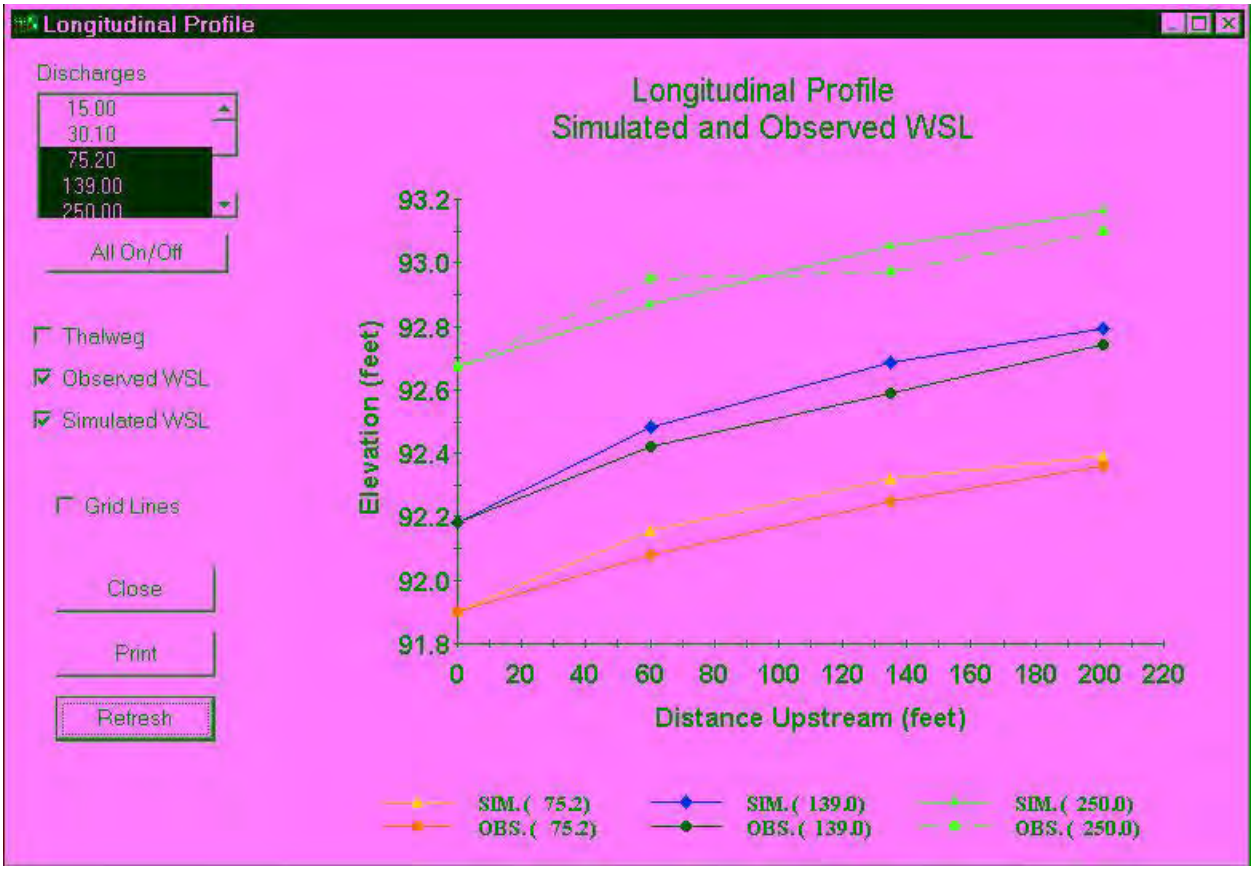
Figure L5-1 shows the plot resulting from raising Manning's n to 0.45 at all cross sections. Display this plot by clicking the Longitudinal button in the **..\WSL\Results** tab.

Windows		DOS	Difference	% difference
Cell bed elevation	91.65	91.65	0	0.00
Water surface elevation	92.456	92.47	0.014	0.02
Depth	0.806	0.82	0.014	1.71
Depth Suitability Index	0.0708	0.096	0.025	26.25
Combined Suitability Index	0.0644	0.087	0.023	26.25
Weighted Usable Area	8.698	11.79	3.096	26.25

Table L5-1. WSP calibration table for Manning's n.

Acknowledgements i
PREFACE ii
A Brief History of PHABSIM
Use of this Document

Figure L5-1. Water surface profiles resulting from Manning's n = 0.045.



Increasing the Manning's n from 0.030 to 0.045 raised the water surface profile at all cross sections. Note that the elevation for 250 cfs at cross section 60 changed from 92.765 feet to 92.871 feet. Is this close enough? What about the 250 cfs WSL at the other transects? In this case they are higher than the observed values by 0.081 ft. for transect 135 and 0.066 ft. for transect 201. This would appear to satisfy the criteria of using a single n value to get the best fit through the data. However, we have a dilemma. Notice cross section 60 at 250 cfs. This is the only place where there is a pronounced rise in observed WSL above the values being predicted by WSP. Also notice that, at the other calibration flows, the predicted water surface profile lies above that of the calibration data. Examination of the cross section shapes, the thalweg profile, or relative transect location does not reveal a clear reason for the high observed value at cross section 60. The channel index codes in this study are based on bed material size. There are a few CI values of 7, but the predominant value is 6. The predominant value at cross section 0 is also 6. So, while the bed at cross section 60 may be slightly rougher than at cross section 0, there is no compelling reason to increase roughness above that at cross section 0.

In this particular situation, we may suspect an error in measurement at the high discharge. Following this assumption, we adjust the n values such that the simulated 250 cfs water surface profile closely matches the observed values at the upstream two transects. To accomplish this, reduce the n values in **Edit\Cross Sections** and re-run WSP until good agreement is reached. As you make those adjustments, record n and WSL in Table L5-1. Agreement will occur near n = 0.041 at all cross sections.

With global n = 0.041, the WSL is 0.109 ft. low at cross section 60, 0.032 ft. high at 135, and 0.005 ft. low at 201. The 0.109 ft. difference seems large. What kind of error may have occurred when the measurements were made? One possible scenario is that the water surface was recorded 0.1 ft. higher than reality. Let us use that assumption and determine which further local adjustments to n should be made to reach a WSL of 92.85 ft. instead of 92.95 ft.

Local adjustments to n are best made in pairs stepping upstream. The Manning's n at the first cross section is changed concurrently with the value at cross section 60.0 since the predicted water surface at cross section 60 is dependent on the initial roughness at the down stream cross section as well as at cross section 60. Changing both Manning's n values also reduces the chance of obtaining unrealistic Manning's n values at upstream cross sections during the calibration process. To reach 92.85, we must raise n at the first two cross sections. Try a value of 0.042.

Go to **\Models\WSL\WSP Options** and enter 0.042 for the first two transects. Then set the roughness modifiers to 1.0 for 250 cfs, 1.1 for 139 cfs, and 1.2 for 75.2 cfs, if you have not already done so, and click **Run**. Look at the table and longitudinal plot in **..\Results**. Note that while the elevation for 250 cfs at cross section 60 has now reached 92.848, the elevations upstream have increased. To get those values back down to within 0.02 ft. of the observed values will require low n values for cross sections 60 and
135. It is possible to set the n value at cross section 0.0 high enough that even a low n value at cross section 60 will produce an elevation of 92.85. However, there is no evidence in this stream that radical changes in n are justified. Thus, the global value of 0.041 appears to be a reasonable best fit value that causes the simulated water surface profile at the selected discharge (250 cfs) to "bracket" the observed values.

Set the n values back to 0.041 for all cross sections and re-run. Now look at the water surface profile (longitudinal) plot. Note that the observed water surface profiles for the three calibration flows appear to arch up in the center and become flatter at cross section 201. This suggests that there is a legitimate increase in roughness between cross sections 135 and 201. Try modifying the n values for those cross sections to obtain a better overall fit for the 250 cfs water surface profile. Be sure to record both the Manning's n values and associated predictions of the water surface elevations in Table L5-1. An approximate rule of thumb is that no more than a 5% – 15% change in n values should occur between transects in an alluvial stream unless there is a topographic or geologic phenomenon to consider. For example, if large car-sized boulders densely filled a short section of stream, large changes in n would be anticipated. That does not appear to be the situation here.

It is important to avoid varying n values merely for the purpose of obtaining an exact fit of the simulated to observed water surface profile. When n values vary substantially between transects, the reliability of extrapolating to higher or lower discharges may be affected. Generally, n represents the combined roughness of the bed particle size and bed form (dunes, for example) that resists the flow of water. Additional losses, such as expansion or contraction losses, are handled to varying degrees within the WSP model. In some circumstances, adjustments to n may be used to ensure such losses are fully represented.

Step 4. Calibration of Roughness Modifiers for Remaining Calibration Data

Now that Manning's n values have been selected to approximately reproduce the water surface profile at the high (250 cfs) calibration flow, the next calibration step involves using a trial-and-error procedure to select RMODs at the remaining calibration flows which most closely reproduce the longitudinal water surface profiles at those discharges. Since WSP treats each simulated discharge independently, calibration of the RMOD for the remaining two calibration flows can occur at the same time. The RMODs represent constants that change the magnitude of the Manning's n values at each cross section while simulating discharges. The RMOD for the calibration flow must therefore be 1.0 and the RMODs at other flows will be either higher or lower than 1.0 depending on whether these discharges are higher or lower than the initial calibration flow. Why?

Recall from Chapter 2 in the manual that roughness or resistance to flow decreases with increasing discharge. Conversely, the roughness should increase as flows are reduced. Since the high calibration flow (i.e., 250 cfs) was used for the initial calibration of the WSP model, the calibrated Manning's n values alone will be too low to correctly predict the water surface elevations at the 139 cfs and 75.2 cfs calibration flows. Therefore, the RMODs at these remaining two calibration flows will need to be greater than 1.0. Think this through and reread Chapter 3 if it is still unclear why. This is why we assigned arbitrary RMODs of 1.1 and 1.2 to the 139 cfs and 75.2 cfs discharges earlier.

Select **\Models\WSL\WSP Options** to display the RMOD table. Set the RMOD values for 139 cfs and 75.2 cfs to 1.1 and 1.2, respectively if they are not already so set. Then select **..\Results** and display the longitudinal plot. Select both **Observed** and **Simulated** water surface elevations and **Refresh** to display them. It is convenient to drag the plot to the lower right of the screen so you can view both the PHABSIM window and plot window simultaneously. In the plot window, magnify (zoom) the area of water surface profiles for the calibration discharges. Now click the **Run** button to run the models. Click **OK** when the program has finished and click the **Refresh** button in the plot window. Where do the simulated water surface profiles for 75.2 and 139 cfs lie in relation to the observed profiles? Are they high or low? Return to the WSP Options tab.

Figure L5-2 shows the predicted versus observed longitudinal water surface profiles at the three calibration flows based on our existing RMODs.

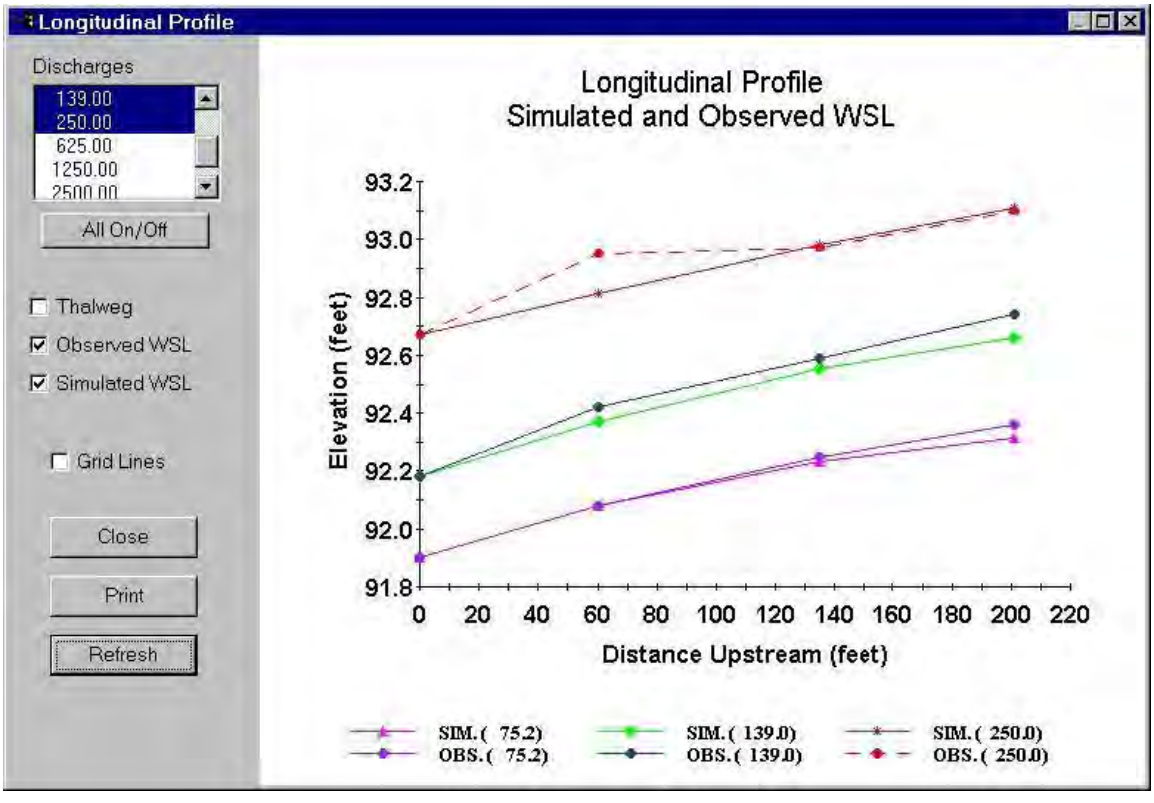


Figure L5-2. Water surface profiles with RMODs of 1.0, 1.1, and 1.2.

This figure illustrates several key factors in the calibration of WSP using RMODs. It should be apparent that the predicted longitudinal profiles for the calibration discharges at 139 cfs and 75.2 cfs 'mimic' the pattern of the water surface profile at the initial calibration flow of 250 cfs. This should be expected since the only effect that the roughness modifiers have in the simulation is to change the magnitude of the Manning's n values and therefore, the relative differences between the individual cross section Manning's n values are retained at the other simulated discharges.

In Figure L5-2 (or by viewing **\Models\WSL\Results\longitudinal**) you can see that the simulated water surface profiles for 139 and 75.2 cfs are generally lower than the observed profiles for those discharges. Do not close the graph window, merely click on the PHABSIM window to move back to it. Remembering that increased roughness will raise a backwater curve, enter new values for the roughness modifiers for 139 and 75.2 cfs in the **\Models\WSL\WSP Options** RMOD table. Click **Run** to re-run the models, click **OK** when the simulation is done and click the **Refresh** button to see the results in the longitudinal profile graph. Continue changing the RMOD values until you achieve the best overall fit at the discharges of 139 and 75.2 cfs. You may record your iterations of this process in Table L5-2.

It should also be noted that if either the 75.2 cfs or 139 cfs flow was selected as the initial calibration discharge, a close agreement between predicted and observed water surface elevations at the other flows would be achieved with the right RMOD. This would be expected given the similarity in the shape of the longitudinal water surface profiles at both of these discharges. However, neither of these lower calibration flows would be expected to achieve close agreement at all cross sections at the high calibration flow given the difference in the observed longitudinal profile at 250 cfs. This should reinforce the concept that

you should carefully consider which initial calibration flow to select, or that you should use multiple calibration flows to see which is best. This determination should be made in light of both model performance and flow ranges of interest in the study.

Staying within the 5%–15% guideline described earlier, try making final small changes to the n values for all cross sections and to the RMODs to best fit all three water surface profiles from cross section 0 to cross section 201. Observe the **diff** column in the **Cal Comparison** table and try to find a set of n values and RMODs that result in not more than a 0.02 ft. difference at all cross sections and discharges. This final step ensures that all observed water surface profile data has been used to achieve the final calibration of WSP over all calibration discharges and over all cross sections. Table L5-3 gives one possible final calibration of n values and RMODs. Other combinations of n and RMOD may give a similar range of WSL calibration errors.

Table L5-2. WSP RMOD calibration table.

Windows		DOS	Difference	% difference
Cell bed elevation	91.65	91.65	0	0.00
Water surface elevation	92.456	92.47	0.014	0.02
Depth	0.806	0.82	0.014	1.71
Depth Suitability Index	0.0708	0.096	0.025	26.25
Combined Suitability Index	0.0644	0.087	0.023	26.25
Weighted Usable Area	8.698	11.79	3.096	26.25

Acknowledgements **i**
PREFACE **ii**
A Brief History of PHABSIM
Use of this Document
Changes Between PHABSIM Version 2 and PHABSIM for Windows
Conventions Used in this Document
Chapter 1, Introduction to the Physical Habitat Simulation System **1**
Objectives
Associated Laboratory Exercises
An Overview of IFIM
The Purpose of PHABSIM
The Structure of PHABSIM
Application of PHABSIM
Scoping
Selection of Target Species and Suitability Curves
Selection of Target Species
Types of Suitability Curves
Transferability of Suitability Curves

Table L5-3. A possible WSP calibration.

Cross section	n value	Discharge	RMOD
0.0	0.038	75.2	1.28
60.0	0.038	139	1.23
135.0	0.043	250	1.00
201.0	0.043		

Laboratories 3 and 4 demonstrated that neither the stage-discharge or MANSQ models were able to simulate rational (water flowing downhill) profiles at the high discharge range. Let us assume that the current WSP model calibration results are the best that can be achieved and move to the next step in the calibration process.

Step 5. Estimate the Roughness Modifiers for all Desired Simulation Discharges

Assuming that our final calibration effort for RMODs listed in Table L5-2 represents the best compromise in matching the predicted and observed water surface profiles at the medium and low calibration discharges, the next step will involve trial-and-error approximation of a linear log-log relation between n and discharge or development of a regression between the $\log_{10}$ of the discharges and $\log_{10}$ of the RMOD values. The resulting regression equation or approximated relation will then be used to estimate the roughness modifiers for all remaining discharges to be simulated in WSP (i.e., 15.0, 30.1, 625.0, and 1250.0). The log regression is easily accomplished with a spreadsheet program.

Figure L5-3 shows the log-log linear regression results for the relationship between discharge and roughness modifiers obtained using a spreadsheet program. The equation is:

$$\text{Log}_{10}\text{RMOD} = -0.2045*\log_{10}\text{Discharge} + 0.502 \quad (5\text{-}1)$$

This regression equation was used to generate the estimated roughness modifiers listed in Table L5-4 for the remaining simulation flows to be used in the laboratory. Note that the $\log_{10}$ of the discharge must be used in the equation and that the result is the Log_{10} of the roughness modifier. Therefore, the correct RMOD estimate is derived by exponentiating the result from the regression equation as the „x' in 10^{x}.

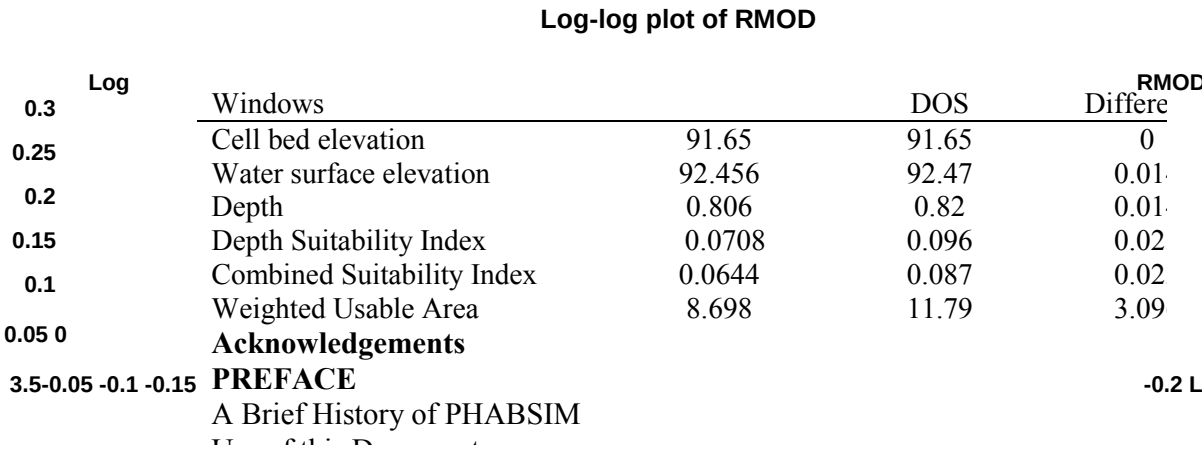


Figure L5-3. Log-log plot of RMOD and discharge.

Table L5-4. Estimated RMOD values at simulation discharges.

Simulation discharge	Estimated RMOD
15.0	1.83
30.1	1.58
625.0	.852
1,250.0	.739

Enter these values in the RMOD table in the **WSP Options** tab and click the **Run** button. We now have a water surface profile for each discharge based on the WSP model. The resulting profiles can be viewed using **..\Results\longitudinal**. If you have not already done so, include the remaining target discharges in the simulation by moving to **..\Output Options** , placing a check in all check boxes, and re-running the simulation.

The log-log linear RMOD versus discharge relationship can be visually approximated by trial-and-error by plotting that relationship in PHABSIM for Windows. In the WSP Options tab, click the **Roughness Modifier Graph** button and the **log-log** radio button. Prior to setting RMOD values for the simulation discharges, the graph will look something like Figure L5-4.

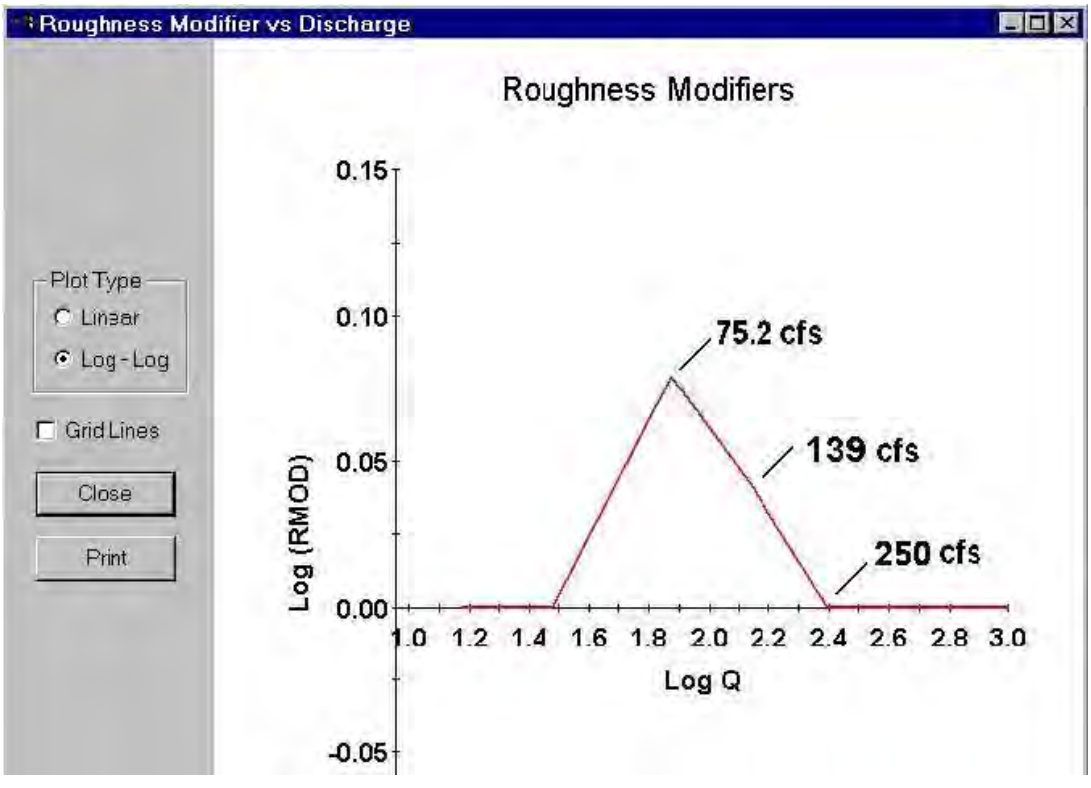


Figure L5-4. Roughness modifier graph.

This plot shows the initial RMODS of 1.0 ($\log_{10}$ of 1 is 0.0) for all simulation discharges and $\log_{10}$ of 1.2, 1.1, and 1.0 for 75.2 cfs, 139 cfs, and 250 cfs respectively. By displaying this plot and the RMOD table in the **..\WSP Options** tab simultaneously, the user can quickly build a linear RMOD vs. discharge relationship visually. While not as precise as the regression approach, this is often an adequate approximation for estimating RMOD values.

Step 6. Evaluate the Hydraulic Simulations

In order to check the effectiveness of the hydraulic simulations, we examine the longitudinal profile and calibration error of the water surface elevations for all our simulated data. In particular, the performance of WSP at the high-simulated discharges is of interest, since neither STGQ nor MANSQ were able to produce rational results above our high calibration flow of 250 cfs.

Zoom in on the water surface profiles for 625 cfs and 1250 cfs in **..\Results\Longitudinal**. Compared to the STGQ and MANSQ results these profiles show water running downhill at the high discharges. The WSP model produces rational results for the high-simulated flows. This would suggest that the WSP model could be used for simulations above the highest calibration flow (i.e., above 250 cfs).

Now zoom in on the water surface profiles for 15 cfs and 30 cfs. Do these results also look rational? It does appear that a weak pool is produced by backwater from cross sections 0.0 and 60. Neither of those sections shows clear evidence of being a strong control. More likely, control is the result of the overall resistance of the channel between those two sections. This condition is often referred to as channel control and helps explain the observed and simulated water surface profiles seen here.

You may compare the water surface profiles developed using WSP and STGQ by starting another copy of PHABSIM and loading the lab03 SAMPLE data set. Longitudinal plots for both data sets can be displayed on the screen at once by sizing windows appropriately. Do not try to load two copies of the same project.

Based on these results, the WSP simulated water surface elevations will be used for the subsequent steps in the laboratory exercises.

A final note: We ignored the water surface elevation at cross section 60 for 250 cfs and assumed it was a measurement error. What if it was not a measurement error? What would need to be done differently in this WSP calibration to achieve the "best" simulation? Specifically, could we stay within the 5%-15% change in „n' guideline? Could the maximum water surface simulation error be held to ∀ 0.02 ft.? How would the RMODs change?

To explore these questions you can make a copy of the project at the present stage using **\File \Save As** and re-calibrate assuming that the cross section 60 value is correct.

Laboratory 6. Velocity Modeling – VELSIM Objectives

Windows		DOS	Difference	% difference
Cell bed elevation	91.65	91.65	0	0.00
Water surface elevation	92.456	92.47	0.014	0.02
Depth	0.806	0.82	0.014	1.71
Depth Suitability Index	0.0708	0.096	0.025	26.25
Combined Suitability Index	0.0644	0.087	0.023	26.25
Weighted Usable Area	8.698	11.79	3.096	26.25

Acknowledgements **i**

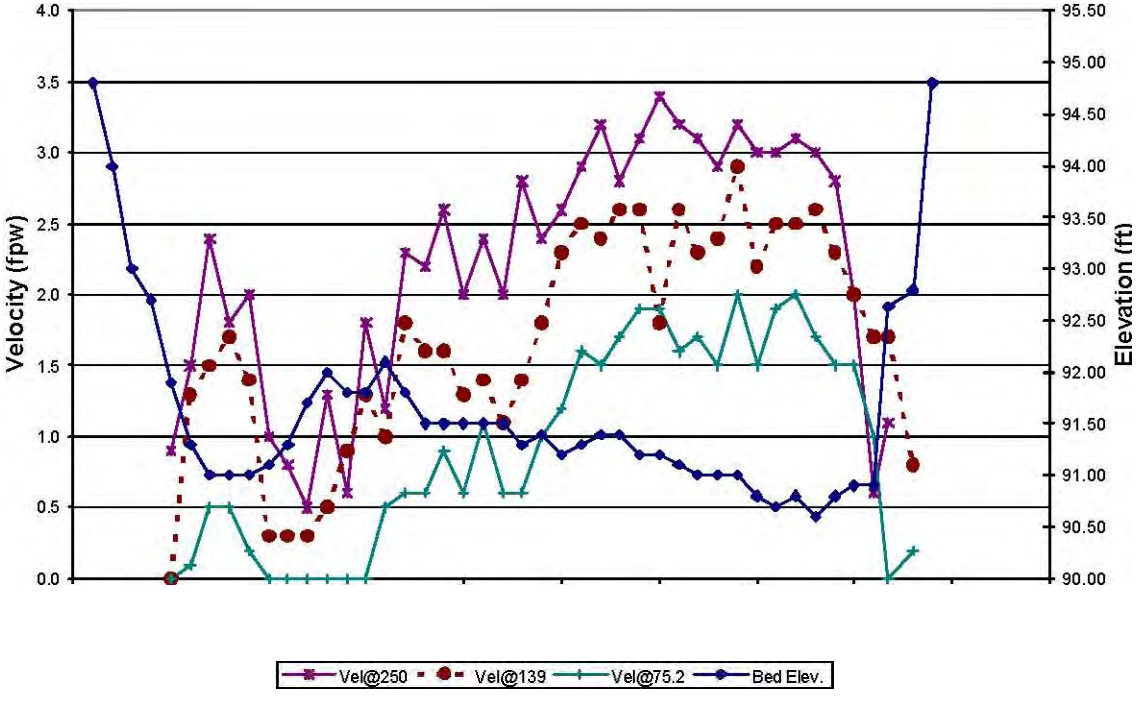
The objectives of this laboratory are to explore various methods for velocity modeling within PHABSIM using the VELSIM program and to introduce the basic techniques for evaluation of the effectiveness of

In this laboratory, different empirical approaches to simulating velocities are examined. Recall from Chapter 2 of the manual, that VELSIM can use specific velocity calibration sets for specific ranges of discharges, and a conveyance area-based velocity distribution can be developed when no calibration velocities are available. The 'best' approach can only be determined by evaluating a combination of available data, model performance, and objectives of the particular study.

This laboratory explores several different velocity set combinations and simulation control options within VELSIM to help the user understand the effects and consequences of selecting a particular velocity calibration data set and modeling option(s) within VELSIM. The laboratory is also intended to demonstrate the implications of selecting a particular water surface elevation model and subsequent effects during the simulation of velocities in VELSIM. The overall objective of velocity calibration and simulation is to pick the best combination of calibration velocity(s) and simulation options to represent the velocity profiles at each cross section over the range of simulated flows. The steps in this lab provide a good sequence for velocity simulation.

Step 1. Evaluate Observed Velocity Profiles

Prior to beginning the modeling efforts, examine the observed velocity profiles at each cross section for all three calibration flows provided in Figures L6-1 through L6-4. The velocity profiles between different cross section geometries are highly variable as would be expected. Also note, however, that the velocity patterns at specific cross sections are 'generally' similar at all three calibration flows, but differences in the location of high versus low velocities and changes in the transverse patterns of velocities between the different calibration flows are also evident.



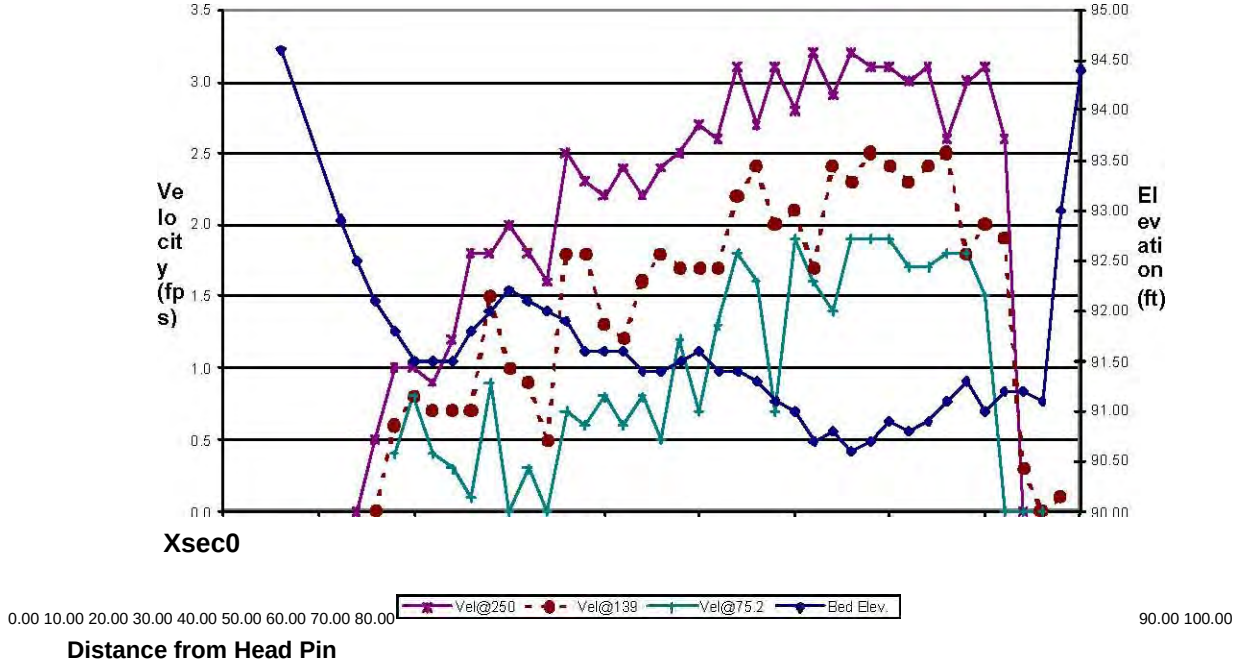


Figure L6-1. Observed velocity distribution for cross section 0.0.



Figure L6-2. Observed velocity distribution for cross section 60.0.

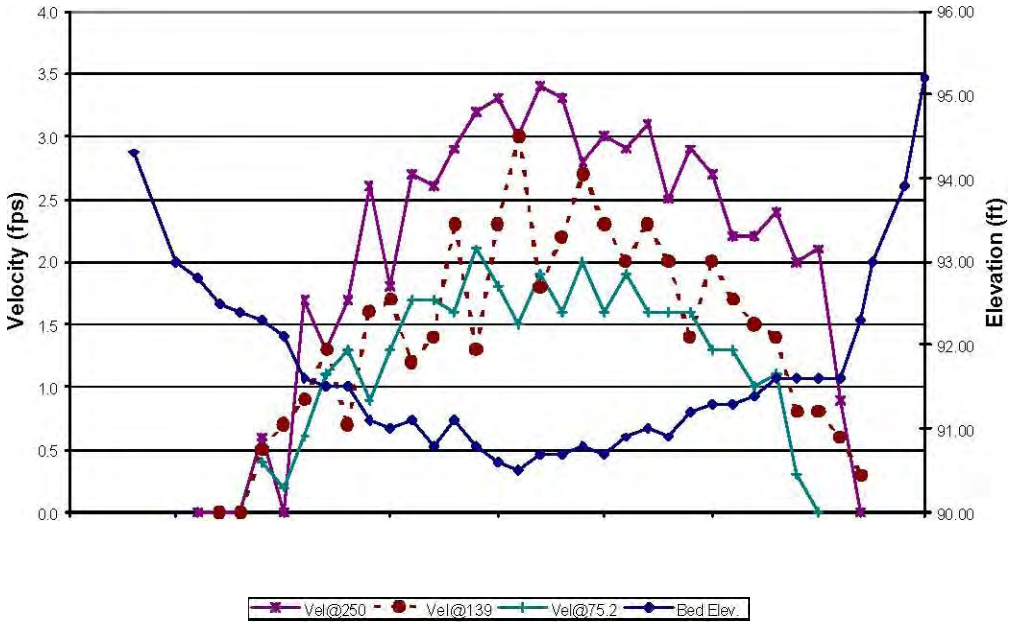
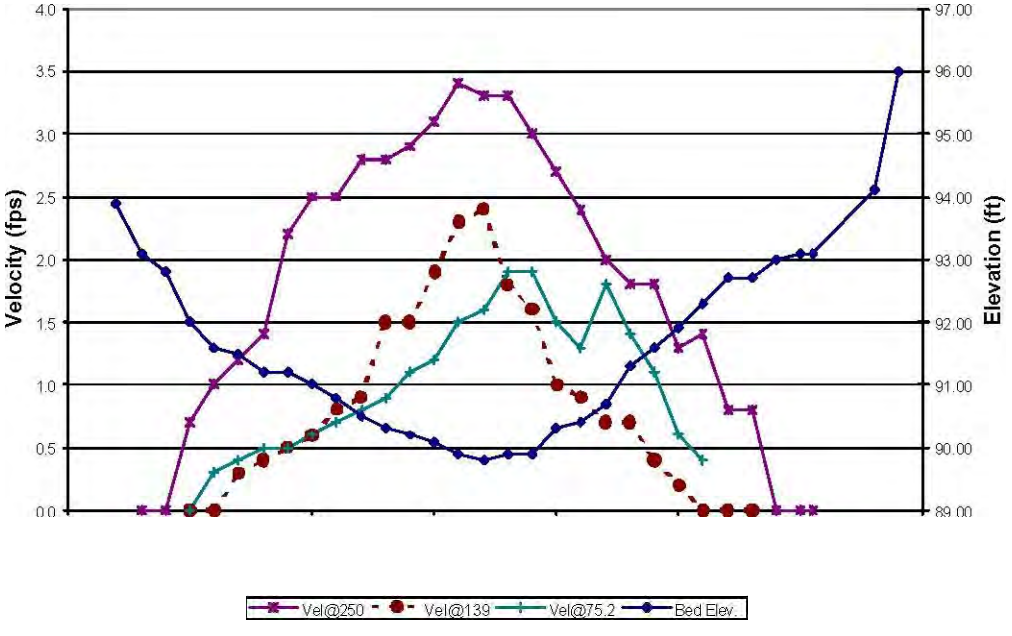


Figure L6-3. Observed velocity distribution for cross section 135.0.

Figure L6-4. Observed velocity distribution for cross section 201.0.



Step 2. Assign Velocity Calibration Sets for Simulation of Velocities Go to **\Models\Velocity Simulation\Velocity Calibration Set Assignments** and assign velocity sets as shown in Table L6-1.

Table L6-1. Initial velocity set assignments.

Transect Discharges

15 30 75.2 139 250 625 1,250 01 1111 11
601 1111 11 1351 1111 11 2011 1111 11

Assigning velocity set 1 to all cross sections and discharges tells the program to use the low calibration discharge velocity distribution as the template for simulating discharges across the entire flow range of the study. Later we will reset some or all of these values and compare the different velocity simulation results to obtain a final set of assigned calibration sets to use for each transect and discharge combination in this table.

We can now simulate velocities for all discharges at all cross sections using the low flow calibration set as the velocity distribution template. Remember that water surface elevations (WSLs) were previously established using the WSP program.

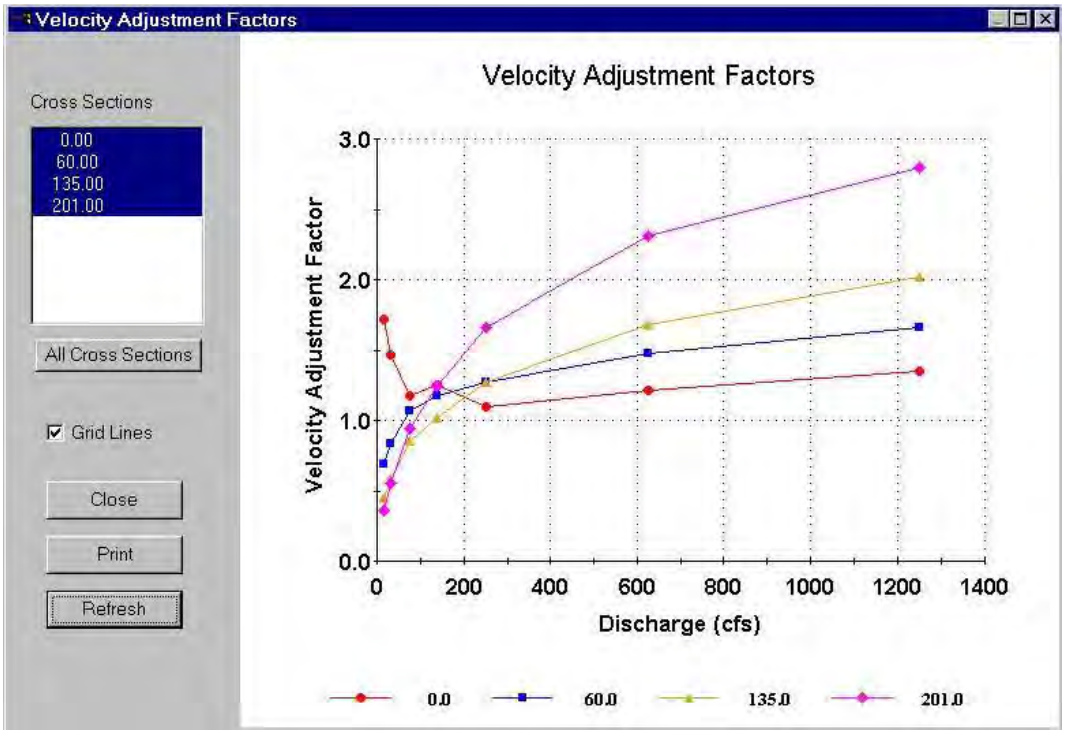
Step 3. Velocity Simulations Based on Different Velocity Calibration Data Sets

Begin by simulating velocities using the low discharge calibration set as the velocity distribution template. To do this, click the **Run** button. When the VELSIM program has completed its execution. A small message box will announce velocity simulation is finished. Click **OK**.

Now click the **Results** tab and the **Cross section** button at its bottom to display cross sectional plots. Click on 75.2 in the discharges table to display results for 75.2 cfs for cross section 0. Click the check boxes such that a check shows in all four boxes for **Observed WSL, Simulated WSL, Observed Velocities, and Simulated Velocities**. Now click the **Refresh** button. The graph should look like Figure L6-10. To view it better, use the Windows maximize button in the upper right corner of the graph window. You can now visually compare the observed and simulated velocities at a discharge of 75.2 cfs for cross section 0 based on using the 75.2 cfs calibration set as the velocity distribution template. Click on cross section 60 in the box at the top left of the window and then the **Refresh** button. The graph changes to display the WSL and velocity data and simulation results for cross section 60 at 75.2 cfs. In the classroom situation, it would take too long for each student to make printed copies of all of the plots of observed and to simulate velocities based on different templates, so the results of using calibration set 1, calibration set 2, and calibration set 3 for all cross sections at all discharges are given in Figures L6-10 through L6-45 at the end of this laboratory.

A cursory examination of these figures shows that the best fit occurs when the simulated discharge is equal to the calibration set discharge. So it seems reasonable to use Cal Set 1 for discharges less than or

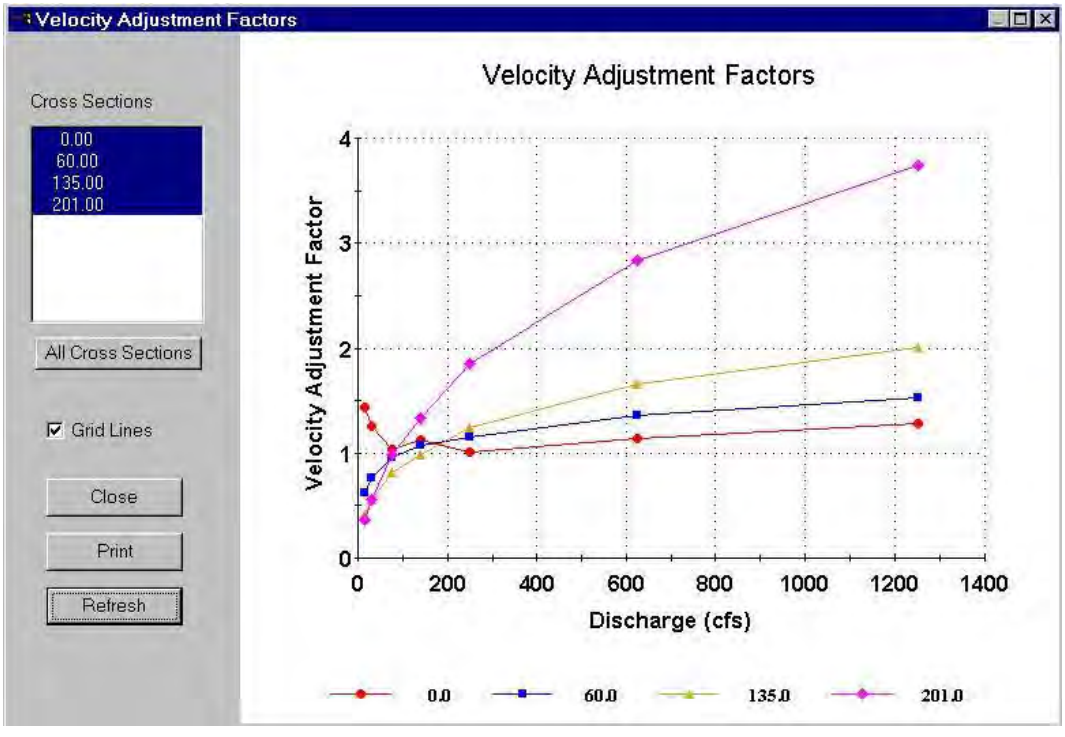
equal to 75.2 cfs, Cal Set 2 for 139 cfs, and Cal Set 3 for discharges greater than or equal to 250 cfs. Try assigning calibration sets in that order and run the model again. Figures L6-5 to L6-8 contain the VAF relationships for the



four velocity template runs. These results will be compared in the next section.

Figure L6-5. Velocity adjustment factor for calibration flow of 75.2 cfs.

LABORATORY 6 –VELOCITY MODELING – VELSIM



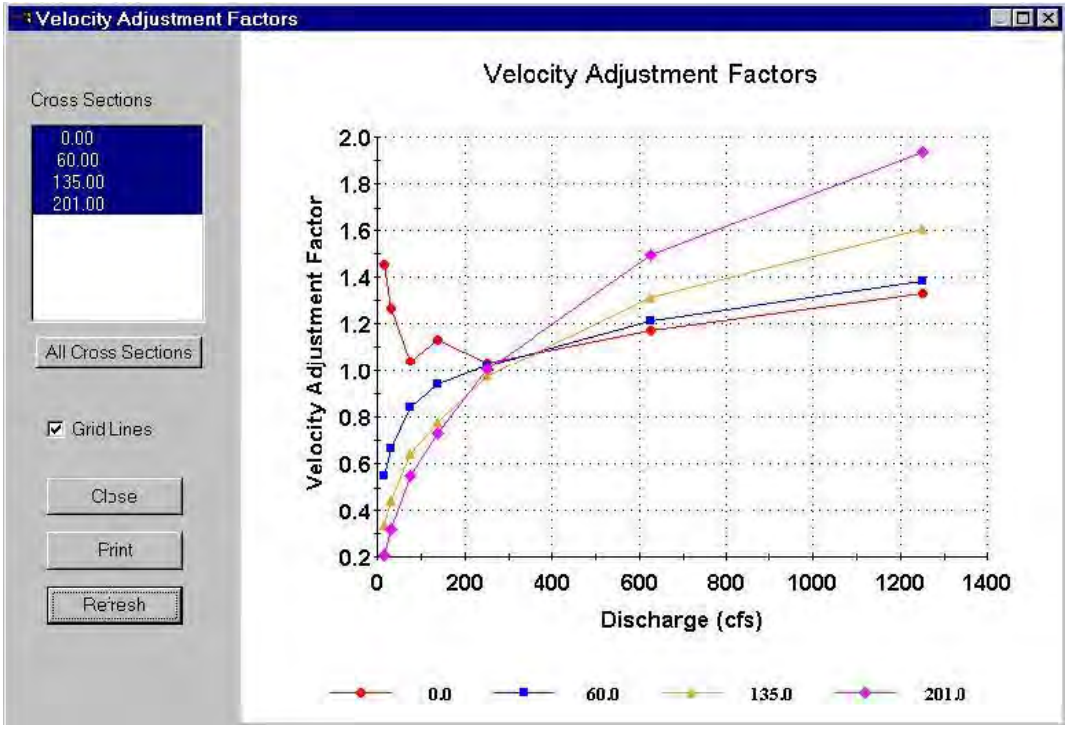


Figure L6-6. Velocity adjustment factor for calibration flow of 139 cfs.

Figure L6-7. Velocity adjustment factor for calibration flow of 250 cfs.

LABORATORY 6 –VELOCITY MODELING – VELSIM

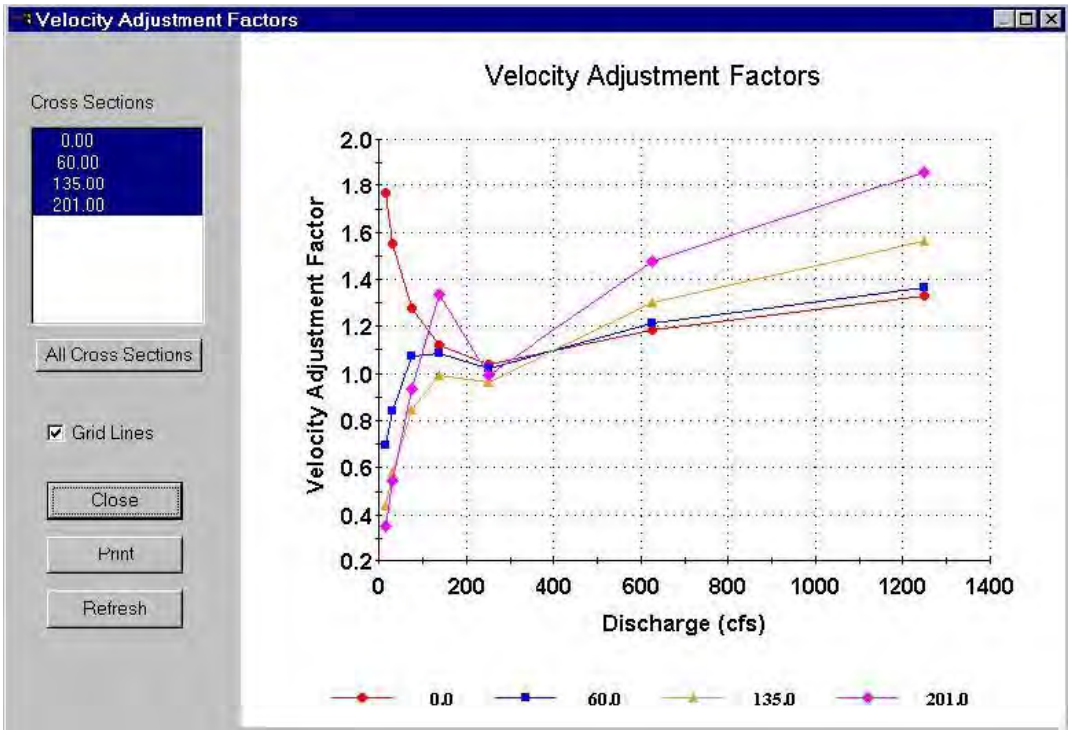


Figure L6-8. Velocity adjustment factor for mixed calibration flow sets.

Step 4. Examine the VAF Relationships and Velocity Profiles

We will first examine the VAF relationships for each of the four simulations. Remember, velocity predictions at a simulated discharge are a function of the Manning's n derived from the calibration velocities at a single calibration flow. Also recall that VELSIM uses the VAF to maintain mass balance between simulated and computed discharges. Since roughness decreases with increasing discharge, VAF's below the calibration flow should generally be less than 1.0 and greater than 1.0 for flows above the velocity calibration flows. The degree to which the VAF departs from 1.0 at the velocity calibration flow is a function of the difference between the calculated discharge and the „best estimate of the discharge' as well as the difference between predicted and observed water surface elevations (see Chapter 2 in the manual).

In Figure L6-5 (where the 75.2 cfs calibration set was used to simulate all discharges), all the VAF relationships except at cross section 0 follow the expected pattern. The relationship at cross section 0 „suggests' that roughness is decreasing with as the discharge decreases below 139 cfs, which is counter to expected results. The remaining cross sections appear to behave „normally'.

The VAF relationships for all four simulations are shown in Figures L6-5 to L6-8. We can learn several things by comparing these figures.

First, it should be apparent that the use of a single velocity calibration set results in VAF relationships, which are more 'typical' of expected results for all but cross section 0. Use of a mix of all three velocity sets produces an irregularity between 75.2 and 250 cfs for all but cross section 0. Though the VAF traces appear to have a break in slope at either 75.2 cfs or 139 cfs and drop to the value at 250 cfs, they do

appear to be ascending with increased discharge within each range of simulation, e.g. 0.0 – 75.2 cfs and above 250 cfs. As only one discharge was simulated using the 139 cfs template, we do not know if this will hold true for the 139 cfs calibration set without running additional discharges. What do the other VAF plot suggest?

Note the magnitude of the velocity adjustment factors using the four different approaches. These results show that the choice of a particular velocity calibration data set can impact both the magnitude and functional relationship of the VAF's. As might be expected, since the WSP modeled water surface elevations were used for these simulations, the VAF relationship for the high flow velocity set is „best behaved' over all ranges of simulated discharges. The results at cross section 0 would suggest that either alternative velocity simulation options in VELSIM should be attempted, that an alternative water elevation modeling approach may be required, that a combination of the two may be warranted, or that the channel conditions warrant further study.

Although an examination of the VAF relationships helps in the general diagnostics of the velocity simulations, an examination of the actual predicted velocities for each vertical for all cross sections at all simulated discharges must be undertaken to critically evaluate the simulation results. Actual velocity predictions should receive more emphasis than „strict' adherence to an expected pattern of the VAF relationships in evaluation of the effectiveness of the velocity simulations.

A careful examination of the results shown in Figures 10 – 45 should reveal several key points about this particular data set and VELSIM velocity simulations in general. First, the predicted velocities at a given calibration flow using that calibration flow velocity set do not exactly reproduce the observed velocities. The velocities measured at each cross section do not necessarily result in a computed discharge equal to the best estimate of the discharge or calibration discharge. Thus, the predicted velocities are adjusted by the computed VAF to maintain mass balance between the simulated flow and computed flow at the cross section (see Chapter 3 in the manual).

The second thing to note is that at a given calibration flow, using that calibration flow velocity set results in some computational cells at the stream margin that have predicted velocities where none were observed. This is due to the discrepancy in the observed and predicted water surface elevations at each cross section and possible errors in the original data.

It should also be apparent that the velocity pattern at the calibration flow used in the simulation is „replicated' at all simulation flows. This can result in relatively large discrepancies between observed and simulated velocities when using for example a low velocity calibration set to simulate high flows or vice versa. This can often occur when the velocity profiles change dramatically between discharges due to channel geometry heterogeneity, especially due to unobserved conditions upstream of the transect.

Collection of a single high flow velocity data set for use in modeling should be carefully evaluated based on complexity of the channel geometry at specific cross sections. If significant changes in velocity profiles are expected over different ranges of discharge of interest in a study, additional velocity data sets should be collected.

The results also suggest that simulation of velocities higher than an observed calibration velocity data set can be problematic at some cross sections since VELSIM must „guess' at a Manning's n value for computational cells where no observed velocities have been provided at the velocity calibration flow.

The simulation results for cross section 201.0 also demonstrate the influence of water surface modeling on the predictions of velocities with VELSIM. Go to **Results\Graphs\Longitudinal Profile** and zoom in on the region encompassing the three calibration discharges. Note that at cross section 201.0 the WSP

model is slightly under-predicting the water surface elevation at the 139.0 cfs and 75.2 cfs calibration flows. Now view **Results\Graphs\Cross Section** and select cross section 201, discharge 75.2 cfs, observed and simulated WSL and velocities. At 75.2 cfs VELSIM predicts slightly slower water at the cross section but one cell on the left bank shows a simulated velocity of 0.236 fps where the calibration velocity was 0.0. This provides enough conveyance to slightly lower the other velocities. At 139 cfs, however, the simulated velocities are significantly higher than the observed velocities. The simulated water surface elevation is 0.001 ft higher than the observed value, not a significant difference. Yet, the velocities are slightly higher. Why? Noting the calibration data, we find that the local discharge was 249 cfs, but the best estimate discharge is 250 cfs. Thus, a VAF slightly greater than 1.0 was needed to achieve mass balance resulting in a very slight increase in velocities in spite of the slightly higher WSL.

In general, improving the water surface elevation predictions for any cross section at the calibration flows would bring the simulated cross sectional areas closer to the observed values. This would therefore reduce the VAF adjustments and result in a better match between observed and predicted velocities at the lower calibration flows. This can be seen the results at the 250 cfs calibration flow which identically match the calibration velocities over most of the cross section. Try simulating additional discharges that match the local discharges measured at cross sections 60 and 135. Do the simulated velocity results match the observed values better?

The final water surface elevation simulation using WSP allowed a very large difference (0.137 ft.) between the observed and predicted water surface elevation at cross section 60 for the 250 cfs discharge. This was based on the assumption that an error of at least 0.10 ft. had been made in the water surface measurement at that discharge. In spite of the large difference in water surface elevation, the simulated velocities are only slightly lower than the observed velocities. Two cells at the right of the channel, which have significant simulated velocities when the measured velocities were zero, explain the lower velocities. The overall close agreement in simulated and observed velocities further supports the assumption of a water surface elevation measurement error.

No single velocity calibration set is guaranteed to work at all ranges of simulated discharges at all cross sections. The 3-calibration data set approach would appear to represent the best compromise at all cross sections for all flow ranges. Selection of an appropriate velocity set(s) should be carefully considered in light of model performance and study objectives. These results should reinforce the importance of accurate water surface elevation modeling prior to undertaking the velocity modeling in VELSIM. A critical examination of the velocity modeling can also be used to revise water surface modeling approaches (for example, what to do with cross section 60) based on the effectiveness of the velocity predictions at specific ranges of discharge of importance to a particular study.

Step 5. Revise Water Surface Elevations at Discharges below 250 cfs Based on MANSQ

The water surface elevation modeling conducted in Laboratories 3, 4, and 5 indicated that either the VELSIM or MANSQ model matched the observed water surface elevations at the medium and low calibration flows. In this step of the laboratory, the WSL data for each cross section will be updated to use the water surface elevation predictions derived from the MANSQ model for all simulation flows below 250 cfs. Table L6-2 lists the water surface elevations for each cross section that will be used for this part of the laboratory.

Table L6-2. derived water elevations for section.

Windows		DOS	Difference
Cell bed elevation	91.65	91.65	0
Water surface elevation	92.456	92.47	0.014
Depth	0.806	0.82	0.014
Depth Suitability Index	0.0708	0.096	0.025
Combined Suitability Index	0.0644	0.087	0.023
Weighted Usable Area	8.698	11.79	3.096

MANSQ surface each cross

Go to **Acknowledgements**

\Models\WSL\Method and set the starting combination for the WSP backwater at cross section 0.0 for discharges of 75.2 and 139 cfs to WSP-MANSQ and **Run** the selection.

Now go to **\Models\Velocity** and click **Run** to re-run the velocity simulation using the new elevations derived from using MANSQ as the starting point in the WSP backwater calculation. Compare the VAF relationship in Figure L6-9 with Figure L6-8. Updating the WSLs at the lower discharge ranges (i.e., below 250 cfs) improves the VAF relationship at cross section 0.0 by reducing the variation above a VAF value of 1.0 even though it does not result in transforming the VAF curve into the desired shape.

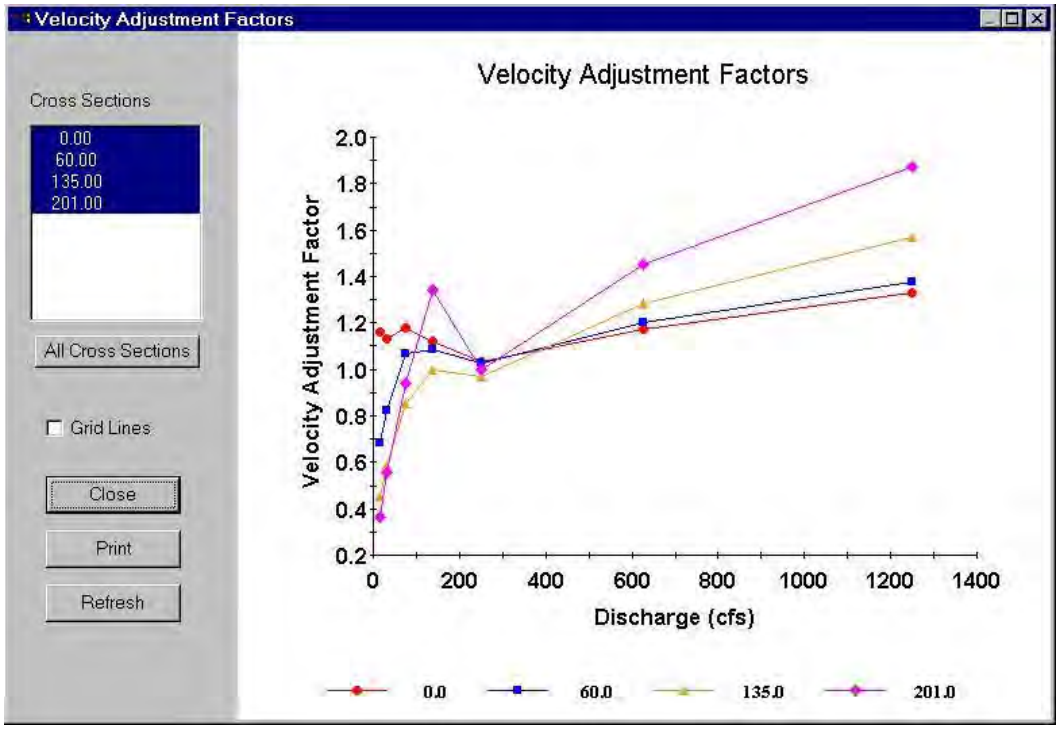


Figure L6-9. Velocity adjustment factors using MANSQ for low flow starting WSLs.

Based on these simulation results, the user would likely conclude that if only one calibration set is to be used, the high velocity calibration data set could be used for all ranges of simulated discharges. Alternatively, the user could also use each velocity calibration data set over a specific range of simulated discharges such as the high velocity calibration set for all flows greater than 250 cfs and for flows down

to a discharge of 139 cfs. The 139 cfs velocity calibration data set could then be used to model flow down to 75.2 cfs and then use the 75.2 cfs velocity calibration data set for all lower simulated discharges. The choice of modeling strategy is a matter of professional judgment based on the quality of the available data. The goal is to produce a simulated velocity distribution that is as near as possible to that which occurs in the stream. A carefully kept set of analysis notes explaining why a particular strategy was selected is strongly advised. PHABSIM for Windows maintains a **History.project name** text file that records the order of model runs. This file can be periodically copied to another file and annotated as a means of tracking the analysis.

Step 6. Use of the NMAX Option in VELSIM to Control Velocity Simulations

One of the ways to control velocity simulations in VELSIM is to restrict the magnitudes of the estimated Manning's n values. This can be accomplished by using the NMAX or NMIN options. Restriction of Manning's n values can often improve velocity simulations in computational cells at the margin of the stream where velocity calibration data does not exist (i.e., verticals in the channel above the highest velocity calibration data set). Since velocity simulations at the stream margins can be controlled, the velocity predictions at all other verticals are also affected due to the interaction of conveyance and the VAF's.

Selection of a limit on Manning's n, whether a maximum or minimum, is a matter of professional judgment. One rational approach is to examine the calculated Manning's n values at computational cells along the margins of each cross section for each calibration flow and select a Manning's n which is an ‚average' of these values. Alternative approaches include the estimation of a Manning's n value using handbook values (see Chapter 3 in the manual) based on substrate characteristics. It should be noted that use of an NMAX and/or an NMIN applies to all computational cells at all cross sections at all flows when running VELSIM. Therefore, in those instances where substrate characteristics vary dramatically between cross sections, separate VELSIM data files containing only selected cross sections may be necessary. In this laboratory, the NMAX constraint will be applied to the entire data set over all ranges of simulated discharges.

Go to **\Models\Velocity\Options** and check the box labeled **Limit Manning's n**. Enter an NMAX value of 0.035 and click the **Run** button. Then view the VAF relation by clicking the **ZVAFF** tab and its **Graph** button.

It is apparent the constraint of Manning's n values to a maximum of 0.035 has resulted in a reduction in the magnitudes of the VAF's at all cross sections. This would be expected since lowering the upper limit on estimated Manning's n should result in higher velocity predictions. This in turn should decrease the VAF that is derived from the ratio of simulated discharge over computed discharge. A comparison of predicted Manning's n and velocities at the first 25 computational cells at cross section 135 at 15 cfs clearly illustrates the effect of NMAX on velocity modeling (Table L6-3).

Windows		DOS	Difference	% difference
Cell bed elevation	91.65	91.65	0	0.00
Water surface elevation	92.456	92.47	0.014	0.02
Depth	0.806	0.82	0.014	1.71
Depth Suitability Index	0.0708	0.096	0.025	26.25
Combined Suitability Index	0.0644	0.087	0.023	26.25
Weighted Usable Area	8.698	11.79	3.096	26.25

Table L6-3.

Acknowledgements **i**
PREFACE **ii**
A Brief History of PHABSIM
Use of this Document
Changes Between PHABSIM Version 2 and PHABSIM for Windows
Conventions Used in this Document
Chapter 1, Introduction to the Physical Habitat Simulation System **1**
Objectives
Associated Laboratory Exercises
An Overview of IFIM
The Purpose of PHABSIM
The Structure of PHABSIM
Application of PHABSIM
Scoping
Selection of Target Species and Suitability Curves
Selection of Target Species
Types of Suitability Curves
Transferability of Suitability Curves

Comparison of Manning's n and velocity predictions at cross section 135.0 at 15.0 cfs.

The overall pattern of velocities generated by limiting Manning's n needs to be considered before accepting the improved VAF relation as the best velocity simulation outcome that can be obtained for velocity simulation. Using **\Models\Velocity\Results\Cross section,** look at the velocity patterns obtained for each cross section at the three calibration discharges. How well do they match? Do you think that limiting Manning's n has improved the overall velocity simulation across all transects over the full range of discharges?

At this point in the analysis, users would need to determine from the context of their particular application which set of velocity simulation options and results is best over what target flow ranges in choosing the appropriate velocity modeling approach. In some applications it may be desirable to use simulation results that minimize the error between measured and observed velocities over the full range of simulations. In other situations, the investigator may choose to use each single velocity calibration set only over a specific range of discharges. This is often the case where velocity patterns vary dramatically across cross section geometries as discussed in Chapter 2 of the manual.

Step 7. Specifying n values for Problem Areas

Look through Figures L6-10 to L6-45 for those cases where simulated discharge is equal to the calibration discharge. Note that some edge conditions are not well simulated due to being dry at the observed discharge. Table L6-4 contains a summary of the diagnostic conditions revealed by those figures. Some data errors can be seen and some velocity simulation problems stand out.

LABORATORY 6 –VELOCITY MODELING – VELSIM

Windows		DOS	Difference	% difference
Cell bed elevation	91.65	91.65	0	0.00
Water surface elevation	92.456	92.47	0.014	0.02
Depth	0.806	0.82	0.014	1.71
Depth Suitability Index	0.0708	0.096	0.025	26.25
Combined Suitability Index	0.0644	0.087	0.023	26.25
Weighted Usable Area	8.698	11.79	3.096	26.25

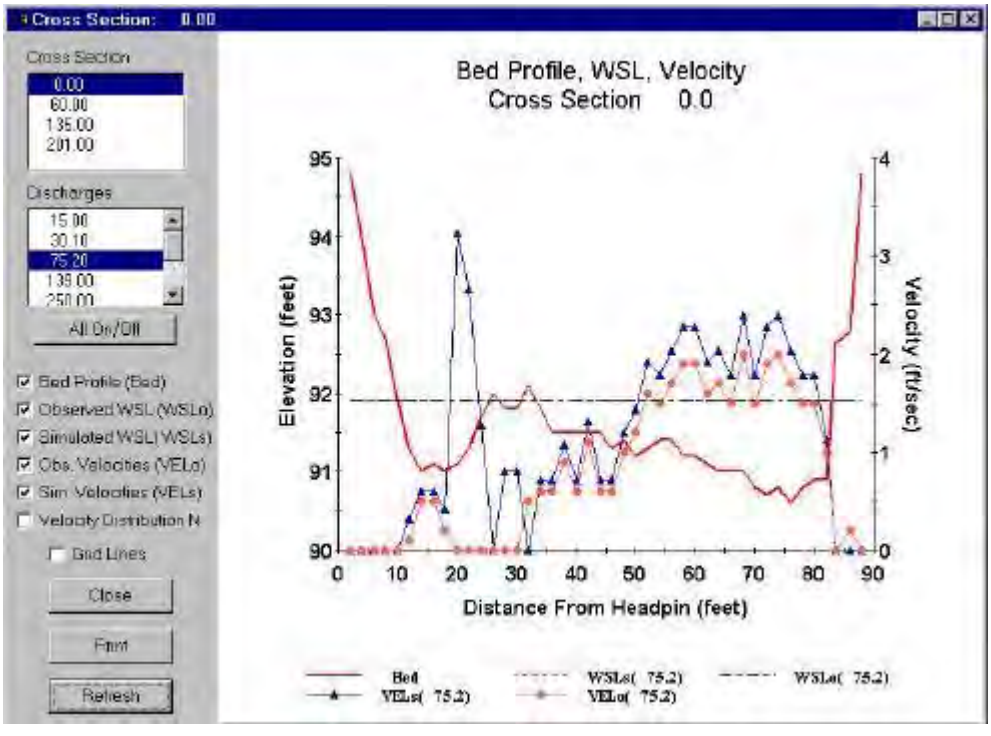
Acknowledgements **i**
PREFACE **ii**
A Brief History of PHABSIM
Use of this Document
Changes Between PHABSIM Version 2 and PHABSIM for Windows
Conventions Used in this Document
Chapter 1, Introduction to the Physical Habitat Simulation System **1**
Objectives
Associated Laboratory Exercises
An Overview of IFIM
The Purpose of PHABSIM
The Structure of PHABSIM
Application of PHABSIM
Scoping
Selection of Target Species and Suitability Curves

Table L6-4. Summary of data and simulation diagnostic conditions.

In **\Edit\Cross Sections \Coordinate Data** you can set Manning's n values for specific cells on each cross section. After examining how VELSIM handles edges (or other parts of the channel) automatically, you may wish to enter n values for specific cells and rerun the velocity simulation. Roughness values set for specific cells apply at all discharges so you must take care that a good n value for one condition does not perturb the results for other discharges. Try setting n values on the left bank of cross section 201 for 250 cfs, rerun the simulation, and see how velocity values are affected at all flows.

The user is encouraged to try additional velocity simulation options within VELSIM (e.g., placing specific Manning's n values at specific verticals or using the NMIN option). Examine the effects on the velocity simulations in terms of both the VAF relationships and observed versus predicted velocity distributions at each cross section. Remember that water surface simulations for each cross section affect the velocity simulations. In some cases water surface errors can be the main contributing factors for discrepancies between observed and predicted velocities.

LABORATORY 6 –VELOCITY MODELING – VELSIM



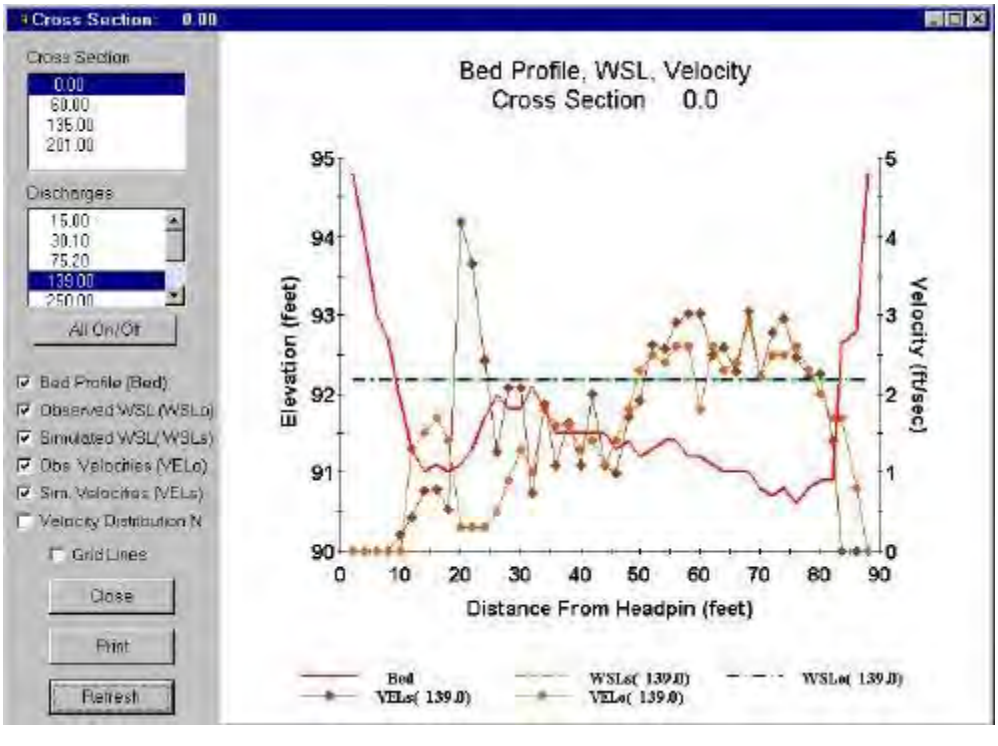
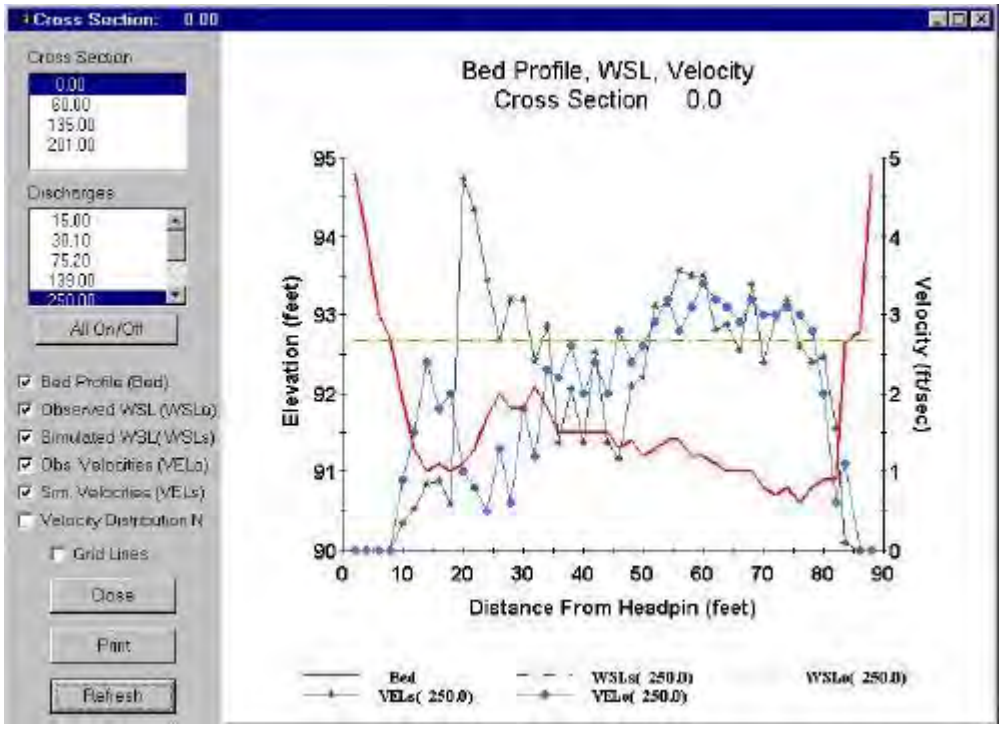


Figure L6-10. Simulated and observed velocity profile for 75.2 cfs at Xsec 0, Cal Set 75.2.

Figure L6-11. Simulated and observed velocity profile for 139 cfs at Xsec 0, Cal Set 75.2.

LABORATORY 6 –VELOCITY MODELING – VELSIM



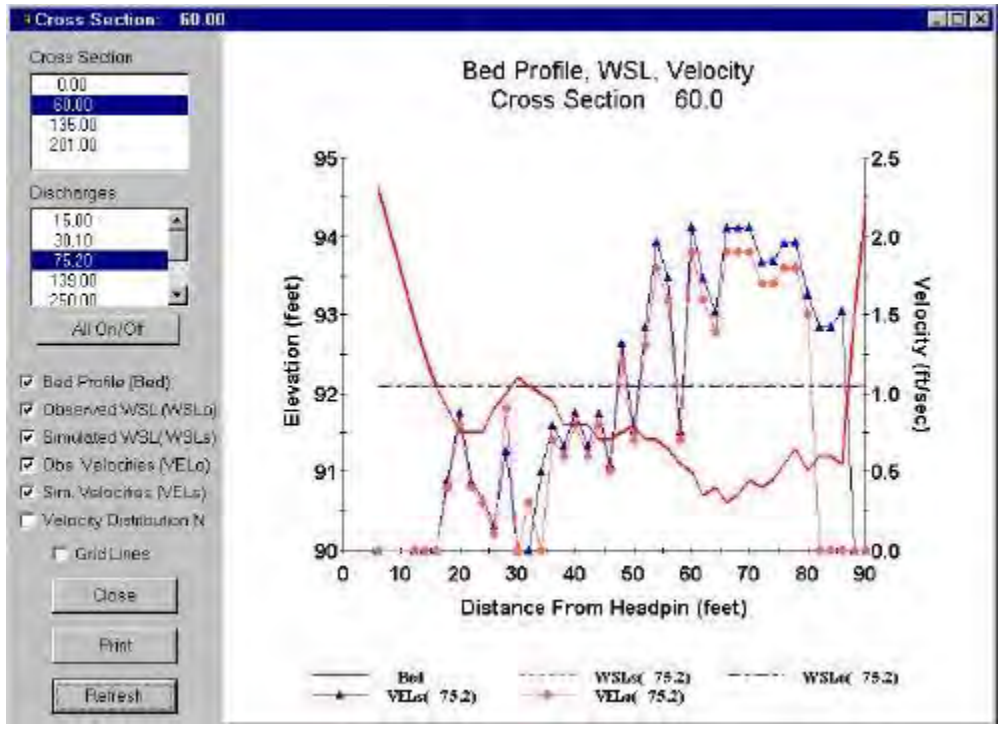
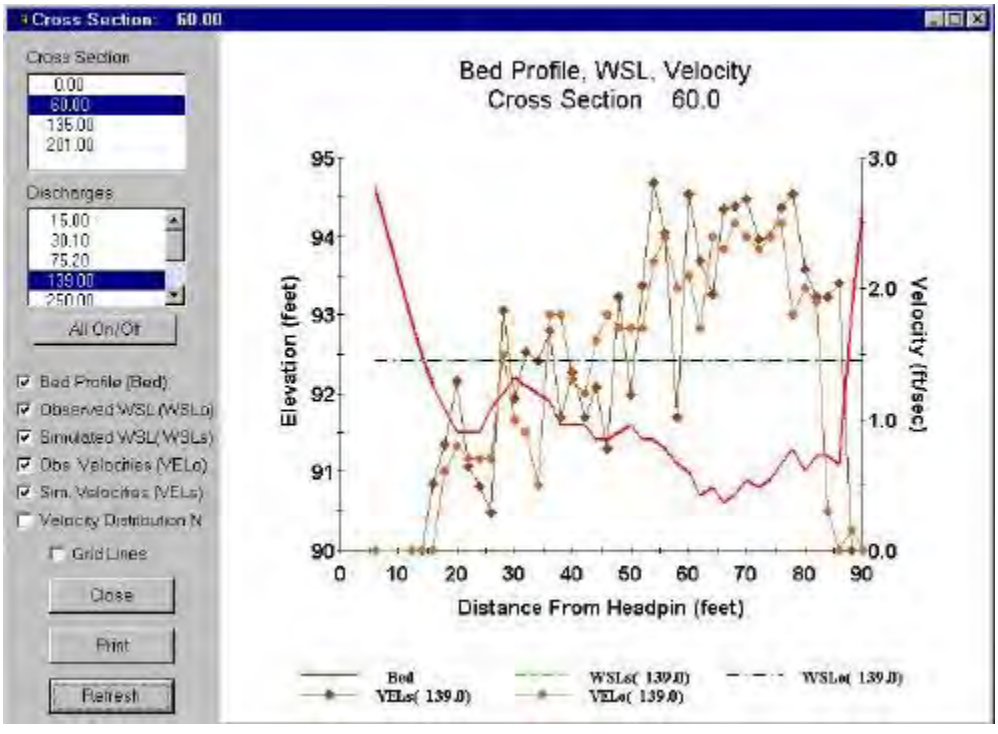


Figure L6-12. Simulated and observed velocity profile for 250 cfs at Xsec 0, Cal Set 75.2.

Figure L6-13. Simulated and observed velocity profile for 75.2 cfs at Xsec 60, Cal Set 75.2.

LABORATORY 6 –VELOCITY MODELING – VELSIM



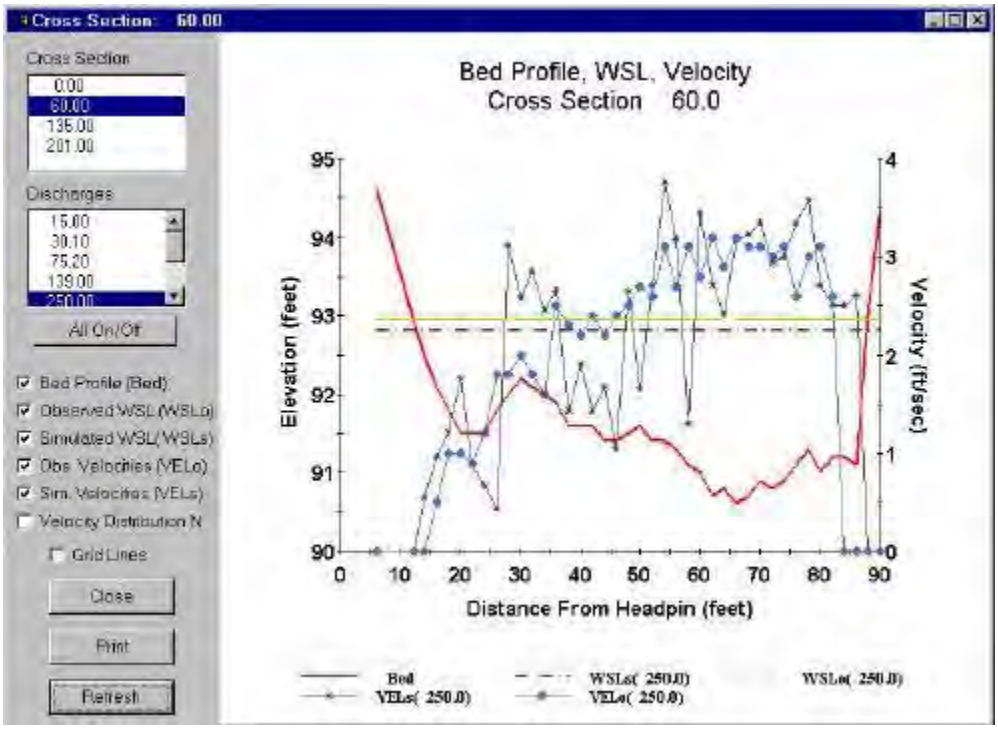
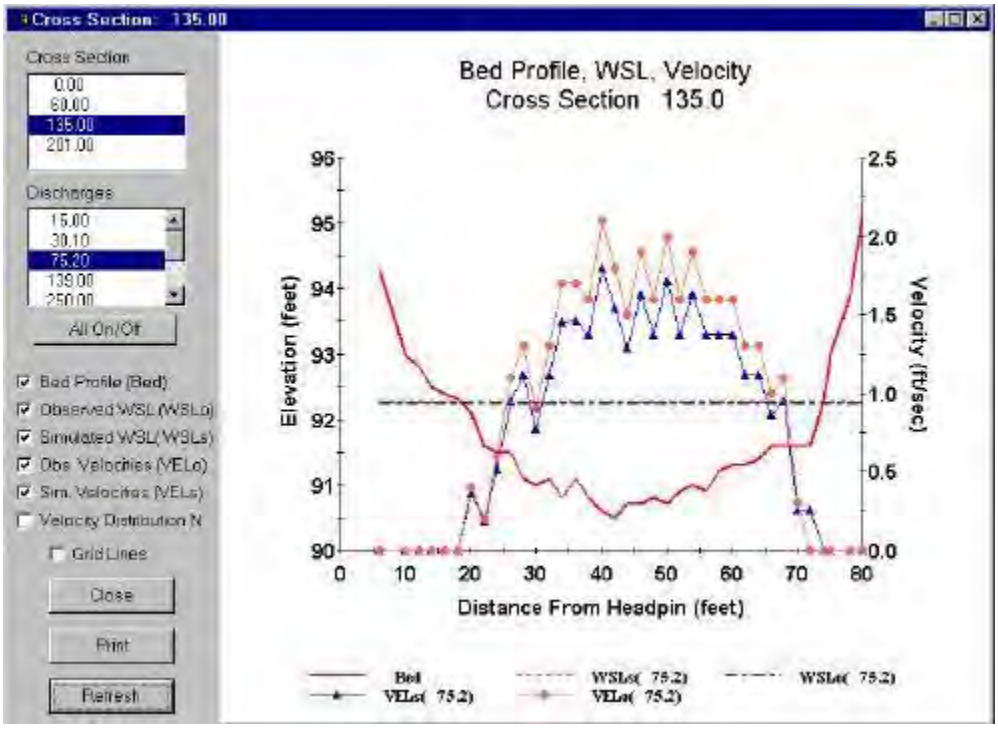


Figure L6-14. Simulated and observed velocity profile for 139 cfs at Xsec 60, Cal Set 75.2.

Figure L6-15. Simulated and observed velocity profile for 250 cfs at Xsec 60, Cal Set 75.2.



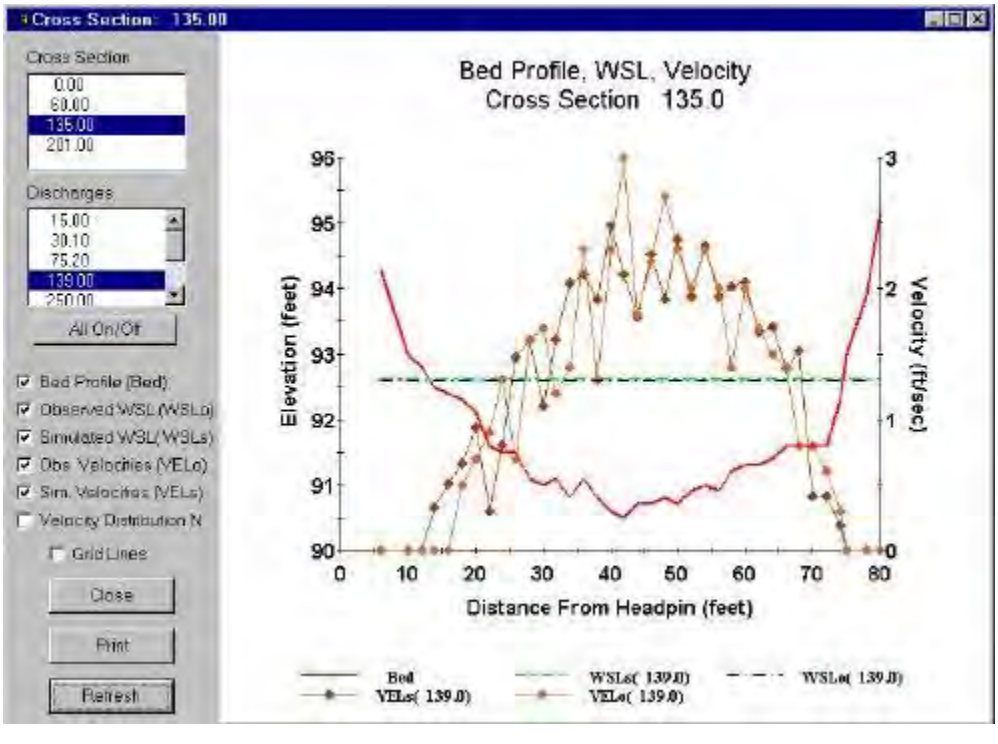
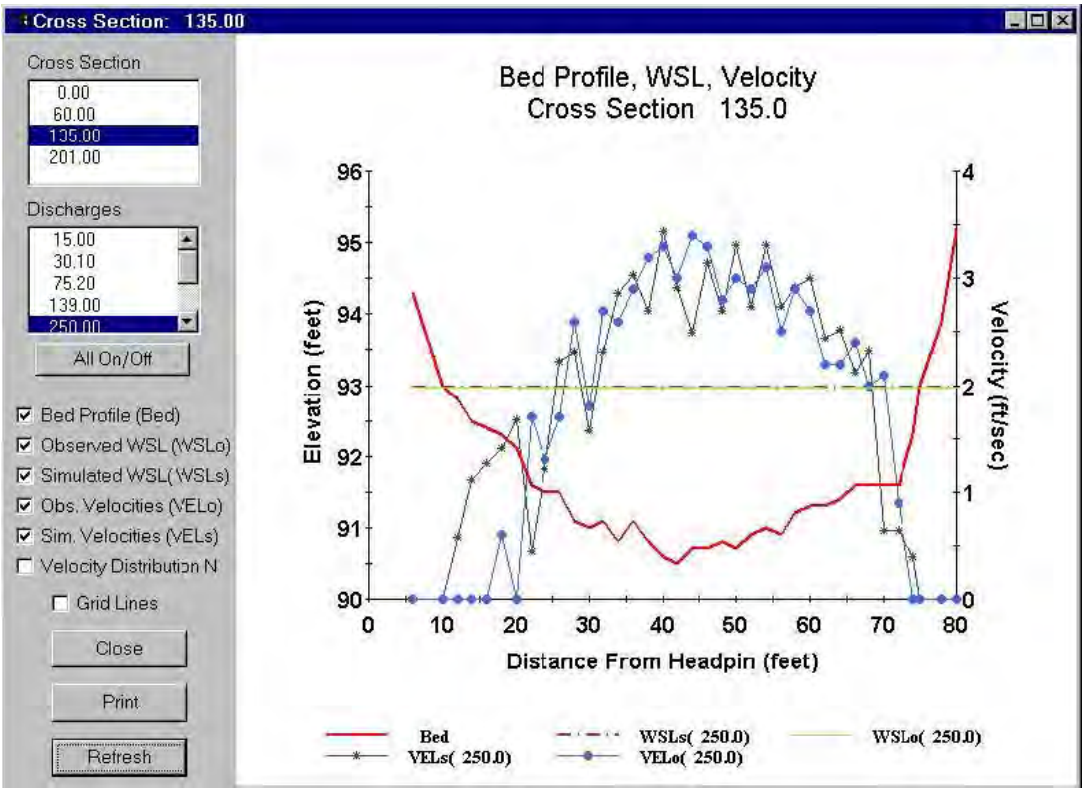


Figure L6-16. Simulated and observed velocity profile for 75.2 cfs at Xsec 135, Cal Set 75.2.

Figure L6-17. Simulated and observed velocity profile for 139 cfs at Xsec 135, Cal Set 75.2.

LABORATORY 6 –VELOCITY MODELING – VELSIM



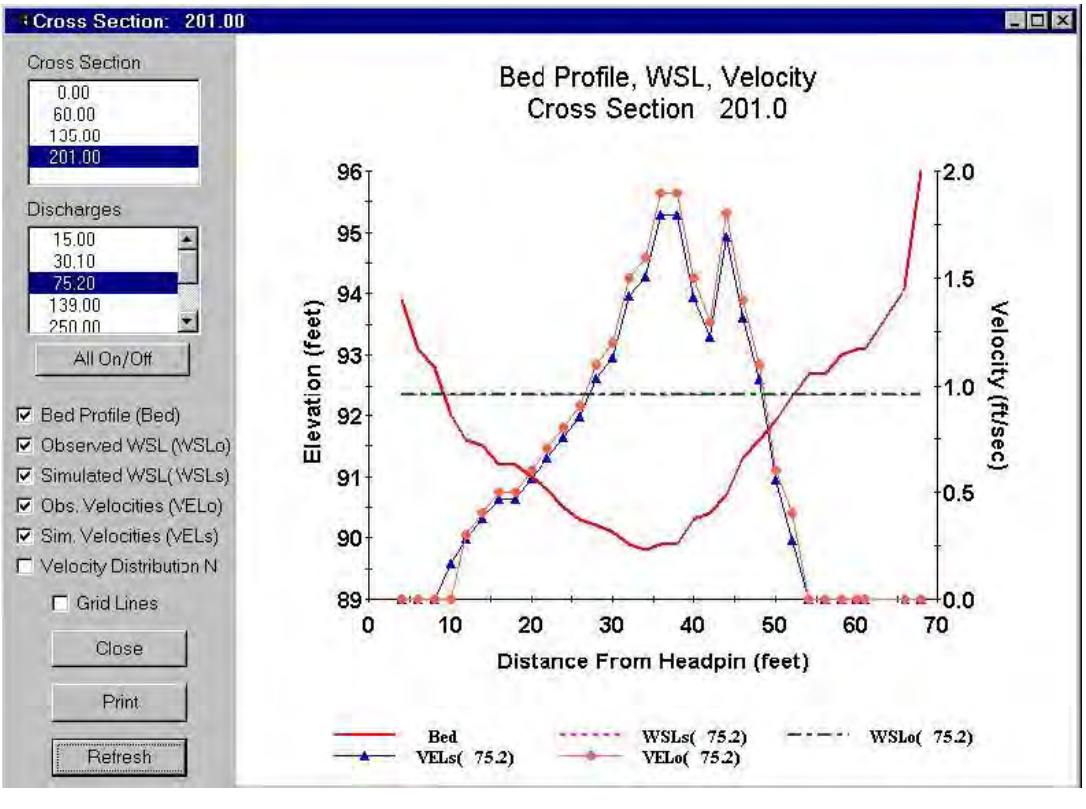
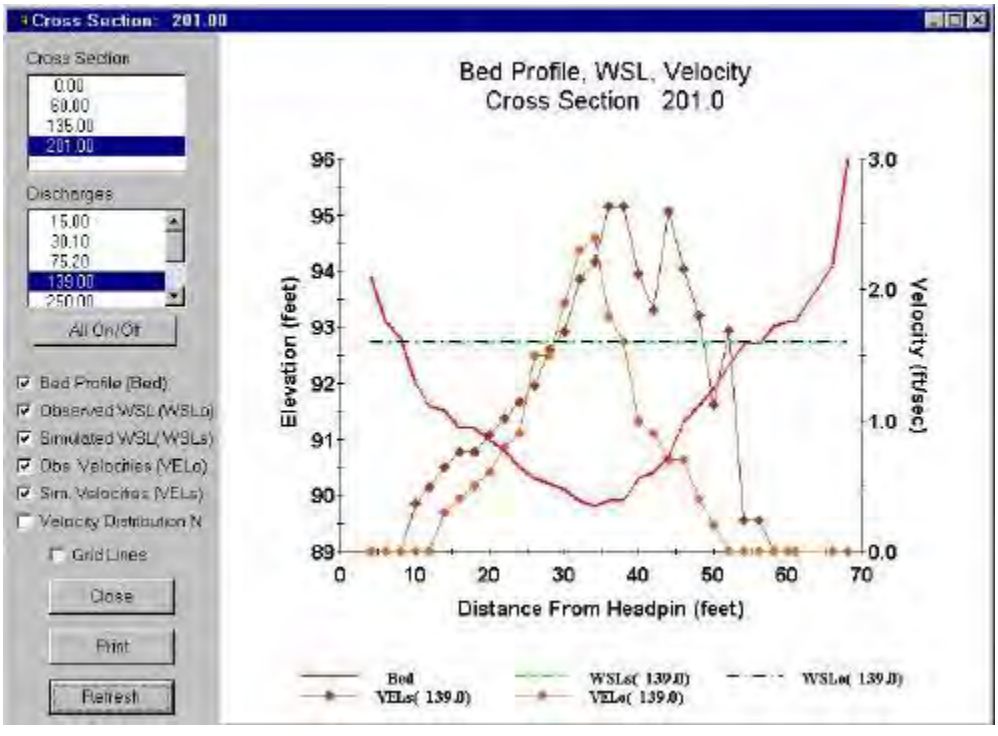


Figure L6-18. Simulated and observed velocity profile for 250 cfs at Xsec 135, Cal Set 75.2.

Figure L6-19. Simulated and observed velocity profile for 75.2 cfs at Xsec 201, Cal Set 75.2.



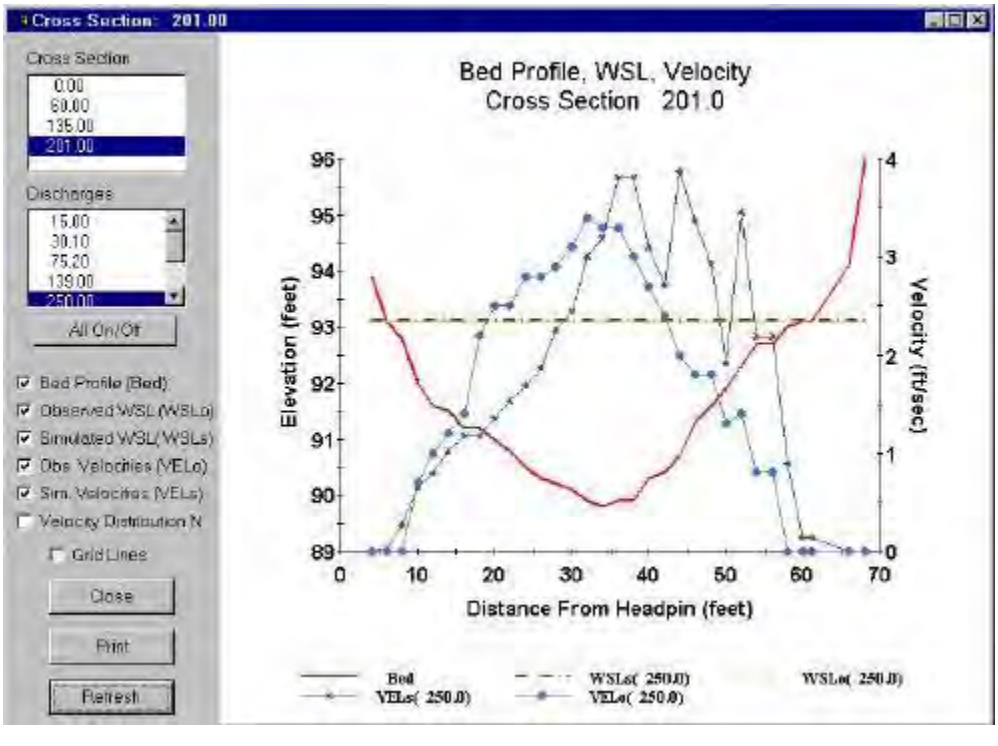
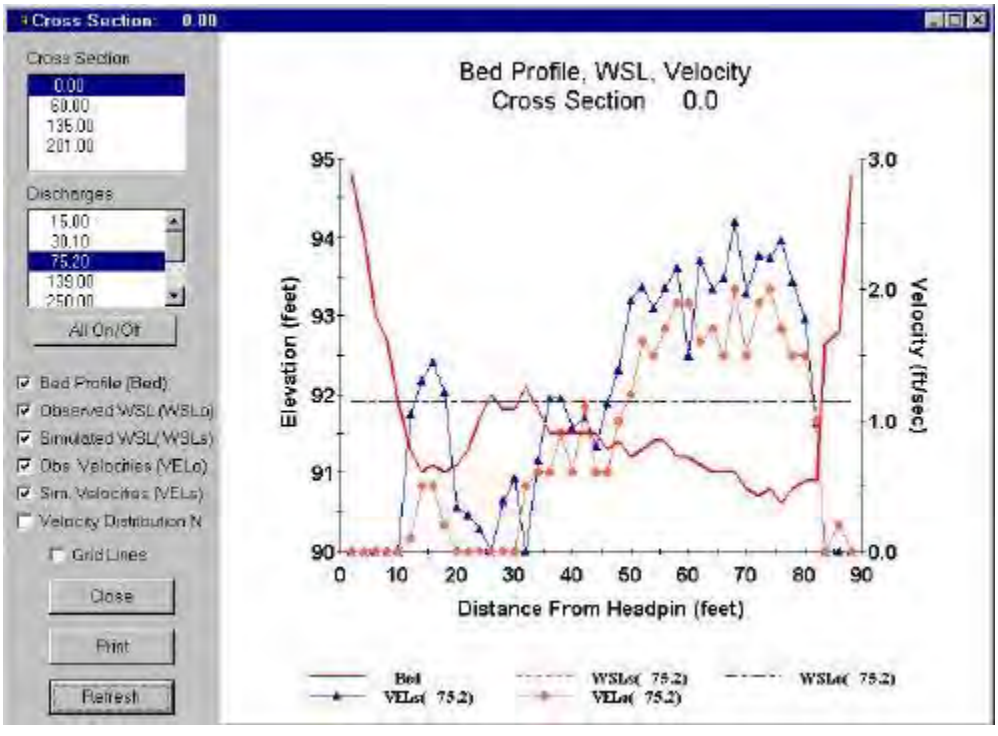


Figure L6-20. Simulated and observed velocity profile for 139 cfs at Xsec 201, Cal Set 75.2.

Figure L6-21. Simulated and observed velocity profile for 250 cfs at Xsec 201, Cal Set 75.2.

LABORATORY 6 –VELOCITY MODELING – VELSIM



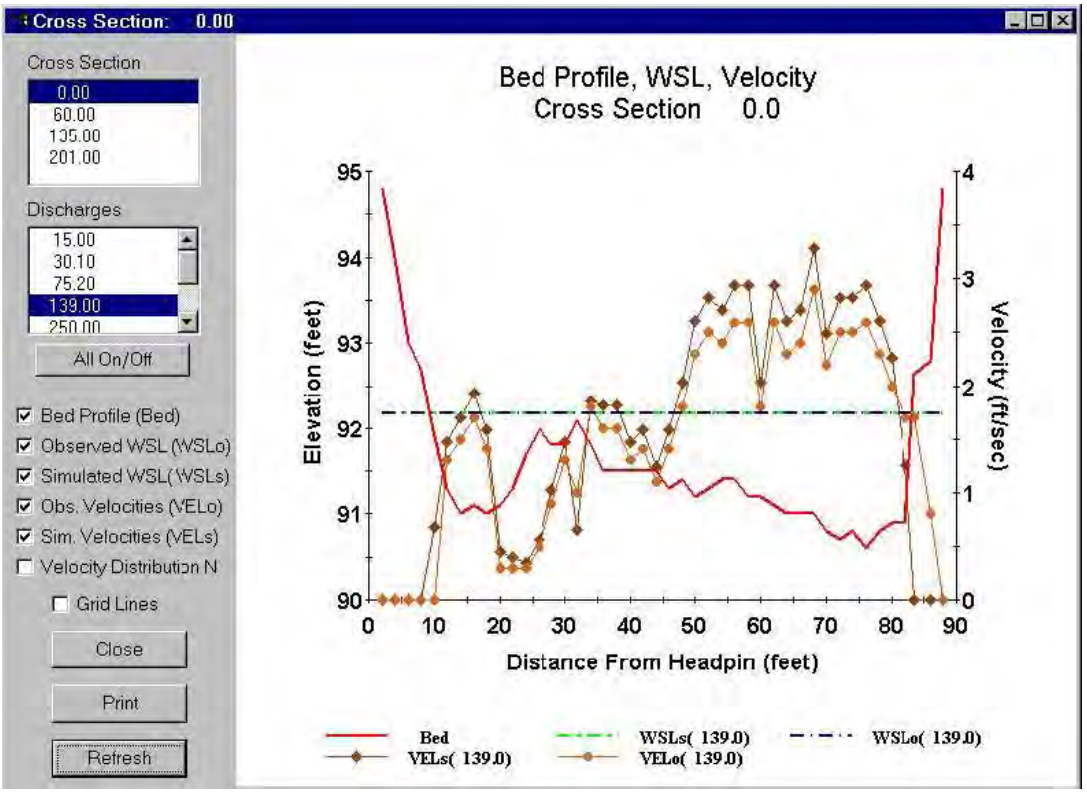
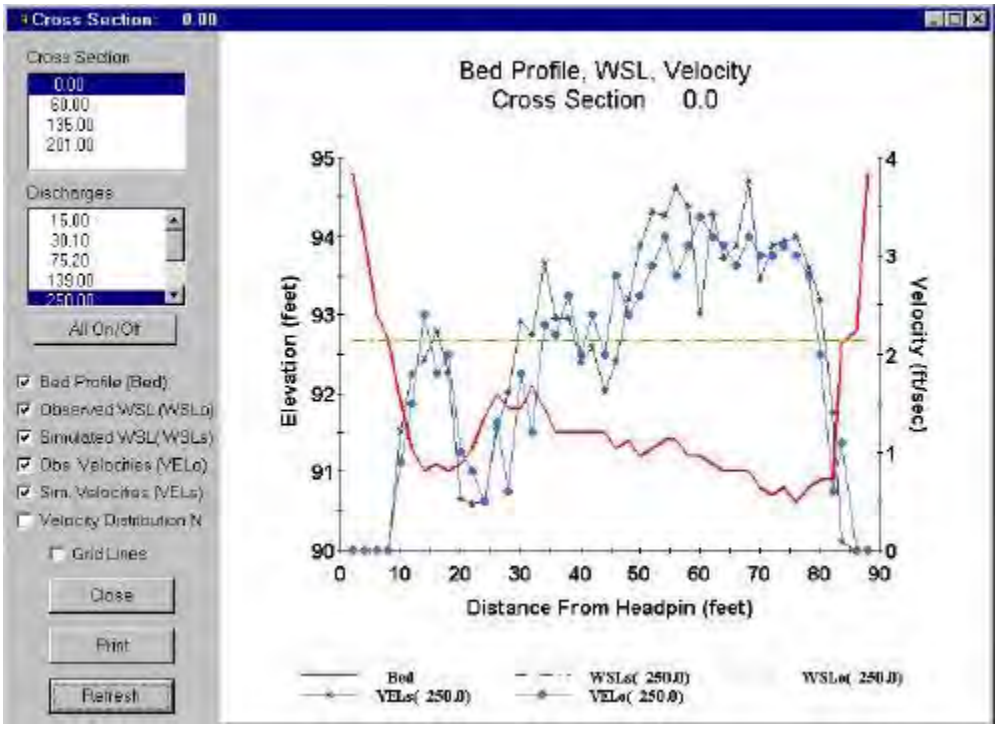


Figure L6-22. Simulated and observed velocity profile for 75.2 cfs at Xsec 0, Cal Set 139.

Figure L6-23. Simulated and observed velocity profile for 139 cfs at Xsec 0, Cal Set 139.



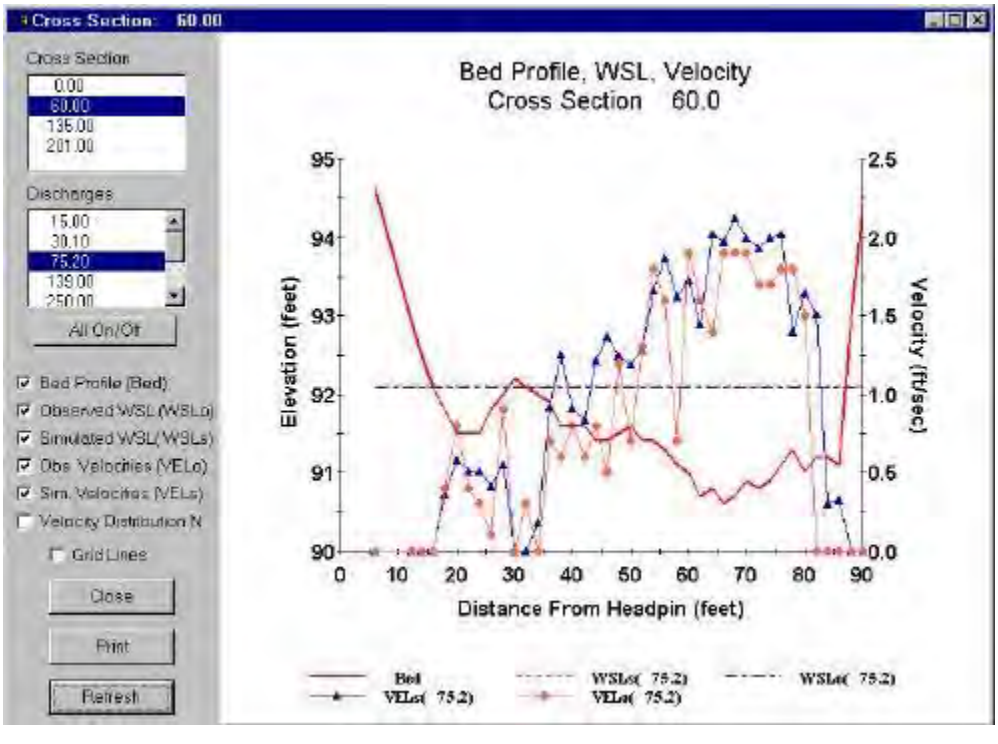
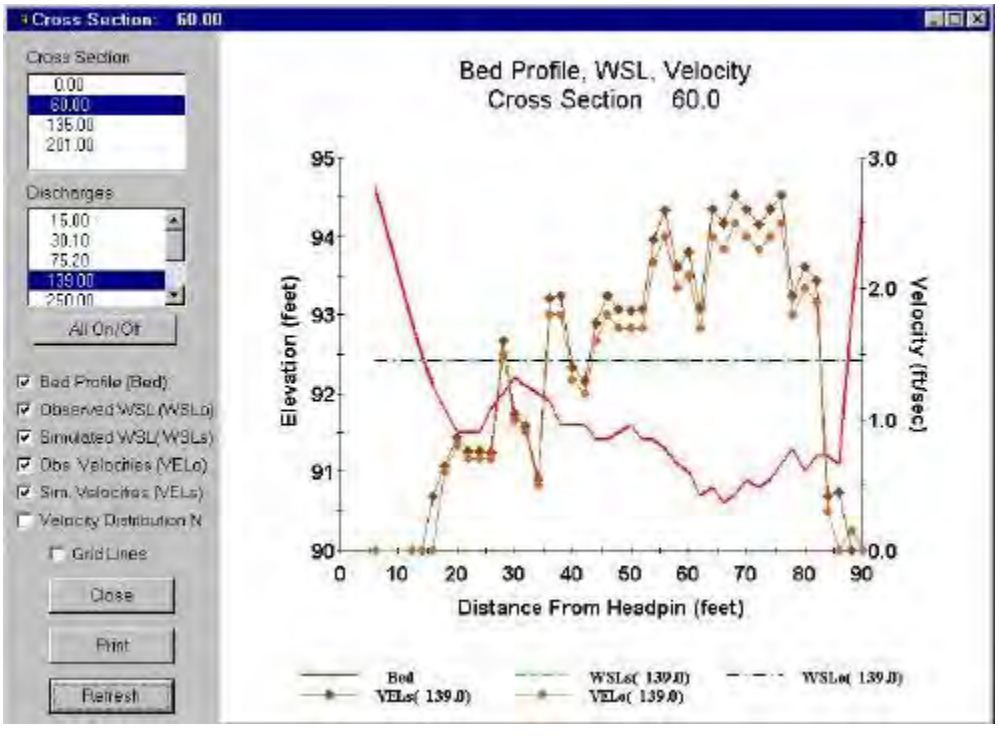


Figure L6-24. Simulated and observed velocity profile for 250 cfs at Xsec 0, Cal Set 139.

Figure L6-25. Simulated and observed velocity profile for 75.2 cfs at Xsec 60, Cal Set 139.



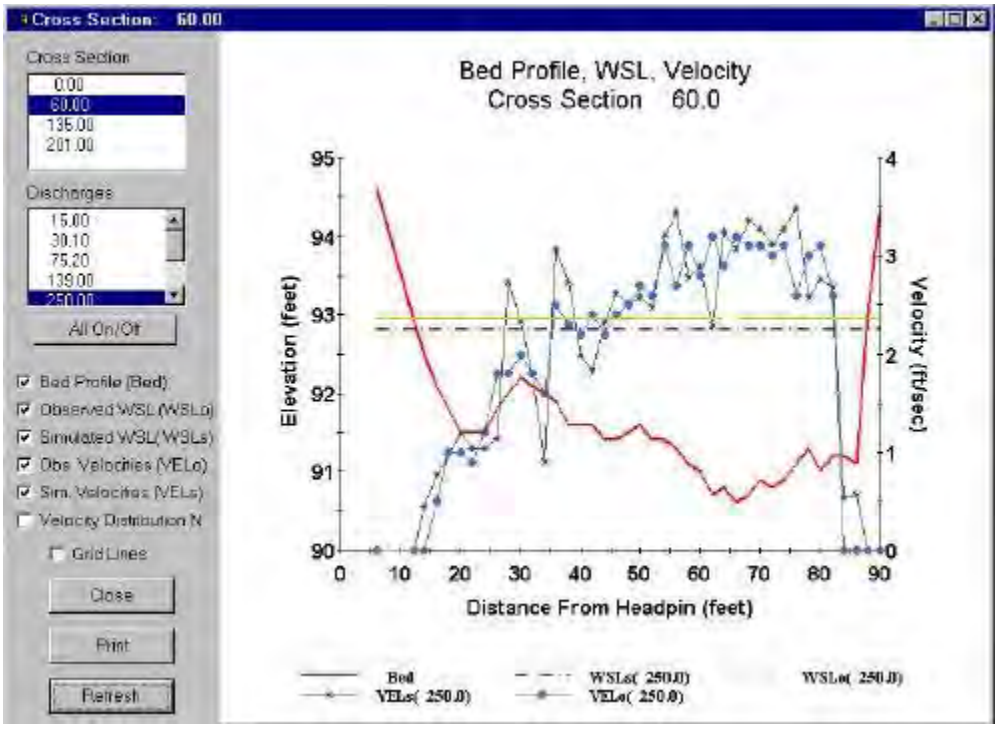
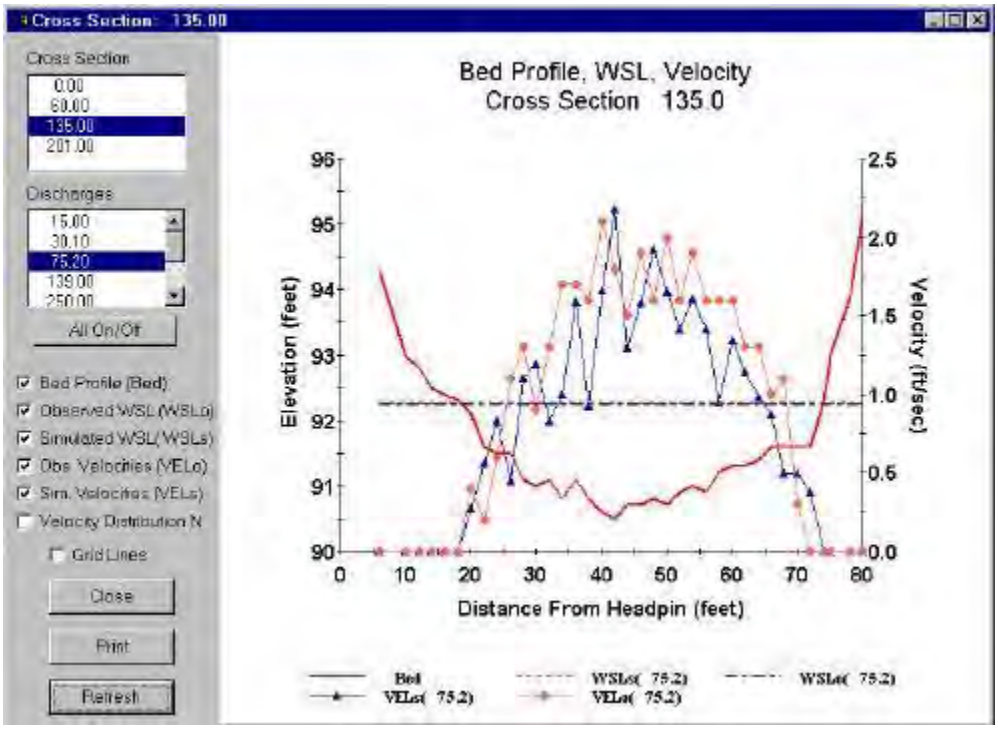


Figure L6-26. Simulated and observed velocity profile for 139 cfs at Xsec 60, Cal Set 139.

Figure L6-27. Simulated and observed velocity profile for 250 cfs at Xsec 60, Cal Set 139.

LABORATORY 6 –VELOCITY MODELING – VELSIM



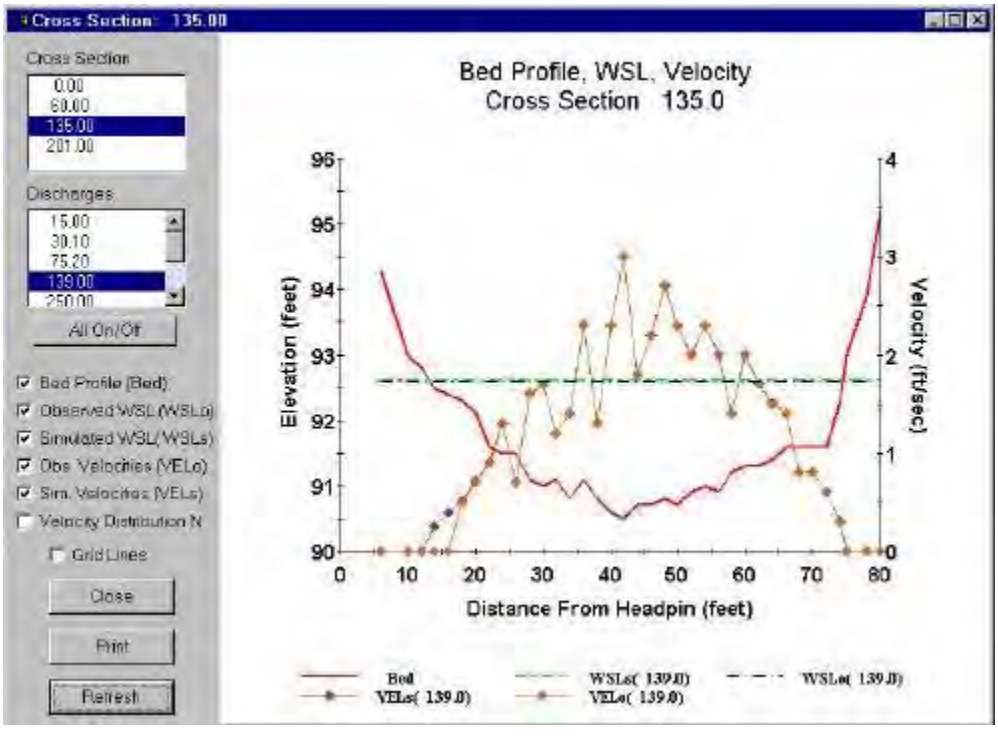
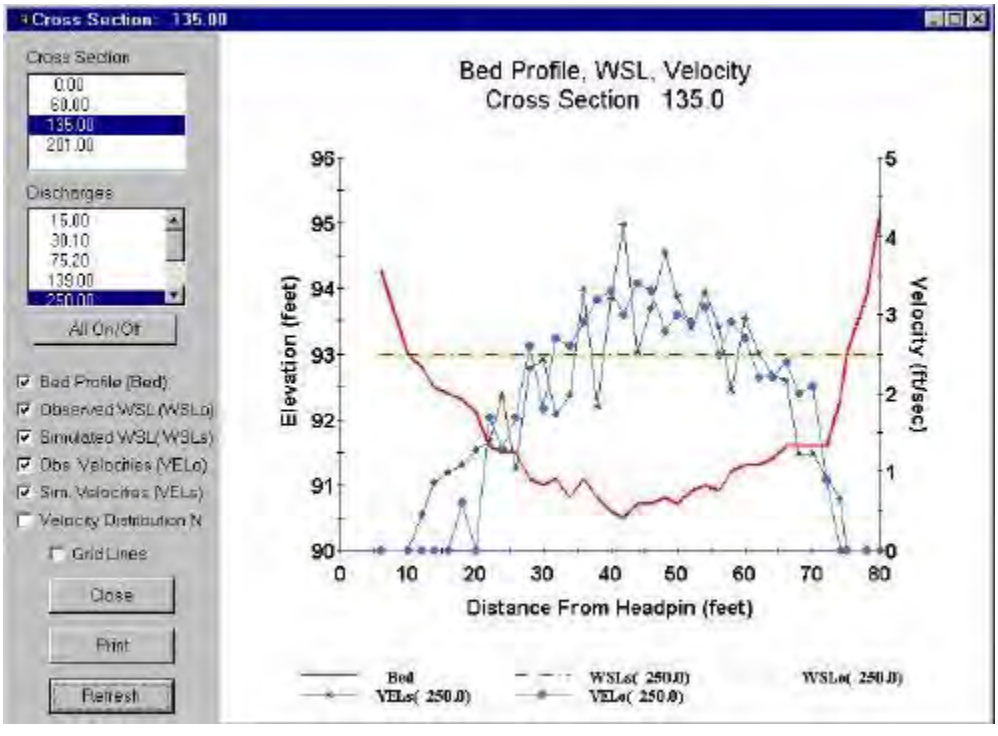


Figure L6-28. Simulated and observed velocity profile for 75.2 cfs at Xsec 135, Cal Set 139.

Figure L6-29. Simulated and observed velocity profile for 139 cfs at Xsec 135, Cal Set 139.



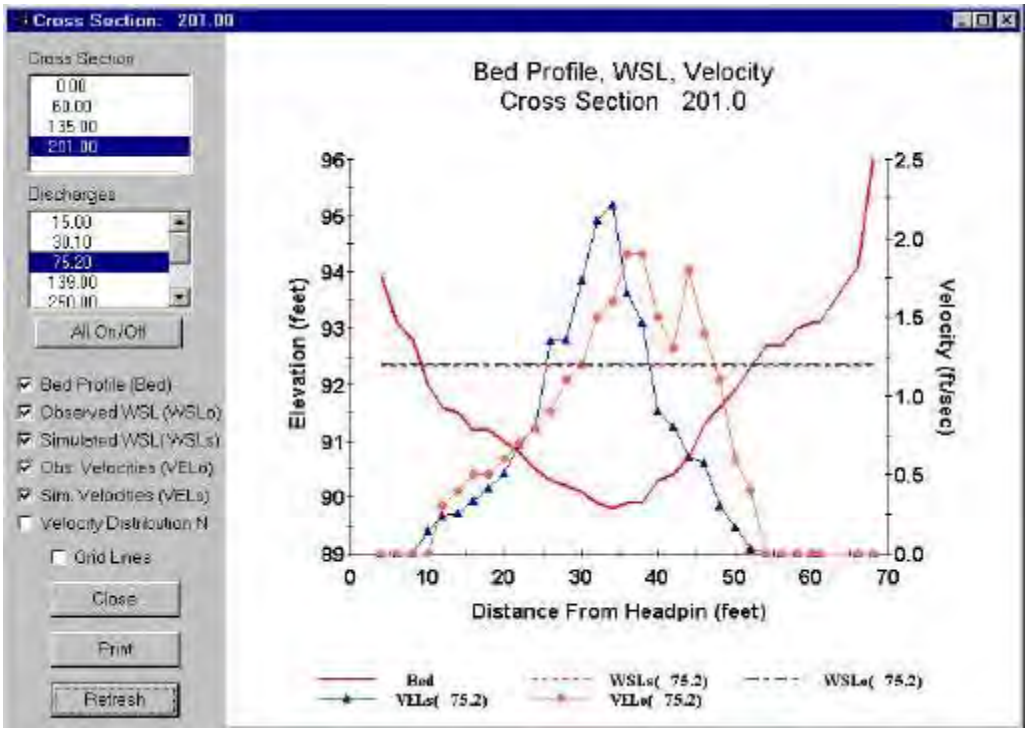
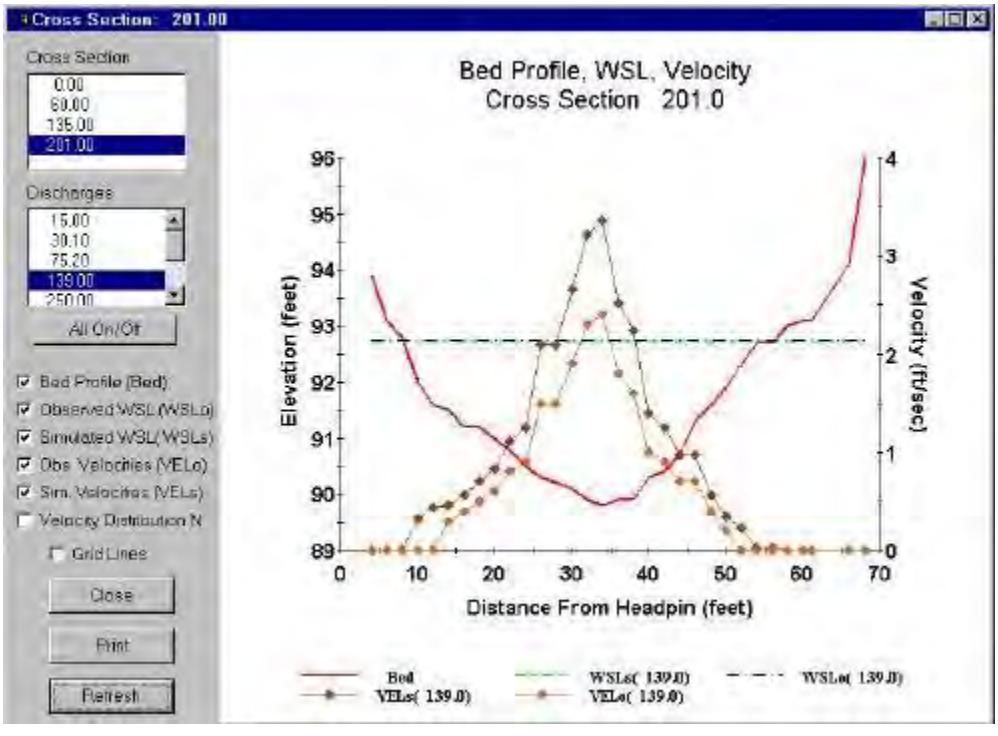


Figure L6-30. Simulated and observed velocity profile for 250 cfs at Xsec 135, Cal Set 139.

Figure L6-31. Simulated and observed velocity profile for 75.2 cfs at Xsec 201, Cal Set 139.

LABORATORY 6 –VELOCITY MODELING – VELSIM



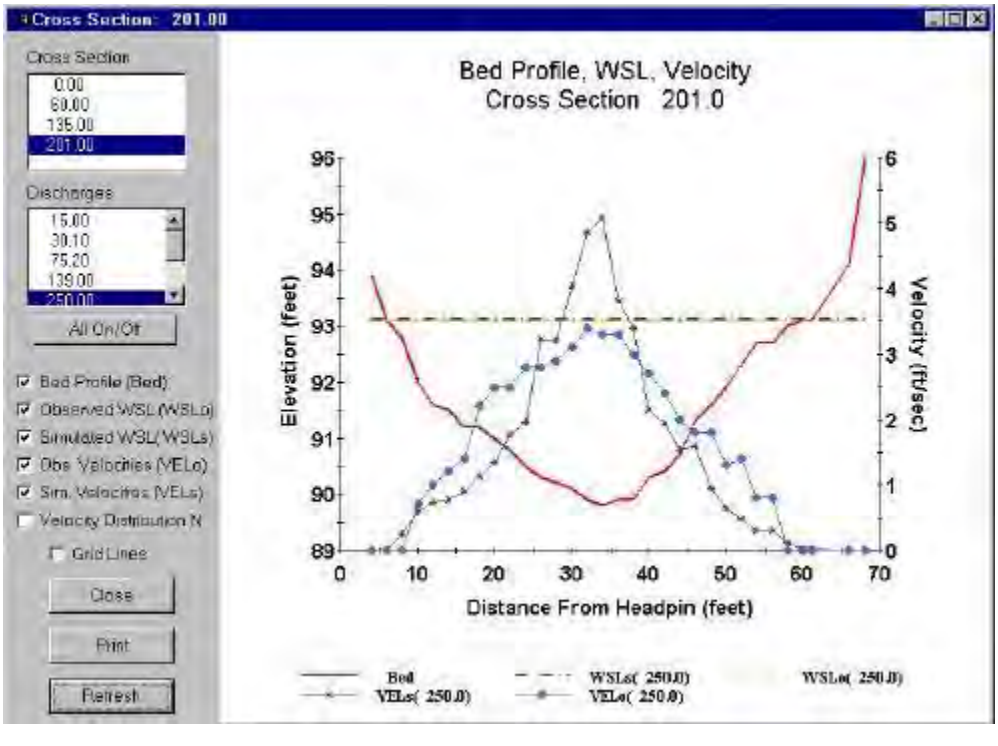
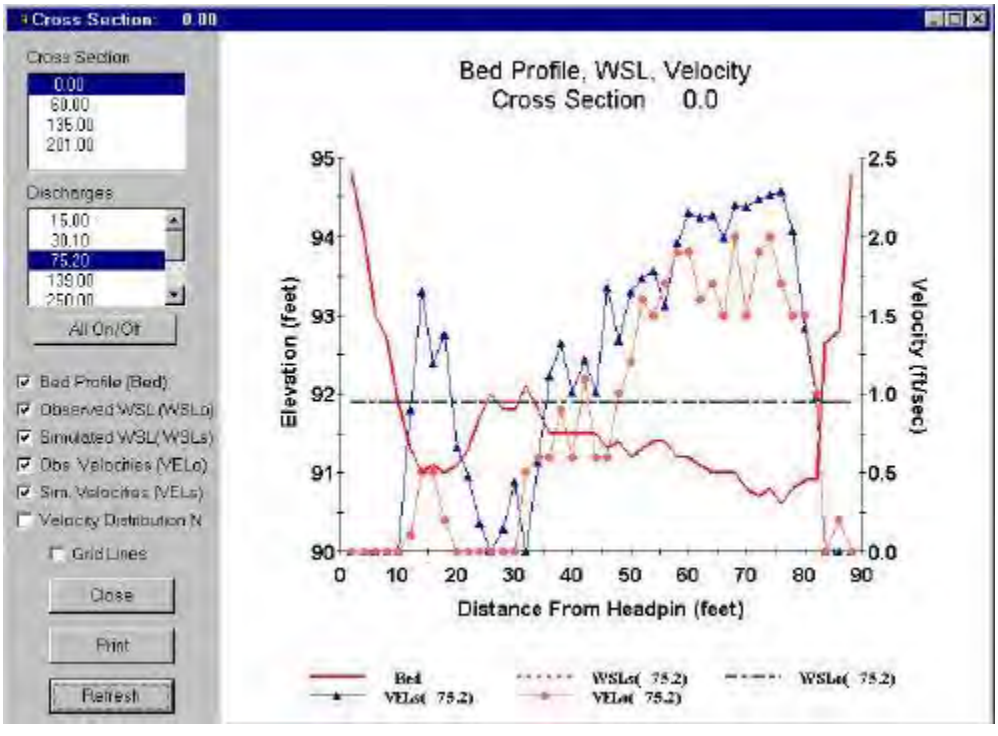


Figure L6-32. Simulated and observed velocity profile for 139 cfs at Xsec 201, Cal Set 139.

Figure L6-33. Simulated and observed velocity profile for 250 cfs at Xsec 201, Cal Set 139.

LABORATORY 6 –VELOCITY MODELING – VELSIM



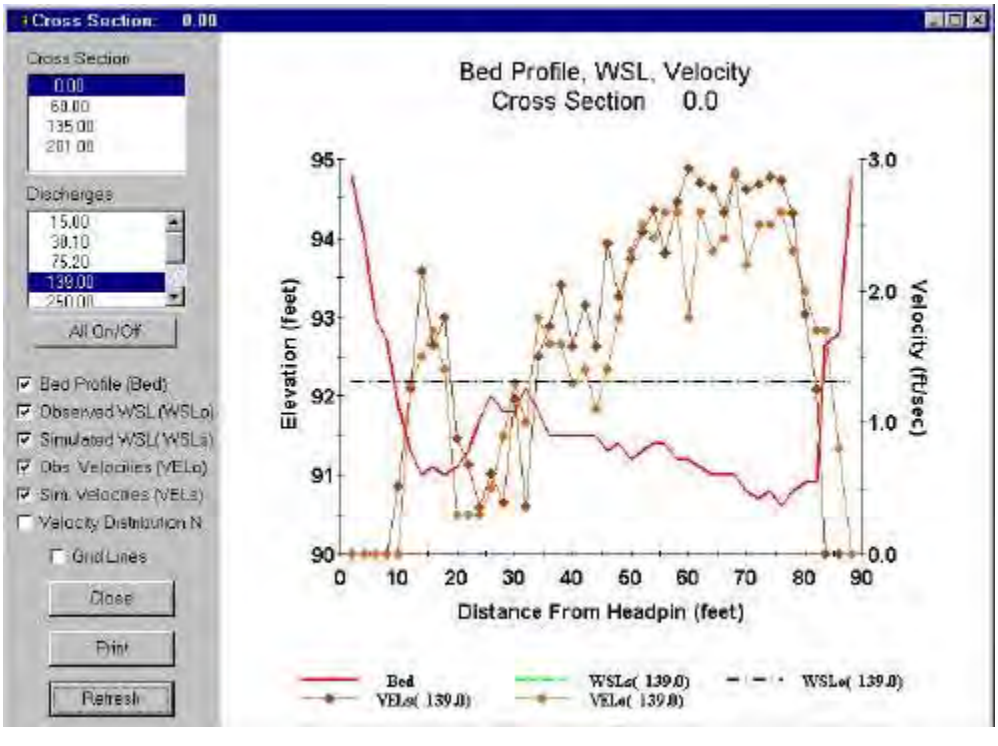
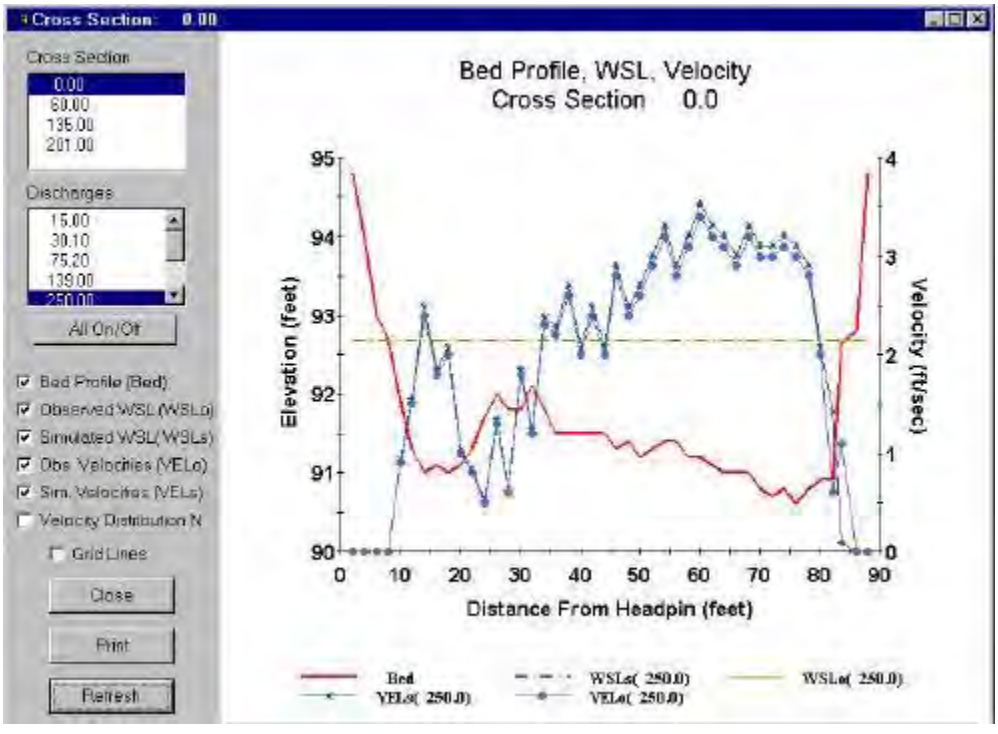


Figure L6-34. Simulated and observed velocity profile for 75.2 cfs at Xsec 0, Cal Set 250.

Figure L6-35. Simulated and observed velocity profile for 139 cfs at Xsec 0, Cal Set 250.

LABORATORY 6 –VELOCITY MODELING – VELSIM



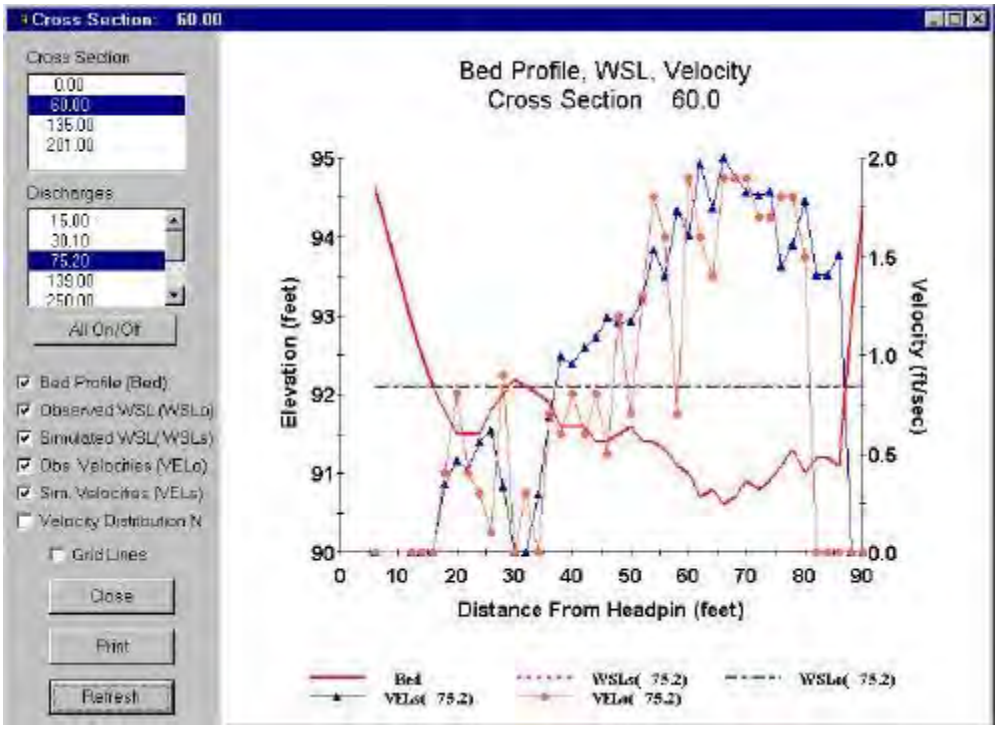
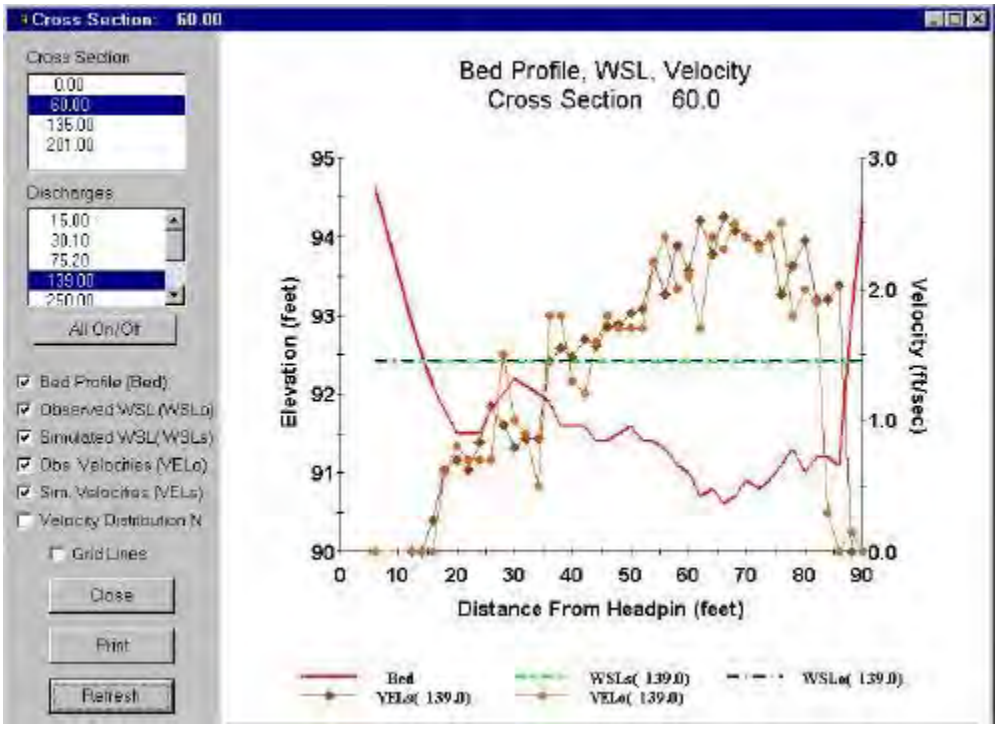


Figure L6-36. Simulated and observed velocity profile for 250 cfs at Xsec 0, Cal Set 250.

Figure L6-37. Simulated and observed velocity profile for 75.2 cfs at Xsec 60, Cal Set 250.

LABORATORY 6 –VELOCITY MODELING – VELSIM



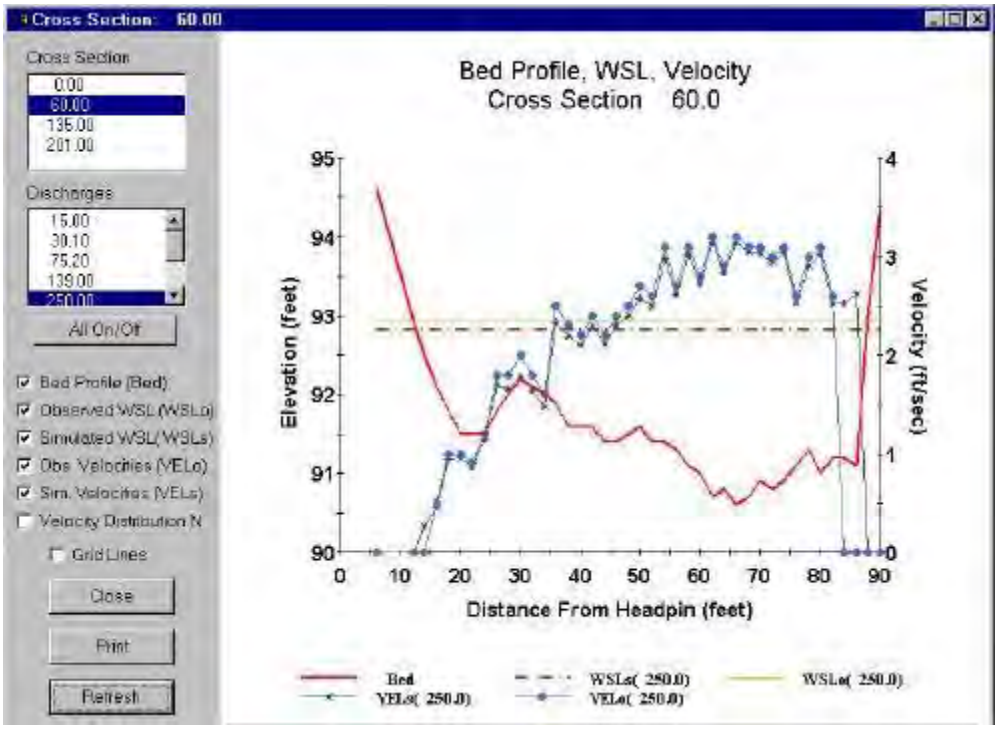
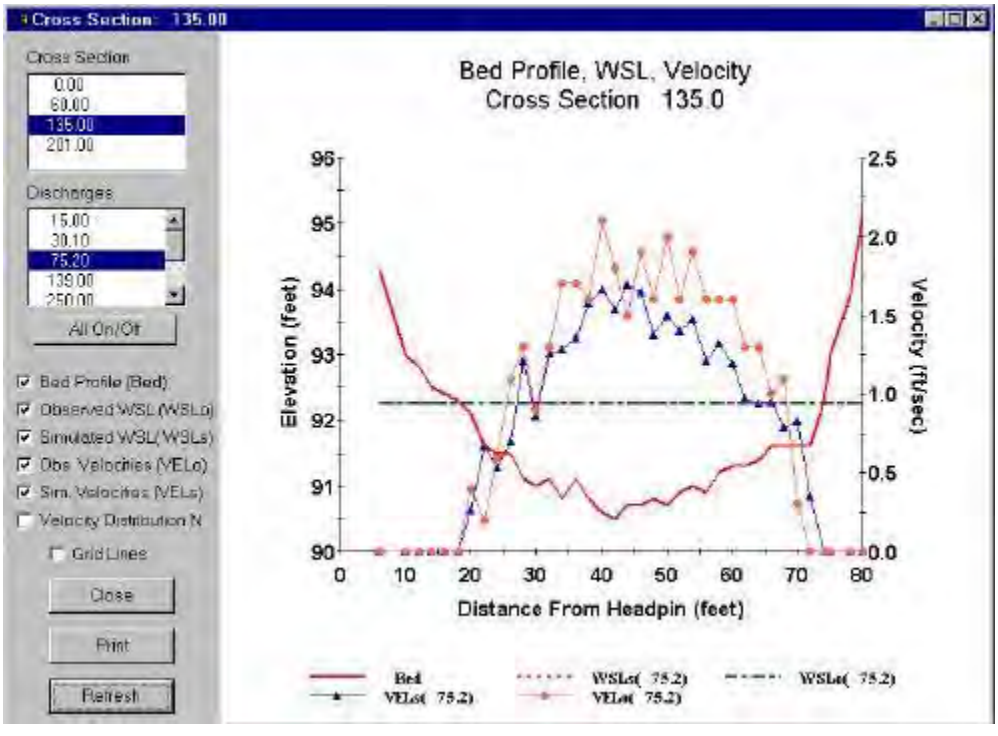


Figure L6-38. Simulated and observed velocity profile for 139 cfs at Xsec 60, Cal Set 250.

Figure L6-39. Simulated and observed velocity profile for 250 cfs at Xsec 60, Cal Set 250.

LABORATORY 6 –VELOCITY MODELING – VELSIM



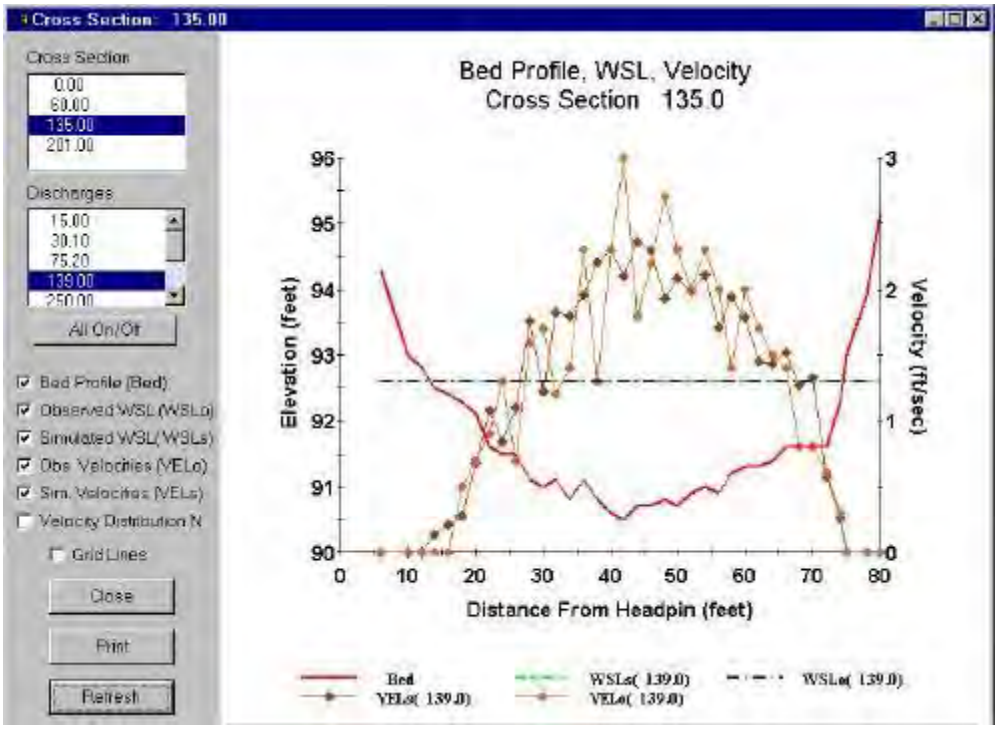
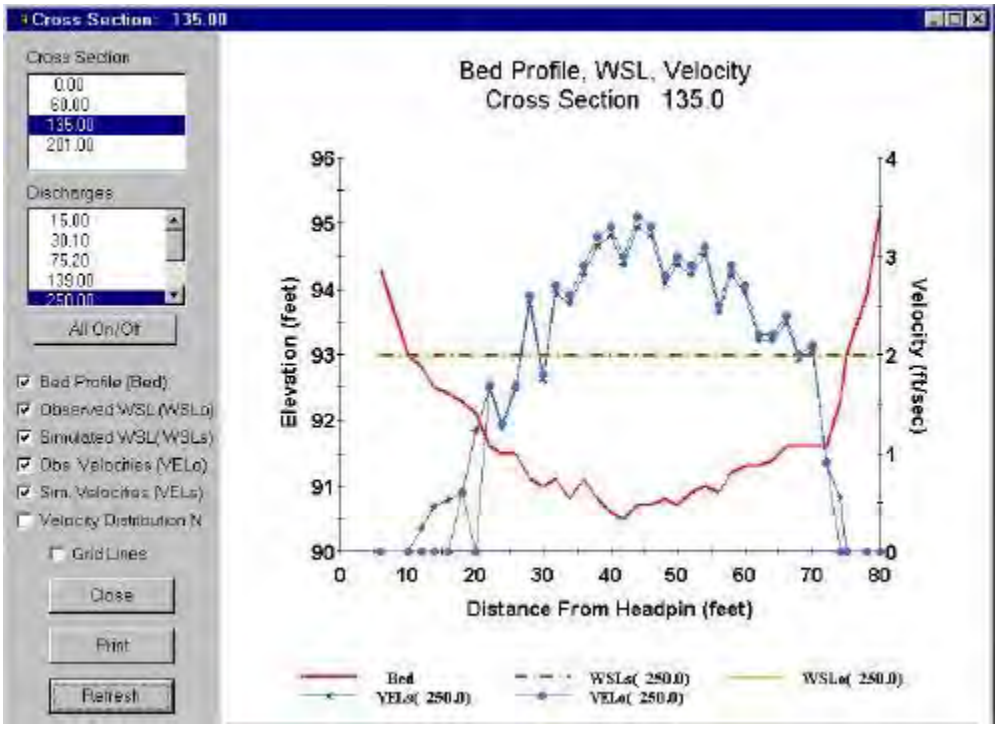


Figure L6-40. Simulated and observed velocity profile for 75.2 cfs at Xsec 135, Cal Set 250.

Figure L6-41. Simulated and observed velocity profile for 139 cfs at Xsec 135, Cal Set 250.

LABORATORY 6 –VELOCITY MODELING – VELSIM



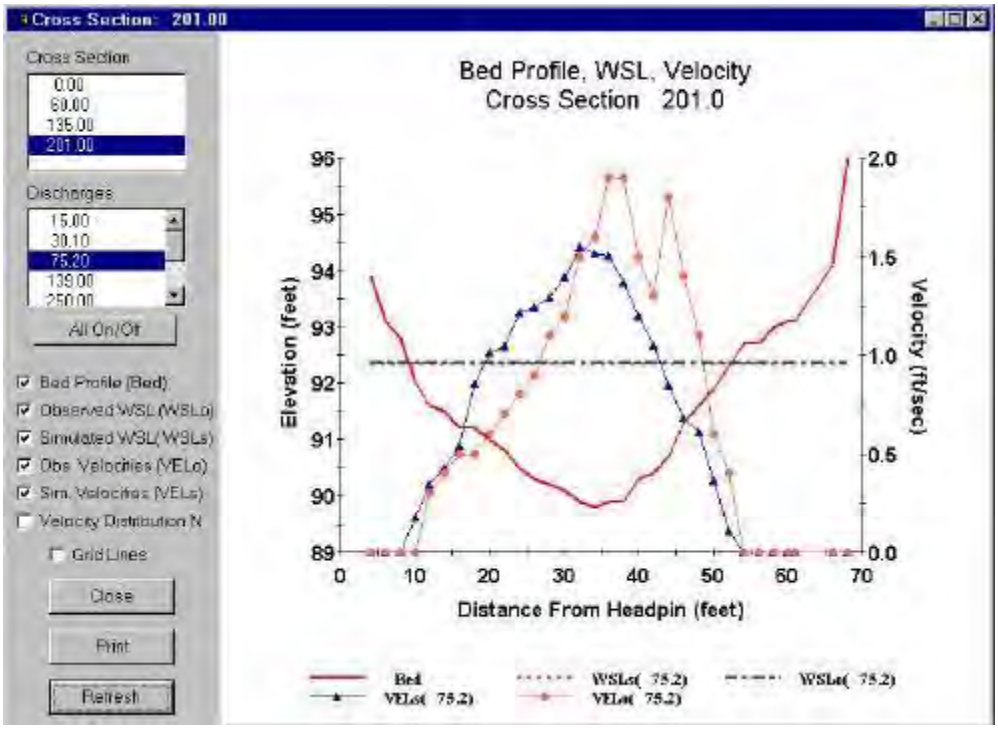
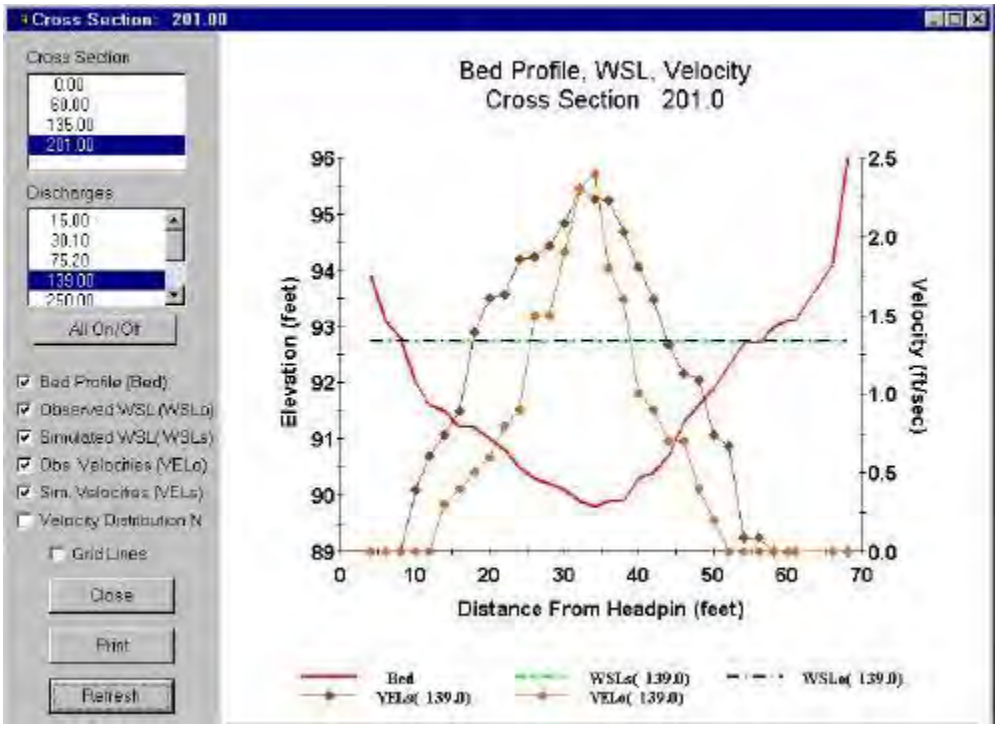


Figure L6-42. Simulated and observed velocity profile for 250 cfs at Xsec 135, Cal Set 250.

Figure L6-43. Simulated and observed velocity profile for 75.2 cfs at Xsec 201, Cal Set 250.

LABORATORY 6 –VELOCITY MODELING – VELSIM



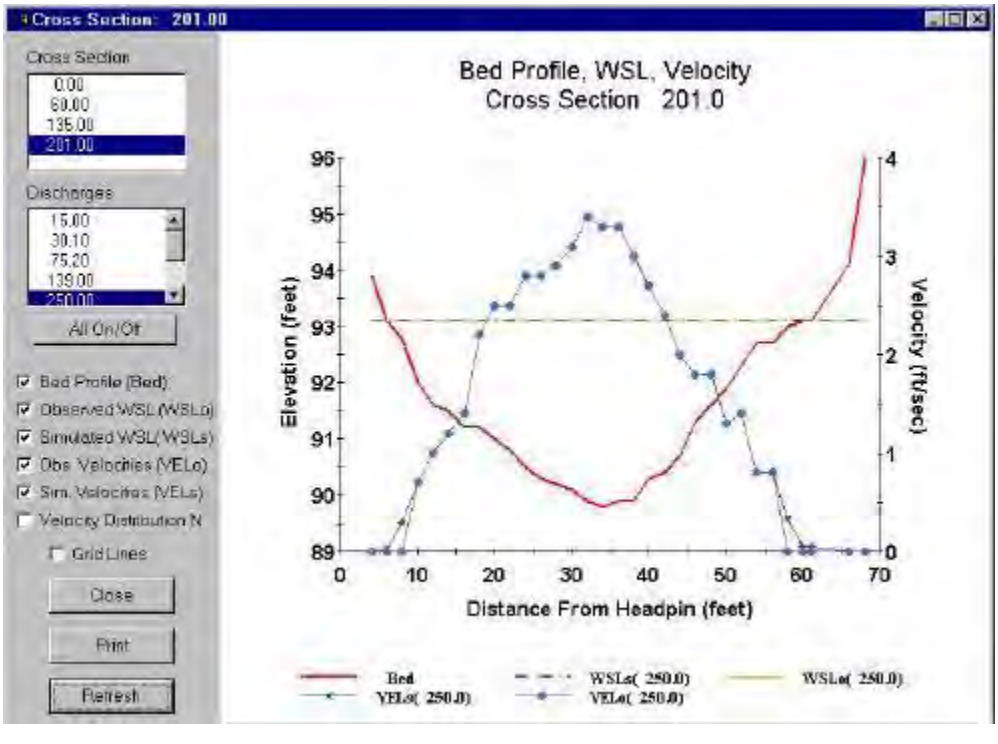


Figure L6-44. Simulated and observed velocity profile for 139 cfs at Xsec 201, Cal Set 250.

Figure L6-45. Simulated and observed velocity profile for 250 cfs at Xsec 201, Cal Set 250.

LABORATORY 6 –VELOCITY MODELING – VELSIM

Laboratory 7. Habitat Suitability Criteria in PHABSIM

Objective

The objective of this laboratory is to introduce the use of habitat suitability criteria (HSC) within the PHABSIM for Windows system. The laboratory will illustrate the method used to input HSC for use within PHABSIM and examine several of the available criteria maintenance programs.

Data Files Used: Lab7.phb, Curvlib.phb

Introduction

The principal means by which PHABSIM integrates biological information for habitat modeling purposes is through the use of HSC (sometimes referred to as suitability-of-use criteria) within the various habitat models. The laboratory will not deal with the specifics of HSC development. However, the various means by which HSC can be entered and manipulated within PHABSIM will be examined. See Bovee et al. (1998) for a detailed description of HSC and their development.

In PHABSIM, HSC data are created, edited, and stored in the **\Edit\Suitability Curves** section of the program. These data contain the HSC coordinate data for species and life stages in terms of depth, velocity, channel index, and temperature.

HSCs for a particular species and life stage are typically grouped into three sets of HSC data representing the relationships between depth, velocity, and channel index and their corresponding suitability values.

In PHABSIM, HSC data are referenced by HSC numbers. Although these HSC numbers can be arbitrarily assigned within any PHABSIM project file, the structure of the numbers does control the format of the output results from the habitat programs as will be discussed later in this lab. The steps in this lab are designed to build basic skill in using HSC w/in PHABSIM.

Step 1. HSC Numbering

HSC numbering within PHABSIM allows the user to organize HSC curves by species groups. The basic format for HSC numbering is:

xxxxyy

The first four digits (i.e., xxxx) denote the >species=, while the last two digits (i.e., yy) denote the >life stage=. Figure L7-1 contains a list of habitat suitability criteria for use in a particular study. This list is obtained by clicking **\Edit\Suitability Curves\Curves\Select by ID**.

The **Graph** button in the **\Edit\Suitability Curves** window allows you to view individual habitat suitability criteria graphically. To view all HSC for a species/life stage, select **Display All Graphs** in the **\Edit\Suitability Curves\Curves** menu. Figure L7-2 shows an example of the resulting plot. Note that there are no temperature HSC values in this curve set for Black Trout.

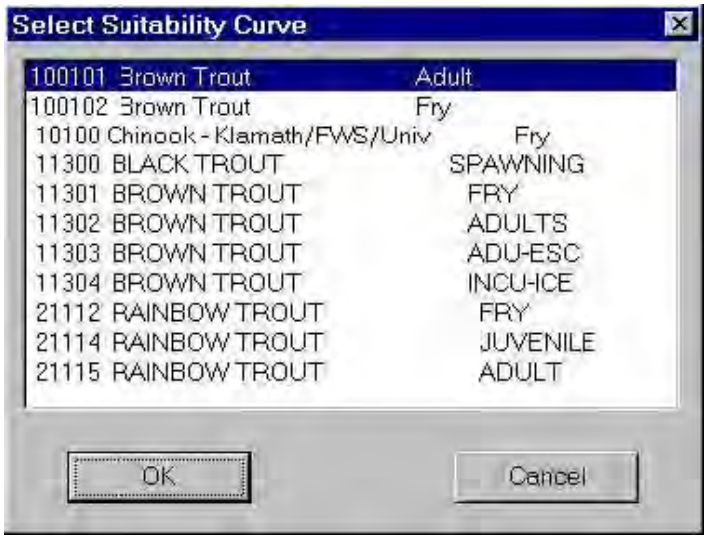


Figure L7-1. List of suitability curves showing species and life stage numbering.

Note that each HSC set (i.e., velocity, depth, and channel index) is associated with a unique HSC number for each species and life stage. In the example above, the user should identify that Rainbow Trout Fry has a HSC number of 21112. HSC number 21114, on the other hand, identifies the Rainbow Trout Juvenile curve set. Be sure you recognize how this follows the numbering convention described above.

Step 2: HSC Data Structure in PHABSIM

Move to **\Edit\Suitability Curves** in the SAMPLE.phb project and click **Select\By ID**. This displays a list (as in Figure L7-1) of the HSC curves that have been entered in the sample project including curve number, species, and life stage. New curves are entered by clicking the **\Edit \Suitability Curves\File** menu item, selecting **New Curve**, then filling in the boxes for Curve number, Species, and Life stage. Enter the HSC values in the table shown in that window (the first table is velocity). To change from velocity to depth, channel index or temperature, click the appropriate radio button in the **Curve Type** box to the upper right. Click the desired radio button (i.e., depth) and enter the HSC values in the table. Be sure to fill in all HSC tables before exiting. Habitat suitability criteria are discussed in Chapter 3 of the manual. Remember the PHABSIM convention that all HSC curves must begin at 0 and end at 100. In most situations the starting and starting values will be 0.0, 0.0 and ending values will be 100.0, 0.0. When might this not be the case?

In the suitability curve-editing portion of our Sample project, select Rainbow Trout Fry and note that the first velocity coordinate point at a velocity of 0.0 has a suitability value of 1.00. Note the last value. Again, failure to include the coordinate points with 100 for all curve sets will result in an error message indicating that the 100 value has not been entered. You cannot exit HSC data entry until all curves have final values of 100.

While in the **\Edit\Suitability Curves** window, each HSC set can be viewed graphically by clicking the **Graph** button. For Rainbow Trout fry, the HSC value of velocity descends from 1.0 at a velocity of 00.0 to 0.0 at a velocity of 0.5. For more complicated HSC graphs, using the zoom feature may enhance viewing of particular portions of the curve. The graph automatically updates when a different curve is selected. For example: click **Graph** and drag the plot to the lower right so the **Curve** box with radio buttons is revealed. Then click the **Depth** (or any other) radio button. The graph will update to show the depth curve at the same degree of zoom that was previously selected.

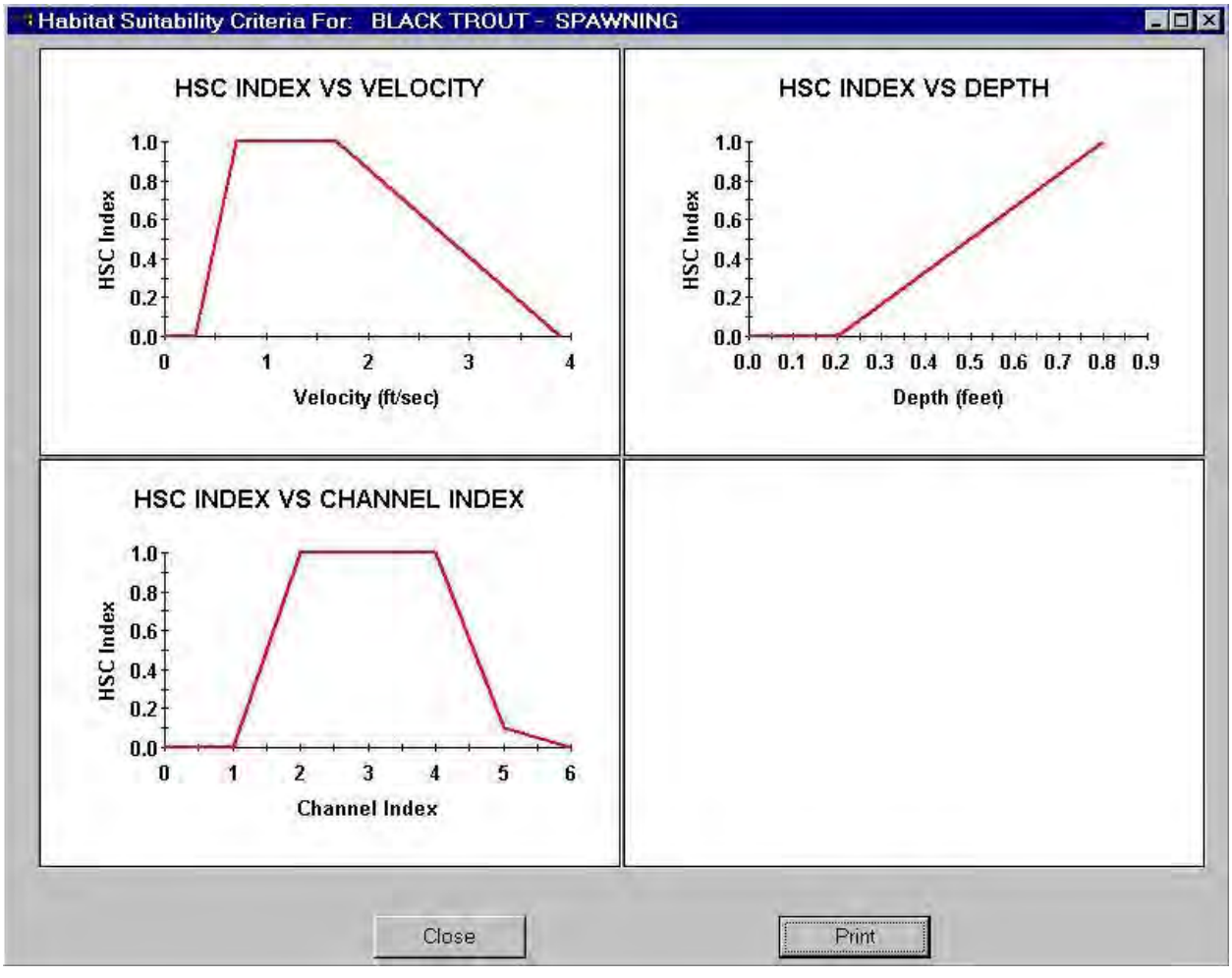


Figure L7-2. An example of displaying all HSC for a selected species and life stage.

When you are finished entering or viewing HSC curves, click **OK** to exit the **\Edit\Suitability Curves** window.

Step 3. Building HSC Libraries

The **\Edit\Suitability Curves** section of PHABSIM can be used for entering HSC data to create a set of HSC curves. Users of PHABSIM Version 2.0 (DOS) will recall the term FISHCRV libraries applied to such HSC sets. Table L7-1 lists HSC coordinate data for Brown Trout adult and fry for velocity, depth, and channel index which will be used to construct HSC data. The HSC numbers for each species and life stage are also indicated in this table.

Table L7-1. Brown trout adult and fry HSC ID numbers and criteria coordinates.

Brown Trout - Adult HSC ID Number: 100101

Velocity SI Depth SI Channel Index SI

0.0 0.40 0.0 0.00 0.0 1.00
0.5 1.00 1.0 1.00 1.0 1.00
2.5 0.00 100.0 1.00 9.0 1.00
100.0 0.00 100.0 1.00

Windows		DOS	Difference	% difference	Brown
Cell bed elevation	91.65	91.65	0	0.00	Trout –
Water surface elevation	92.456	92.47	0.014	0.02	Fry
Depth	0.806	0.82	0.014	1.71	HSC ID
Depth Suitability Index	0.0708	0.096	0.025	26.25	
Combined Suitability Index	0.0644	0.087	0.023	26.25	
Weighted Usable Area	8.698	11.79	3.096	26.25	

Acknowledgements **i**
PREFACE **ii**
A Brief History of PHABSIM
Use of this Document
Changes Between PHABSIM Version 2 and PHABSIM for Windows
Conventions Used in this Document
Chapter 1, Introduction to the Physical Habitat Simulation System **1**
Objectives
Associated Laboratory Exercises
Number: 100102

Enter these HSC in the SAMPLE data set using **File\New Curve** in the **Suitability Curves** Window. Examine the newly created HSC sets using the **Graph** feature. When finished, go back to the main menu and save the project.

The HSC in this project can now be used in other projects by importing the HSC data. In the **\Edit\Suitability Curves** window the ability to import from an existing project is found under **File\Import\From Existing Project**. One may also import FISHCRV format text files prepared in DOS PHABSIM version 2 format using the **Import From Text File** menu item. You will be prompted to select which curves to import.

Thus, it is possible to create a project with the sole purpose of containing a library of HSC curves and import the desired HSC for each specific study from this library as needed. Try creating a new project and importing the HSC from this revised Lab7 project. Give the new project the name "New Curves". The "New Curves" project could become a library of curves by importing or building successive HSC data sets as described above. Note that any individual curve can be selected from the source project and placed in the receiving project as long as the curve ID numbers are unique.

Laboratory 8. AVDEPTH and AVPERM Models

Objective

Windows		DOS	Difference	% difference
Cell bed elevation	91.65	91.65	0	0.00
Water surface elevation	92.456	92.47	0.014	0.02
Depth	0.806	0.82	0.014	1.71
Depth Suitability Index	0.0708	0.096	0.025	26.25
Combined Suitability Index	0.0644	0.087	0.023	26.25
Weighted Usable Area	8.698	11.79	3.096	26.25

Acknowledgements **i**
PREFACE **ii**

The objective of this laboratory is to introduce the user to the hydraulic parameter based model AVDEPTH/AVPERM. This concatenated name is retained for familiarity with past versions of the PHABSIM system. The laboratory will demonstrate the use of this model as well as illustrating the type of model outputs

The AVDEPTH \AVPERM model characterizes a study site channel in terms of hydraulic properties at each cross section. The AVDEPTH/AVPERM model can be used to characterize a stream in terms of a qualified wetted perimeter at each simulated discharge. The wetted perimeter can be reported for areas at least as deep as up to five user-specified depths. The output is provided for each cross section as well as for reach-aggregated results. In addition, the program produces summary output of average channel velocity, hydraulic depth, hydraulic radius, wetted width, wetted perimeter, Froude number, wading parameter, drag parameter, and cross sectional area. The wading parameter is calculated as the product of the depth times the velocity and can be used as an index of safe wading conditions at a cross section. The drag parameter is computed as the velocity squared times the depth.

The AVDEPTH/AVPERM model requires that the simulated hydraulic properties for use within the model have been generated by one of the hydraulic models (i.e., STGQ, MANSQ, or WSP). At least one of those models must have been run prior to use of AVDEPTH/AVPERM.

Simulate the Hydraulic Properties within the River

Ensure that the SAMPLE2.phb project file is available in the current working directory before starting the laboratory. At this point, STGQ, WSP, and VELSIM have been run in previous labs so the needed depth and velocity information is contained in the project database.

Run the Model and Examine the Output

Move to **\Models\AVDEPTH/AVPERM** and note the table for input of depth increments to be used in AVDEPTH/AVPERM. For this exercise, the five depth increments of 0.5, 1.0, 1.5, 2.0, and 2.5 ft. will be used. If the user does not supply any depths, the program computes the summary parameters based on all available depths at a cross section. Results are viewed in the **Average Parameters** and **Depth Parameters** tabs. Scroll these tables to see all entries. As with all PHABSIM for Windows output tables, these can be copied by dragging the mouse from the upper left to lower right corner, right clicking, and selecting copy from the pop-up menu. Figure L8-1 provides a partial Average Parameter and Depth Parameter table listing. Average parameters for the entire reach are available in text output only; click the **Text File** button to obtain this output. Figure L8-2 shows a reach level summary table produced by AVDEPTH/AVPERM.

```
Average Parameters
XSEC Q WSL Ave. Hyd. Hyd. Wetted Wetted Froude Drag Wading Flow C/SVel Depth Radius Width Perimeter No. Param. Parm. Factor Area

0 15 91.37 1.03 0.33 0.33 44.05 44.39 0.32 0.35 0.34 2.17 14.54
•         0 30.1 91.57 1.21 0.42 0.42 59.29 59.79 0.33 0.62 0.51 2.18 24.83
•         0 75.2 91.90 1.65 0.67 0.66 68.53 69.29 0.36 1.81 1.10 2.18 45.58 0 139 92.18 2.11 0.89 0.88 73.80 74.79 0.39 3.98 1.88 2.30 65.76 0
250 92.67 2.44 1.35 1.33 75.89 77.19 0.37 8.05 3.29 2.02 102.34 0 625 93.53 3.66 2.09 2.05 81.78 83.53 0.45 27.94 7.64 2.27 170.95 0 1250 94.44
5.07 2.91 2.83 84.73 87.06 0.52 74.73 14.75 2.53 246.74 60 15 91.59 0.71 0.43 0.43 49.25 49.61 0.19 0.22 0.30 1.25 21.15 60 30.1 91.78 0.95 0.55
0.55 57.67 58.14 0.22 0.49 0.52 1.42 31.79 ..... ..... ..... 201 625 93.98 4.07 2.50 2.46 61.41 62.27 0.45 41.45 10.18
2.23 153.46 201 1250 94.87 5.99 3.32 3.26 62.81 63.98 0.58 119.31 19.90 2.73 208.52

Depth Parameters Widths and continuous widths at depth greather than

XSEC Q Wetted 0.5 0.5 (cont) 1 1 (cont) 1.5 1.5 (cont) 2 2 (cont) Width
0 15 44.05 10.16 10.16 0.00 0.00 0.00 0.00 0.00 0.00
•         0 30.1 59.29 24.21 19.55 0.00 0.00 0.00 0.00 0.00 0.00
•         0 75.2 68.53 46.26 35.43 11.00 11.00 0.00 0.00 0.00 0.00 0 139 73.80 61.04 47.87 29.84 21.84 1.60 1.60 0.00 0.00 0 250 75.89 73.77 73.77
60.88 47.80 29.47 21.63 1.40 1.40 0 625 81.78 80.28 80.28 74.97 74.97 72.32 50.48 58.61 46.72 0 1250 84.73 83.01 83.01 81.51 81.51 79.72 79.72
74.67 74.67 60 15 49.25 19.15 17.67 0.00 0.00 0.00 0.00 0.00 0.00 0.00 60 30.1 57.67 29.68 21.62 6.78 4.62 0.00 0.00 0.00 0.00 60 75.2 67.97 49.74
36.50 19.57 17.94 0.00 0.00 0.00 0.00 ..... ..... ..... 201 625 61.41 57.87 57.87 51.10 51.10 44.12 44.12 40.33 40.33 201 1250
62.81 62.28 62.28 60.75 60.75 57.00 57.00 49.55 49.55
```

Figure L8-1. Partial average parameter and depth parameter tables from AVDEPTH/AVPERM.

```
Summary of Average Parameters for Whole Reach

            Wetted Widths with depth greater than: Discharge Perimeter Width 0.500 1.000 1.500 2.000 Depth C/S Area
Velocity
     15.00 47.33 47.03 23.53 5.26 1.99 0.00 0.57 26.6 0.56
     30.10 53.47 53.08 32.17 12.13 2.95 1.13 0.70 37.1 0.81
     75.20 60.13 59.59 47.91 24.57 7.48 2.51 0.94 56.0 1.34
    139.00 65.49 64.81 55.16 40.40 19.95 4.61 1.18  76.2 1.82
    250.00 69.16 68.30 63.67 53.90 34.10 14.75 1.51 103.2 2.42
    625.00 74.84 73.64 70.85 66.66 61.52 51.99 2.23 164.1 3.81 1250.00 78.40 76.84 75.36 73.11  70.24 65.87 3.02 232.2
 5.38
```

Figure L8-2. Whole study site average parameter table from AVDEPTH/AVPERM.

The summary table in Figure L8-1 shows the stream width at each of the simulated discharges at cross section 0.0, followed by the total width of the stream (i.e., the SUM column) with a depth greater than 1.0, as well as the maximum contiguous width with depths greater than 1.0. These summaries are repeated for each of the depths specified by the user in the **AVDEPTH/AVPERM input** tab. Use the scroll bars to view all of the output in the **Average Parameters** and **Depth Parameters** tables.

The final output summary at the bottom of the file (see Figure L8-2) contains this same information for depths aggregated over the entire study reach. The user should note that the AVDEPTH/AVPERM model computes the reach-aggregated results using the cross section weighting factors assigned in **\Edit\Cross Sections**. Therefore, changing the weighting given to particular cross sections will change the summary results displayed in this table.

Laboratory 9. The HABTAE Model

Objective

The objective of this laboratory is to introduce the HABTAE model for calculating available habitat quantity and quality. The lab will explore several commonly used modeling options as well as demonstrate the sensitivity of habitat model predictions to different approaches taken in the hydraulic modeling phase of PHABSIM.

Programs Used: HABTAE

Data Files Used: Lab9.phb

Introduction

The HABTAE program allows integration of biological requirements of target species and life stages, represented in the form of Habitat Suitability Criteria (HSC), with hydraulic simulation results. This integration generates a number of indices of available habitat quantity and quality. These include weighted usable area, bed area, and volume. These results can be computed for each cross section, as well as for aggregated summaries at the study site level. A description of the calculations used in the HABTAE program can be found in Chapter 4 of the manual.

In this lab, we assume that water surface profile modeling has been finished and quality controlled so the VELSIM program will be used for all hydraulic simulations. However, several different modeling approaches for simulation of velocities will be explored to examine the impact on calculated available habitat. The lab is divided into several steps, which address a specific computational aspect or evaluation of HABTAE model sensitivity to different modeling options. The principal sections of the lab are:

a. Aggregation Method for Computing Combined Suitability
b. Computing Habitat for Cross Sections versus Reaches
c. Calculation of Habitat Quality
d. Effects of Velocity Simulations on weighted usable area (WUA) Results

The user is encouraged to examine the full range of computational capabilities for the HABTAE model contained in Chapter 4 of the manual and explore use of the options not covered in this lab manual. An effective way to determine whether a particular option has value to the user for a given problem is to run the HABTAE model with 'standard' or 'default' settings and then compare the computational detail listings in the output with other selected options. This is often the best way to determine how or what the program is actually calculating and whether or not a particular option is appropriate for the problem you are attempting to solve.

Compare Aggregation Methods for Computing Combined Suitability

In this section of the lab, three computational methods by which the HABTAE program combines individual suitability for depth, velocity, and channel index within a cell to derive WUA will be examined. The three approaches include multiplicative, geometric mean, and limiting value methods (see manual Chapter 4). Make sure that the requisite data files listed above have been copied to the current working directory prior to beginning the laboratory. The following steps proceed in the general order of a habitat analysis.

Step 1. Generate Hydraulic Characteristics for Selected Stream Flows using VELSIM

The Lab9.phb project contains the results of simulating water surface profile and velocity distributions for the sample study site. You may want to compare the results you obtained at the end of the previous laboratory with these results.

To determine if the Lab9 project is ready for this next step, go to **\Reports\Graphs** and view the longitudinal profile for all discharges. Then view the velocity distribution for the simulated and observed discharges at each cross section. When you have determined that these are the correct profiles, you can assume the project now contains the necessary hydraulic and channel geometry property information needed to proceed with this laboratory.

Step 2. Select Species and Life Stages

Prior to setting the HABTAE options, the target species and life stages to be used in the analysis must be determined. Specifically, HSC identification numbers must be selected or input to PHABSIM. Go to **\Edit\Suitability Curves\Select\By ID** to view a list of all of the HSC curve sets that have been loaded into the project thus far. Locate the HSC ID numbers for Bull Trout fry, juvenile, adult, and spawning life stages (i.e., 100101, 100102, 100103, and 100104). If Bull Trout HSC has not been loaded, you may load them now by importing them from an old PHABSIM format FISHCRV file. You will find FISHCRV.LAB in the working directory.

Step 3. Set the HABTAE Options

Next go to the HABTAE computational options tab at **\Models\Habtae\Computations.** Note that **Habitat Calculations** (old IOC Option 9) has been set to **Standard Calculation** so multiplicative combination of depth, velocity, and channel index HSC values for each computational cell will be the form of the WUA calculation. This option will be changed in subsequent HABTAE model runs as part of the laboratory to examine effects of different suitability aggregation techniques on WUA predictions. Note that WUA Calculations are set to **Calculate WUA for Reach**. Also note that **Use Zero CI in calculations** (IOC 18) has been selected so that a channel index code of '0' will match the associated HSC curve coordinate data of '0' for channel index.

Next go to the **\Models\Habtae\Limits** tab and select **No restrictions on velocities** to allow the HABTAE program to run if it encounters negative velocities or velocities that are greater than 15 feet/second.

Finish setting options by going to the **..\Life Stages** tab and clicking on each HSC curve set ID number you wish to use in the habitat simulation. Select the 4 life stages of Bull Trout (i.e., 100101, 100102, 100103, and 100104) by clicking on each of them to highlight the Bull Trout entries.

Step 4. Run the HABTAE Program and Examine Output

Click the **Run** button in the **..\Output Options** tab to run HABTAE. Move to the **..\Results** tab where you will find tabular values indicating the combined suitability for each cell. Select the **Discharge** and **Result** you want to view and the table will update automatically. You may view a color graph of the habitat suitability distributed over the study site for the selected result by clicking on **Graph**.

Next move to the **..\ZHAQF Results** tab to review tabulated WUA values calculated for the study site. As in the velocity and WSL sections, the results may be viewed by clicking on the **Graph** button. The relative differences in magnitude and shape of the WUA versus discharge curves for these life stages are a result of the habitat calculated from the HSC curves in response to the hydraulic properties at each discharge. The program also writes to a numbered ZOUT file as illustrated in Figure L9-1.

These summary tables are aggregated totals for all cross sections. This information is repeated for each life stage in the numbered ZOUT file produced by running HABTAE. To view this table, check the filename.history file for the number of the ZOUT file produced by the last HABTAE run and open the ZOUT with a text editor.

To easily view the ZOUTxx file, move to Windows Explorer and the working directory for your study. Then drag and drop the latest ZOUTxx file on to the Wordpad icon on the desktop. Highlight all text in the file and set the font size to 8 pt for ease of viewing the text without scrolling the lines.

The tabular listing in the **..\Zhaqf Results** tab contains a tabular summary of total WUA for each species and life stage at each discharge. Clicking the check box marked **Include total area** will add a column for total surface area at each discharge. A list box for **Species** is provided so analysis results for different species can be displayed sequentially. Note that all life stages for Bull Trout are given in one table due to the format of HSC curve numbers used in the FISHCRV.LAB data file (i.e., 100101, 100102, 100103, etc.). If these HSC curve numbers had been 100001, 200001, 300001, 400001, then output for each life stage would have been displayed as a separate species.

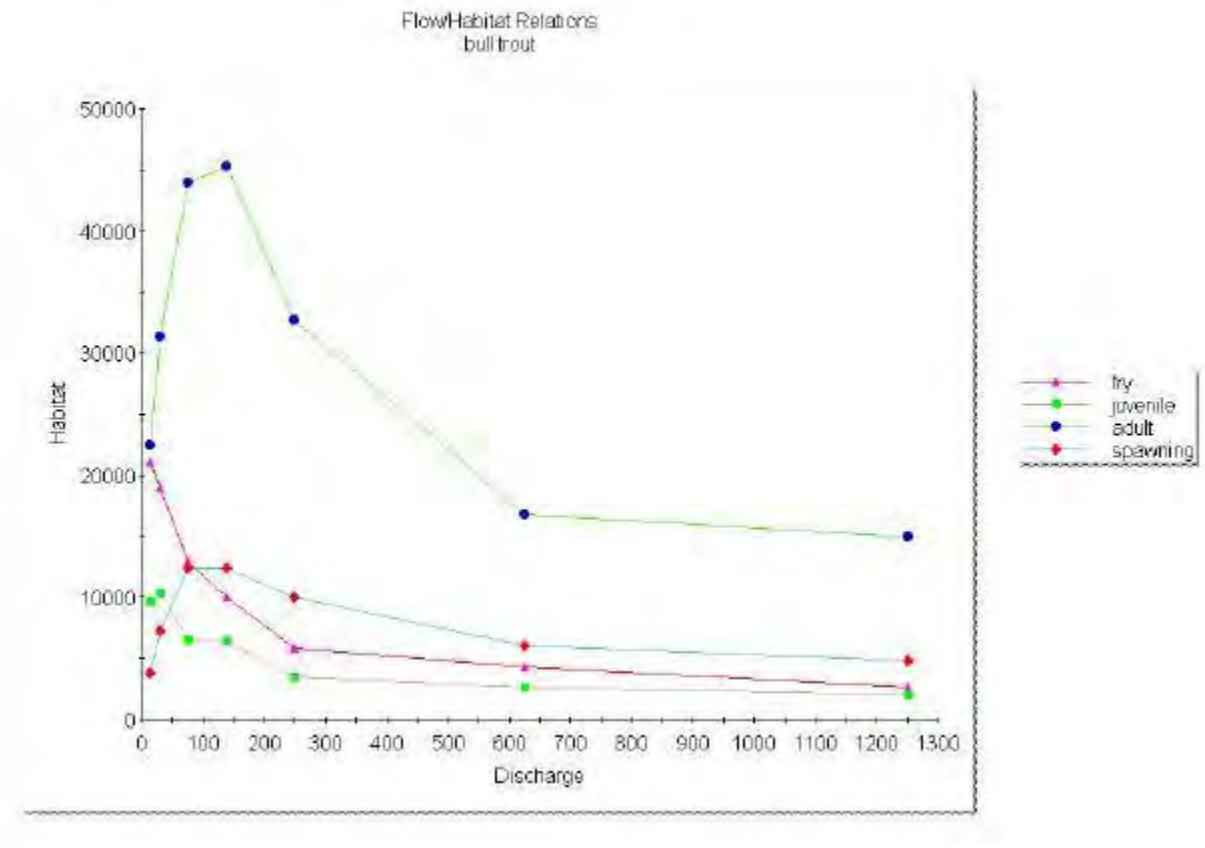
As would be expected from the differences in HSC curves for different life stages, the WUA versus discharge plot found using the **..\Zhaqf Results\Graphs** button shows that adults have the most habitat overall, and that as flows increase, fry and juvenile habitat availability tends to decrease (See Figure L9-2). This should make intuitive sense because velocities are increasing within the main channel areas, which makes these areas increasingly unsuitable for life stages with less swimming ability. Once this plot has been examined, return to the **..\Zhaqf Results** and click **Print** to produce a copy (or copy and paste the table to a spreadsheet) of your Bull Trout results using multiplicative combination of HSC criteria. Label this copy "Standard Multiplicative WUA Results".

Windows		DOS	Difference	% difference
Cell bed elevation	91.65	91.65	0	0.00
Water surface elevation	92.456	92.47	0.014	0.02
Depth	0.806	0.82	0.014	1.71
Depth Suitability Index	0.0708	0.096	0.025	26.25
Combined Suitability Index	0.0644	0.087	0.023	26.25
Weighted Usable Area	8.698	11.79	3.096	26.25

Figure L9-1.

Acknowledgements **i**
PREFACE **ii**
A Brief History of PHABSIM
Use of this Document

Aggregate habitat results for Bull Trout fry life stage at each of the simulated discharges. **Figure L9-2**. Multiplicative WUA values for Bull Trout.



Step 5. Compare the Effect of Various Combined Suitability Values on Habitat Predictions

Changing the manner in which the HABTAE program computes combined suitability for each computational cell has the potential to change resulting predictions of WUA. In previous habitat simulations, WUA was computed using the multiplicative approach. In this step, the HABTAE program will use the geometric mean.

Go to the **\Models\Habtae\Computations** tab and click **Geometric Mean**; then move to the **..\Output Options** tab and click **Run**. The results of this simulation are shown in Figure L9-3.

Comparing Figures L9-2 and L9-3 clearly demonstrates that the magnitude of WUA predictions change but in general the shape of the functional relationship in the WUA curves has remained essentially the same using both simulation options. The increased magnitude of WUA predictions should make sense since the geometric mean "compensates" for a single low suitability factor in a computational cell if the remaining two suitability factors are high. This should increase WUA values overall.

Finally, go to the **..\Computations** tab and click **Lowest Limiting Factor**; and again click **Run** in the **..\Output Options** tab. The results of this simulation are shown in Figure L9-4.

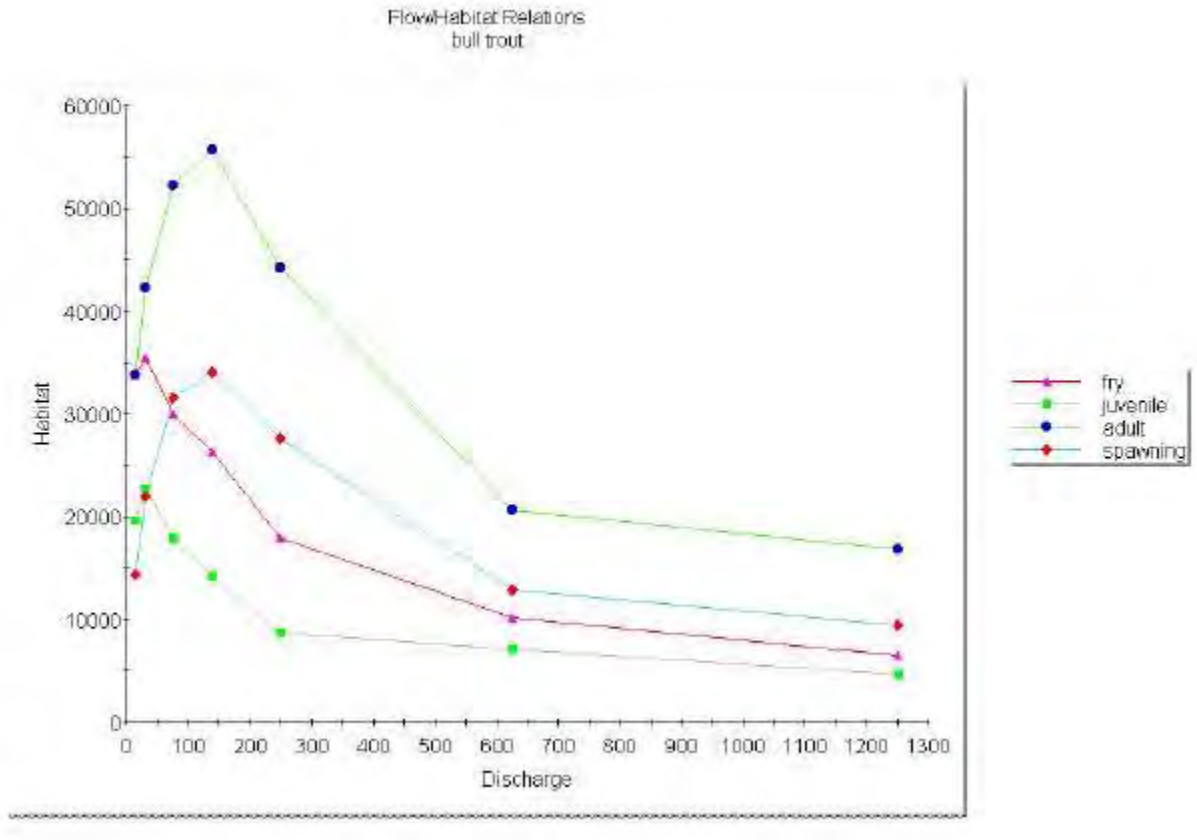


Figure L9-3. Geometric mean WUA values for Bull Trout.

A comparison of all three simulation results illustrates several interesting patterns. The geometric mean always produces more habitat than either the multiplicative or limiting factor method as would be expected. The limiting factor approach is always greater than the multiplicative method. These differences are an interplay between estimated hydraulic properties from hydraulic modeling and the functional form of species and life stage HSC curves.

The user should carefully consider which option or combination of options to use when estimating habitat. Each of the computational approaches tells the user something different that, when interpreted in the context of the biology of the target species and life stages, may help in the evaluation of flow regimes.

Computing Habitat for Cross Sections versus Reaches

The HABTAE program can be used to calculate WUA, weighted usable volume, or weighted usable bed area either for an entire reach or individual cross sections. This is accomplished by selecting the appropriate item for **WUA Calculations** in the **..\Computations** tab. In the next step of the laboratory, the HABTAE program will be used to produce results for each cross section. The analysis of habitat at particular cross sections can identify not only the amount contributed to total WUA by each habitat area but can also be used to focus your study on specific critical habitats.

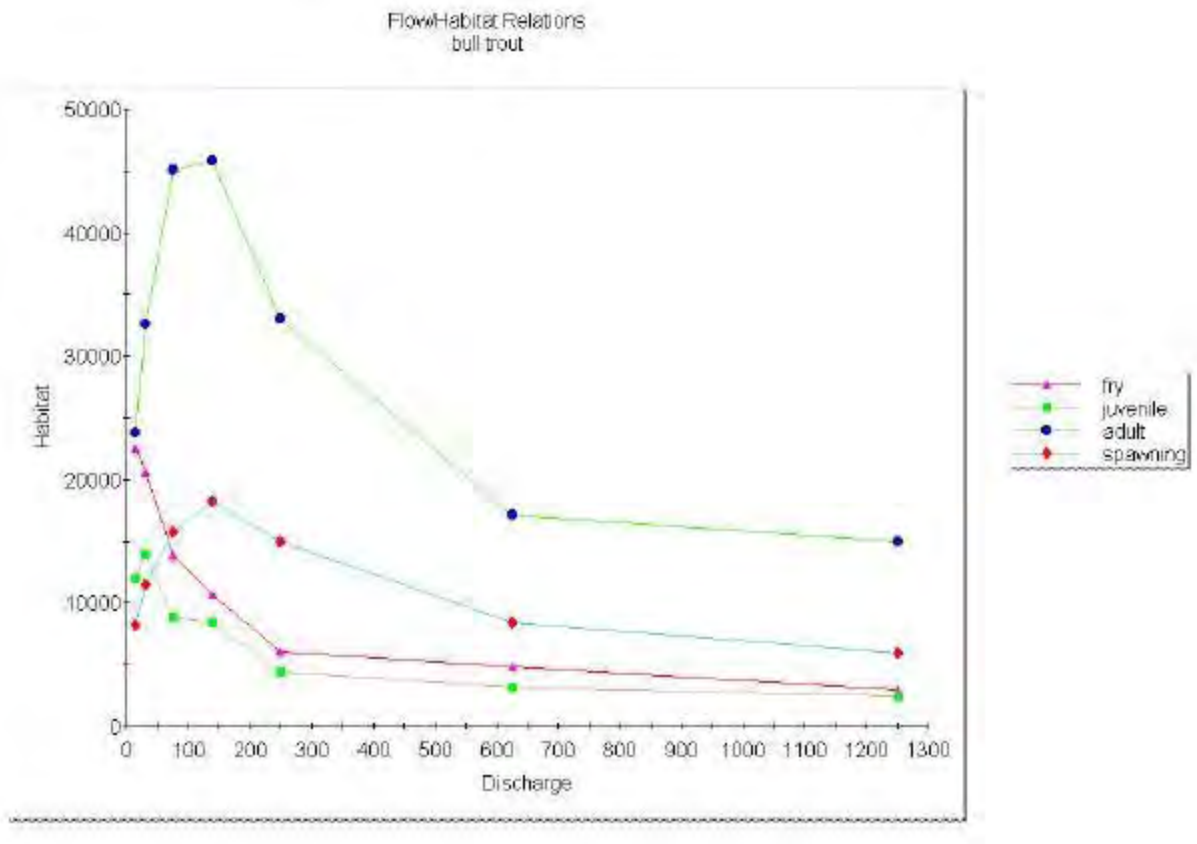


Figure L9-4. Lowest limiting factor WUA for Bull Trout.

Step 6. Change Habitat Options to Produce Cross Section Output

In the **..\Computations** tab, set **WUA Calculations** to **Calculate WUA for Independent XSEC** and set**Habitat Calculations** to **Standard Calculation**. Then click **Run** in the **..\Output Options** tab.

Using this option in HABTAE will generate summary tables for each species and life stage for each cross section. These tables are only contained in the ZOUT file created after running this HABTAE option. View the latest numbered ZOUTxx file using Wordpad and scroll down through the output to examine these results. When finished, exit Wordpad and return to the HABTAE program in PHABSIM for Windows. In the output (see Figure L9-5), you will find terms for weighted width and percent WUA. These terms are provided because each cross section is treated independently and therefore, there is no longitudinal direction over which to compute area of the computational cells.

This option in HABTAE is particularly useful for understanding how predicted habitat changes for a given species and life stage within specific types of mesoscale habitats. This may be important when considering impacts of alternative flow regimes on spawning habitat in riffles or over wintering habitats in pools, for example.

```
SPECIES -bull trout      LIFE STAGE -fry UNITS: TRADITIONAL VELOCITY TERM - MEAN          CFMIN = 0.00

    CROSS SECTION 0.000000
```

Windows		DOS	Difference	% difference
Cell bed elevation	91.65	91.65	0	0.00
Water surface elevation	92.456	92.47	0.014	0.02
Depth	0.806	0.82	0.014	1.71
Depth Suitability Index	0.0708	0.096	0.025	26.25
Combined Suitability Index	0.0644	0.087	0.023	26.25

Figure L9-5. Excerpt of habitat results for individual cross sections.

Evaluation of Habitat Quality

All HABTAE program runs to this point in the laboratory have estimated total WUA. For a given discharge the program may indicate that of a total stream surface area of 100 ft^2 that there are 10 ft^2 of WUA. WUA could be composed of a single 10 ft^2 area with a combined suitability of 1.0 with the remaining 90 ft^2 of habitat having a combined suitability of 0.0. Alternatively, all 100 ft^2 of stream may have a combined suitability of 0.1. In both cases, total WUA would be 10 ft^2. In this section of the lab, the HABTAE program will be used to set a threshold on the magnitude of combined suitability to compute the amount of "high quality" habitat at each discharge.

Step 7. Calculate Habitat With Minimum Combined Suitability Factors

Go to the **..\Limits** tab and click **Specify minimum factor by life stage** in the **Minimum Effective Composite Suitability Factor (IOC 19)** box**.** Then move to the **..\Velocity Replacement Options** tab and enter the minimum composite suitability factor value you will accept in the CFMIN column for each life stage HSC number shown. For this laboratory, use 0.75 for all life stages. Then click **Run** in the **..\Output Options** tab.

The results for total WUA and "high quality" habitat can be compared for each species and life stage. In the **..\ZHAQF Results** tab, click the **Graph** button, select Bull Trout Fry and click the **Refresh** button. Figure L9-6 displays the results for Bull Trout fry where the line labeled No Limit is total WUA and the line labeled CF Limit = 0.75 is WUA with a combined suitability greater than 0.75. Making two runs of HABTAE with and without composite suitability factor limits and copying the results to a spreadsheet produced this figure. The Bull Trout Fry graph in PHABSIM for Windows should look like the CF Limit = 0.75 line in Figure L9-6.

Note the apparent decline in WUA at 30.2 cfs (the second discharge) compared to 15.0 and 75.2 cfs. By clicking the Graph button in **..\Habitat Results** you can view a plot of composite suitability for all cells in the study site. The color key allows visual evaluation of which cells have more than 0.75 combined suitability. At 30.2 cfs, only cross section 201 has a significant amount of Bull Trout fry habitat. Whereas at either 15.0 or 75.2 cfs, at least one other cross section has relatively large amounts of fry habitat with a combined suitability of 0.75 or greater. At these low flows, large relative changes in habitat may occur with changes in flow as highly suitable areas become wetted and those same areas develop high velocities at greater flows.

Display the results for the remaining life stages of Bull Trout in both the **..\Habitat Results** and **..\ZHAQF**

Results tabs. Note that for this particular data set, high quality habitat is contributing to less than half of the total WUA over all ranges of discharge for all life stages. However, this is not always the case. In some instances, the amount of high quality habitat may make up only a small proportion of total available habitat over certain ranges of flows while dominating total available habitat at others. It is also not uncommon that the discharge at which high quality habitat is maximized may be different than the discharge at which total habitat is maximized. This type of analysis with HABTAE permits evaluation of tradeoffs between flows that may sacrifice total habitat to maximize high quality habitat at an alternative discharge.

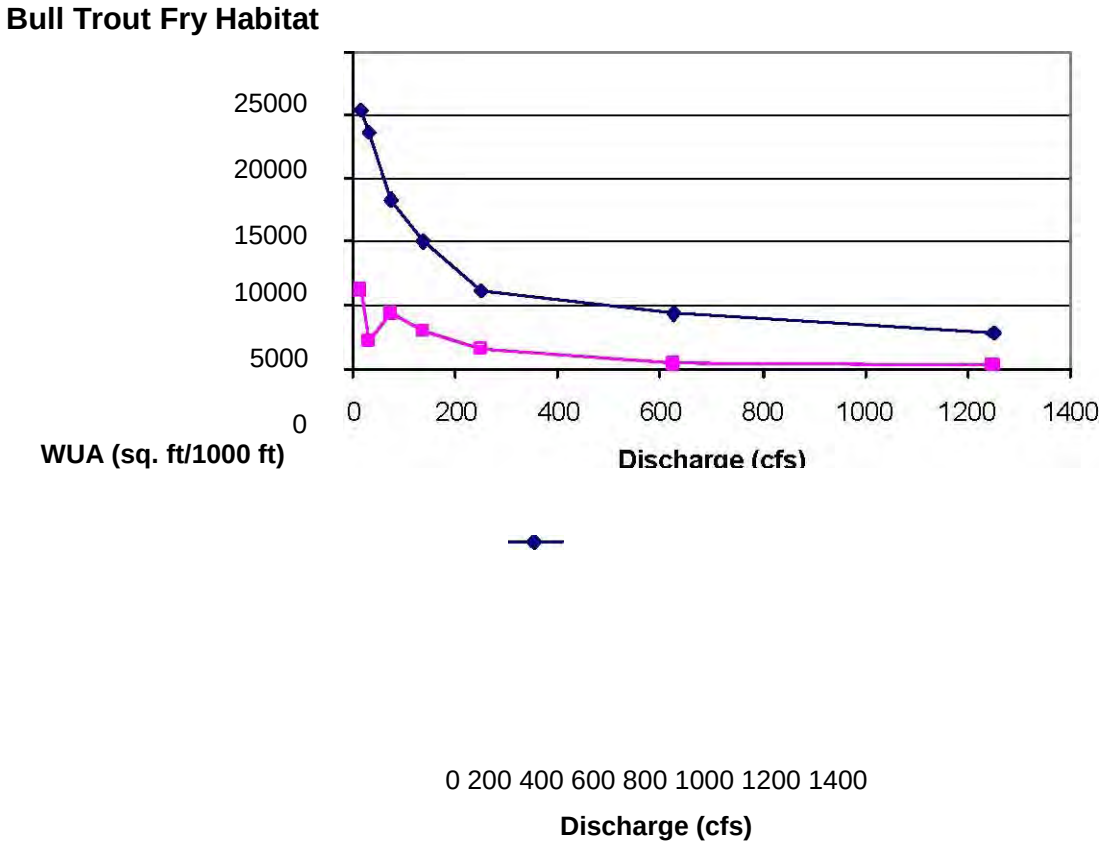


Figure L9-6. Bull Trout fry habitat with and without composite suitability limits.

Evaluate the Effects of Velocity Simulations on WUA Results

To illustrate the effects of hydraulic simulations on computation of available habitat, this part of the laboratory will use four different calibration\simulation velocity data sets as input to HABTAE for the production of WUA. Setting a total of four different velocity simulation options and generating WUA for each of the resulting velocity distributions will accomplish this. We will simulate velocities using the high flow velocity calibration data set, the medium flow velocity calibration data set , the low flow velocity calibration data set, and the discharge range distributed set as templates. We

currently have modeled velocities using the low flow velocity set as the template from 15 –75.2 cfs, the mid-flow velocity set for 139 cfs, and the high flow velocity set for 250 cfs and up. So we will begin there.

Step 8. Select different CAL sets within the VELSIM Program and Compute WUA with HABTAE for each

Velocity Template

Set HABTAE to produce standard WUA for the entire study site by setting **No limiting factor specified** on the **LIMITS** tab and **Calculate WUA for Reach** and **Standard Calculation** on the **Computations** tab. Click **Run**, go to **Zhaqf Results,** and **Print** the table. Alternatively, you may copy the table into a spreadsheet. (Do not forget to enter the column and row headings.) Label the printed copy or spreadsheet block, "Combined Velocity Templates". Save the project using **\File\Save Project** before proceeding. We will come back to this project in the next lab so it is important to save the file now.

Next, go to **\Models\Velocity Simulation\Velocity Calibration Set Assignments** and set all combinations of discharge and cross section to 1. This will assign the low velocity set as the template for all velocity simulations. Click **Run** followed by **OK** to exit the velocity simulation window. Save this project under a new name using **\File\Save As**. Give the project the name "Lowvel" and ensure it is located in a directory subordinate to the working directory "Lab9".

In **\Models\HABTAE**, click **Run** (you have already set all the options). Go to the **Zhaqf Results** tab and print the table of WUA values. Label this copy or spreadsheet block "Low Velocity Template".

Repeat this process by setting all combinations of discharge and cross section to velocity calibration set 2 and then 3 with appropriate labels for middle and high velocity calibration set on the printed (or copied and pasted) tables of weighted usable area. Save the projects under new names using **\File\Save As**. Name the projects "Midvel" and "Highvel", and ensure they are located in directories subordinate to the working directory "Lab9". You should now have four sets of habitat results and four projects located in separate directories.

Examining the four sets of results for Bull Trout juveniles shown in Figure L9-7 shows convincing evidence that the choice of velocity calibration data set can impact the relationship between WUA and discharge over at least part of the flow range. Results for different species and life stage HSC relationships and different hydraulic calibration data can produce similar or widely differing results. The user needs to carefully consider her (his) choice of calibration data sets, HSC, and modeling options when applying PHABSIM. It is up to the investigator to justify the choice of options and data used in the context of the particular instream flow assessment. Usually these choices are made based on goodness-of-fit, reasonableness, and study objectives.

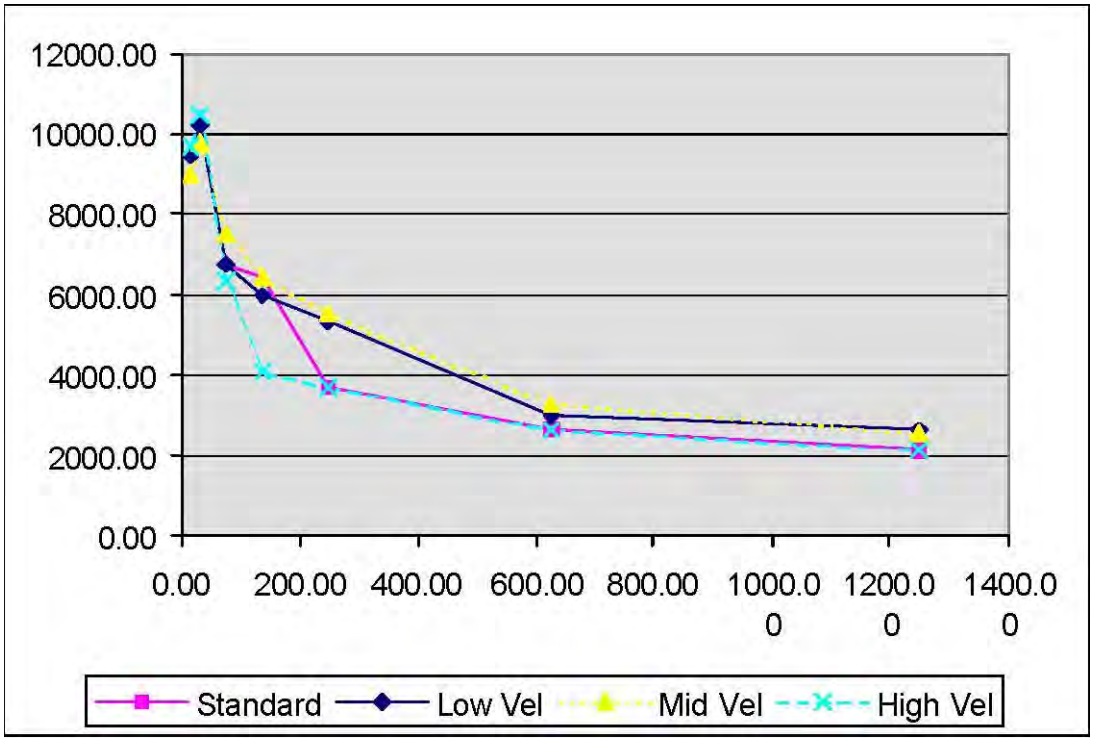


Figure L9-7. Bull Trout juvenile habitat produced by four different velocity set templates.

Laboratory 10. Conditional (Adjacent) Velocity Habitat Simulations Objective

The objective of this laboratory is to introduce calculation of habitat based on adjacent or "conditional" velocities using the HABTAE model.

Programs Used: HABTAE, Excel

Data Files Used: Lab10.phb, highvel.phb, midvel.phb, lowvel.phb, adjvelhab.xls

Introduction

In addition to "standard" Weighted Usable Area calculations, the HABTAE program allows the user to generate available habitat where adjacent velocity conditions are combined with the habitat suitability criteria to determine habitat worth.

In this lab, the VELSIM program will be used for all velocity distribution simulations using four different velocity simulations to explore the impact on calculation of available habitat within HABTAE. To facilitate presentation of the material, the lab has been broken into several sections, which address a specific computational aspect or evaluation of model sensitivity with HABTAE. The principal activities of the lab are:

- Creation and Modification of HABTAE Options Control Files for Simulations
- Conditional Velocity Simulations
- Generation of Hydraulic Properties using Different Velocity Simulation Approaches
- Conditional Velocity Simulations with Different Velocity Modeling Approaches

The user is encouraged to examine the complete listing of computational capabilities for the HABTAE model contained in Chapter 5 of the manual and explore use of computational options not covered in this lab exercise. The best way to determine whether a particular option has value to the user for a given problem is to run the HABTAE model with 'standard' or 'default' settings and then compare computational detail listings in the output with other selected options. The laboratory is presented in 7 steps that lead you through the conditional velocity analysis process.

Step 1. Run HABTAE with Standard Options

In the **..\Output Options** tab, set the following items:

- Click the **Write Computational Details** check box to cause computational details to be printed to the next numbered ZOUT file.

- Click the **Write WUA or WUV** radio button in the **ZHAQF Options** box to write WUA calculation results to the ZOUT file.
- Click the **Write Flow Data** check box so the ZOUT file will also contain the flow data used to generate these habitat results.
- In the **Computations** tab, set the following items:
- Click the **Use Zero CI in Calculations** check box, as channel index values of zero should calculate as zero.

- Click the **Calculate WUA for Reach** radio button in the **WUA Calculations** box to produce aggregated weighted usable area as the final habitat result.

- Click the Standard Calculation radio button in the Habitat Calculations box to ensure that the "standard" multiciplative calculation of composite suitability is performed.

In the **Life Stages** tab scroll the table and click on each of the four life stages of Bull Trout. For this exercise, do not include any other species. Only the four Bull Trout lines should be highlighted. Make a note of the HSC numbers for each life stage as you will use them later.

Return to the **\Models\Velocity Simulation\Velocity Set Assignments** window and check that Cal Set 3 has been assigned to all discharges at all cross sections. If this has not been done, do it now and rerun the velocity simulation.

These settings prepare the HABTAE model to perform the standard habitat calculation for four life stages of Bull Trout. In the **..\Output Options** tab, click the **Run** button. Move to the **ZHAQF Results** tab. On the Windows Desktop, start Microsoft Excel (or your preferred spreadsheet package) and open the file adjvelhab.zls. Drag the mouse from the upper left to the lower right corner of the ZHAQF Results table, right click, and select **Copy**. Move to Excel and paste to the first block of values starting at cell A9. This places the "standard" habitat calculation results in the spreadsheet.

Step 2. Select HABTAE Options for a Minimum Adjacent Velocity Limit Calculation

In the **Adjacent Velocity** tab, set the following items:

- In the **Use VLIM as** box, click the **Minimum** radio button to search for a velocity that is greater than or equal to the velocity you will define below as VLIM. That is, VLIM is set to act as a lower (minimum) bound.

- In the **WUA Calculation when VLIM not found** box, click **WUA = 0** to cause no WUA to be calculated in the current computational cell if the user-defined minimum velocity is not found within a user specified distance.

Enter scan distances and threshold velocities to be used for each species and life stage in the **Dist** and **VLIM** columns of the table in the **Scan distance, velocity limit, and initial velocity** box. These values are entered next to the appropriate HSC curve ID numbers for Bull Trout; 100101 for fry; 100102 for adult; 100103 for juvenile; and 100104 for spawning. (Scroll the table using the scroll bar until the needed HSC curve numbers are displayed.)

For the purposes of this lab exercise, enter a restrictive scan distance (Dist) for fry (5 feet), a larger distance for juveniles and adults (10 feet), and zero distance for the spawning life stage to simulate immobility of incubating eggs in the analysis. It is incumbent on the investigator to determine an appropriate distance to scan for particular species and life stages when using the adjacent velocity calculations in the HABTAE program.

Similarly, enter a different threshold velocity (VLIM) value for fry (0.5 fps) and adults (1.0 fps), and the same value for juvenile and spawning (1.5 fps). The choice of limiting velocity is again a matter of professional judgement. Examining the HSC curves for velocity can often provide insight as well as searching published literature on sustained swimming speeds or related life history information. The values chosen in this laboratory are for illustrative purposes only.

In the **Velocity Replacement Options** tab, leave all values set to zero as only mean column velocity is being considered and no nose velocity issues are being explored at this point. It is possible, however, to base adjacent velocity calculations on nose velocities as long as you have habitat suitability criteria that reflect nose velocity, search distance and velocity limit information that is appropriate to such a calculation. Little research has been done in this area so such information may be scarce.

This sets up the Adjacent Velocity as Minimum Limit calculation for four life stages of Bull Trout. In the **..\Output Options** tab, click the **Run** button. Move to the **ZHAQF Results** tab. On the Windows desktop, start Microsoft Excel (or your preferred spreadsheet package) and open the file adjvelhab.xls. Drag the mouse from the upper left to lower right corners of the ZHAQF Results table, right click, and select **Copy**. Move to Excel and paste to the first block of values starting at cell A21. This places the "VLIM is Minimum" habitat calculation results in the spreadsheet.

Step 3. Run HABTAE With a Maximum Adjacent Velocity Limit

In the **Adjacent Velocity** tab set the following items:

- In the **Use VLIM as** box, click the **Maximum** radio button to search for velocity less than or equal to the velocity you will define below as VLIM. That is, VLIM is set to act as an upper (maximum) bound.

Leave all other options the same as in Step 2 above. Click the Run button as above and copy and paste the habitat results into the spreadsheet at cell A33. This places the "VLIM is Maximum" habitat calculation results in the spreadsheet.

Step 4. Compare Standard and Adjacent (Conditional) Velocity Simulations

This section of the laboratory will compare HABTAE habitat predictions based on both maximum and minimum threshold conditional velocity simulations. In the previous steps, results have been generated using the standard habitat calculation, conditional velocity simulation using a minimum threshold, and conditional velocity simulation using a maximum threshold. In each instance high flow calibration velocity simulation results from VELSIM were used.

To begin this evaluation, move to the **..\Habitat Results** tab. There you will find dialog boxes for Curve ID, Cross Section and Discharge. Clicking the triangular down arrow at the right of each box displays a menu of the options available for **Curve ID**. Select 100101 Bull Trout fry. For **Cross Section**, select 0.000, and for **Discharge** select 139.0 cfs. The table now displays the velocity suitability index value (VEL SI), the Depth SI, the channel index suitability value (Sub SI), the adjacent velocity suitability factor (Ad Vel), the combined suitability factor for each cell (Factor), the cell area and the cell weighted usable area (WUA). A separate table of results will be displayed for each combination of Curve ID, Cross Section, and Discharge selected as shown in Figure L10-1.

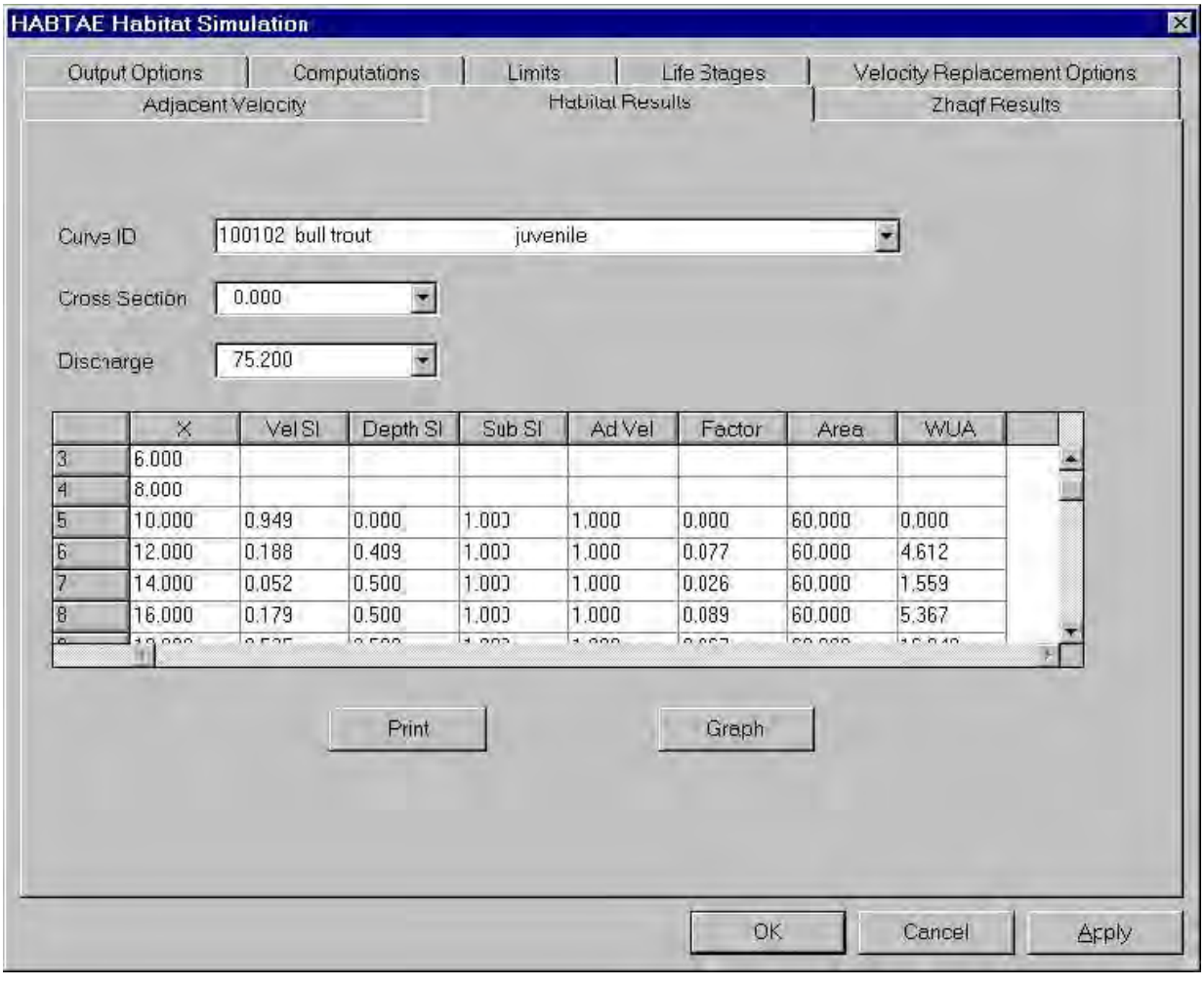


Figure L10-1. Habitat results table.

This table may be copied by dragging the mouse from the upper left to lower right corner, right clic king and selecting copy in the menu provided. The table may then be pasted to a spreadsheet or report as needed. Table headings are not included in the copy operation, so it is often useful to prepare a spreadsheet containing the headings as a template to receive this information.

The habitat results may be graphically viewed by clicking the **Graph** button. Both plan view and 3-D rotatable graphics are provided. The graphical display gives an indication of where on each transect the most suitable conditions exist. At the top of the graph window, dialog boxes similar to the **Habitat Results** tab allow the user to select which **Curve ID** and **Discharg**e are to be viewed. Click **Refresh** to update the plot when each menu change is made.

Note the areas of high quality Bull Trout fry habitat at 139 cfs. Red is used for the highest value range. You can see that the highest composite suitability is less than 1.0. Why is this?

Now select 15 cfs and click **Refresh**. What differences do you see between this view and the 139 cfs view? Reduce the size of this graph window by dragging a corner so you can see the HABTAE window, but leave the graph window open for later use.

In the HABTAE Habitat Simulation window, go to the ZHAQF Results tab and click the graph button. In the Species dialog box select Bull Trout fry. Note the shape of the habitat-discharge relationship. Resize both this and the Habitat Results graph window so both can be viewed on screen at the same time. (On smaller monitors, it may be necessary to overlap the two graph windows and alternately click them to bring one or the other to the foreground or you may find it convenient to print the **ZHAQF** plot.)

While viewing the **ZHAQF** plot, select (and refresh) each discharge in the **Habitat Results** graph. How do the composite suitability values explain the resulting ZHAQF plot?

Note that at the lower discharges, the area of fry habitat occupies much of the stream bed. However, at the higher discharges, fry habitat is relegated to the stream margins. As the flow increases, the number of cross sections with suitable fry habitat at the stream edges decreases and the amount of area represented as high quality habitat (i.e., displays in red) decreases. Figures L10-2 to L10-4 illustrate the difference between the standard, minimum and maximum limit habitat for one discharge.

Note the loss of habitat at the fourth cross section (168 to 201 ft upstream) between the standard and "minimum" adjacent velocity calculations. This accounts for the lower conditioned habitat value at 15 cfs seen in the habitat flow relation displayed at the upper right. Also note that the fourth cross section has a large area of good habitat under the conditions of the "maximum" calculation. When the limiting velocity (VLIM) is treated as a lower bound (minimum) no cells are found within the search distance with velocities higher than VLIM at the fourth cross section. Thus, the final weighting factor is zero due to the adjacent velocity condition. In contrast, when VLIM is treated as an upper bound (maximum), there are ample cells with velocities lower than the limit and the habitat at the fourth cross section at 15 cfs is substantially the same as the standard calculation.

You can use the graphical display to determine the cause of the trend toward less fry habitat at higher discharges by selecting from the **Depth SI, Velocity SI**, and **Channel Index SI** radio buttons in the **Habitat Results** plot. If you select the Depth SI button and click refresh while displaying habitat results for 250 cfs, you will see a large area of the stream turn red. Thus, it is unlikely that Depth is the limiting factor. However, if you select Velocity SI, the plot shows minor changes from the composite suitability plot. Thus, it appears that velocity is the limiting factor that causes the fry suitability to decline with increasing discharge. This is true for the standard and both conditional velocity calculations. Why?

Now that we have considered how the habitat suitability for depth and velocity influences the shape of the habitat-discharge relation, we are ready to compare the three adjacent velocity limit approaches chosen earlier. Return to the adjhabvel.xls spreadsheet and note the graphs displayed to the right of the data entry area. (If you did not have time to complete this portion of the lab, a worked example is contained in Sheet 2 of the spreadsheet.)

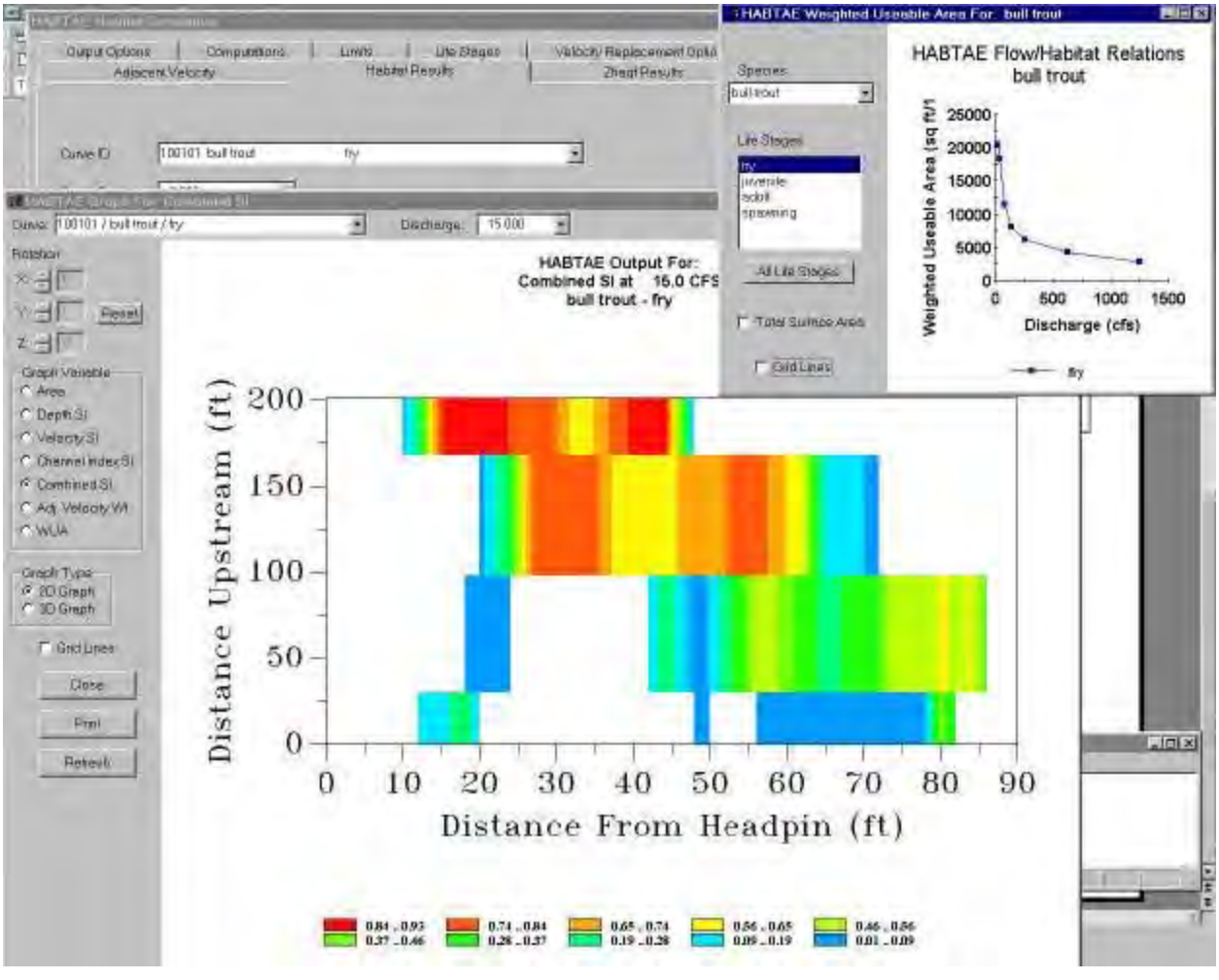
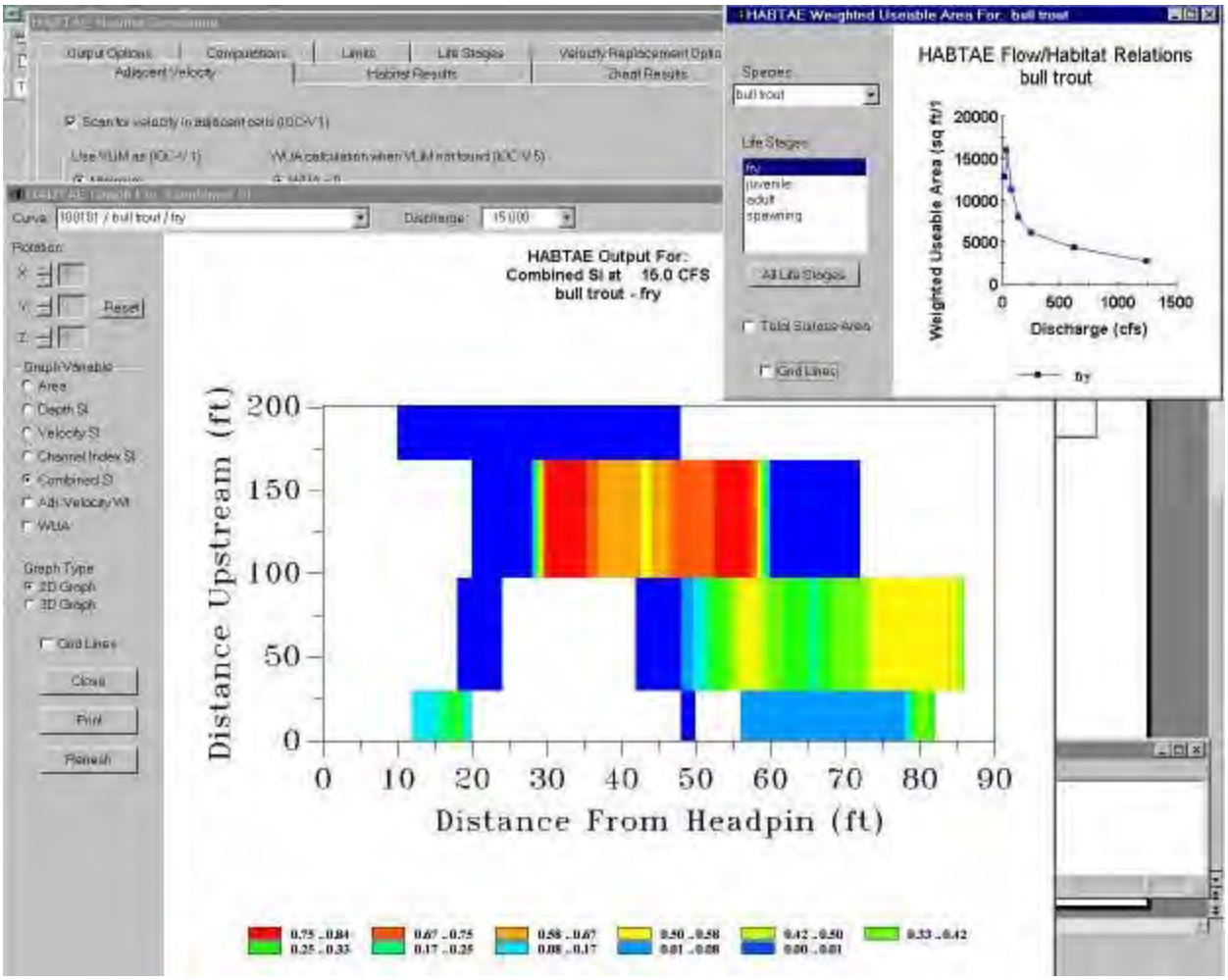
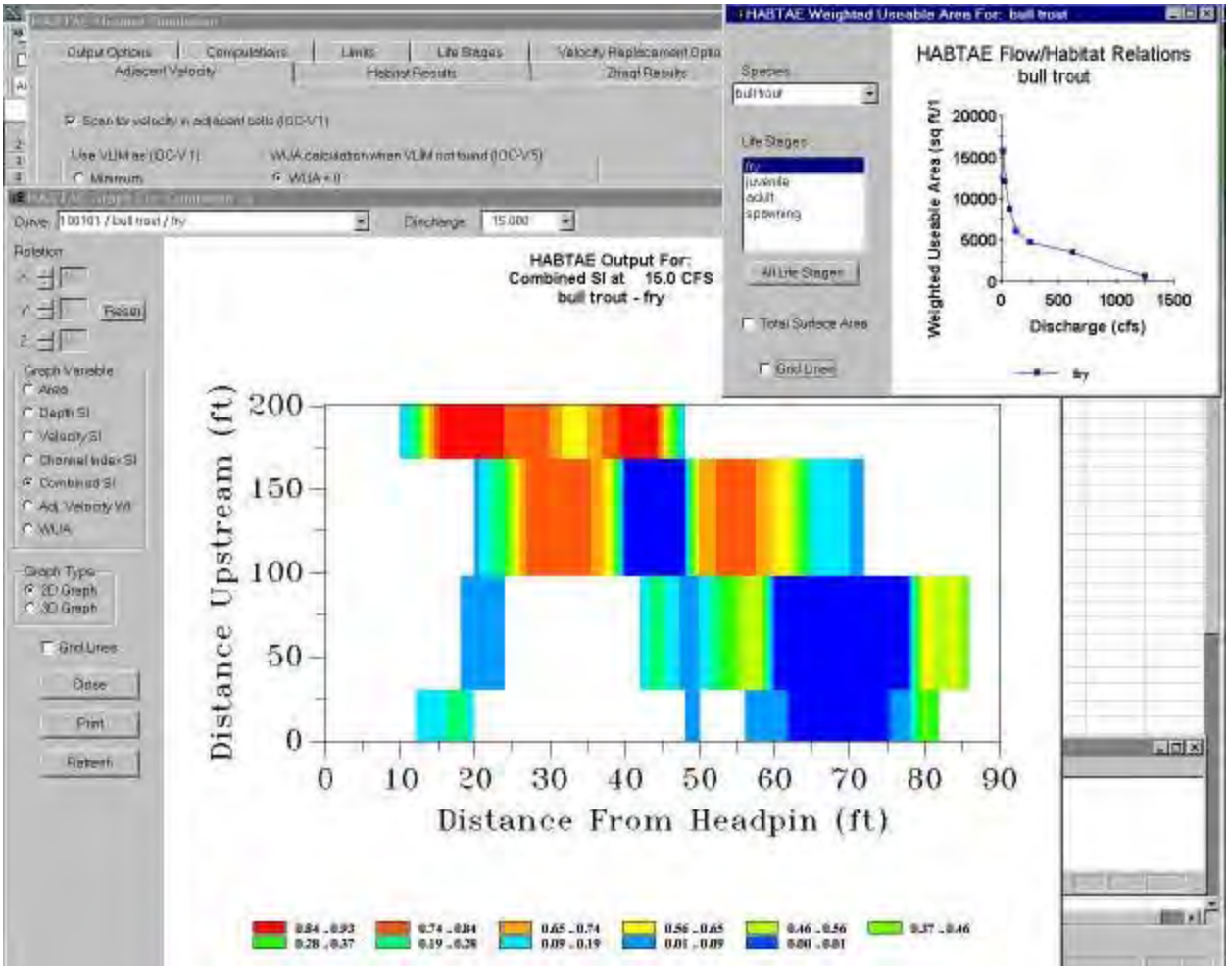


Figure L10-2. Bull trout fry habitat plan view, standard calculation. **Figure L10-3**. Bull trout fry habitat plan view, minimum **adjacent** velocity calculation. **Figure L10-4**. Bull trout fry habitat plan view, maximum adjacent velocity calculation.


HABTAE Weighted Useable Area For: bull trout
Species
bull trout
Life Stages
fry
juvenile
adult
spawning
All Life Stages
Total Station Area
Grid Lines
HABTAE Flow/Habitat Relations
bull trout
Weighted Useable Area (sq ft/1
Discharge (cfs)
fry
Curve: 1001SI / bull trout / fry
Discharge: 15.000
HABTAE Output For:
Combined SI at 15.0 CFS
bull trout - fry
Rotation
Reset
Graph Variable
Area
Depth SI
Velocity SI
Channel Index SI
Combined SI
Adj Velocity Wt
WUA
Graph Type
2D Graph
3D Graph
Grid Lines
Close
Print
Refresh
Distance Upstream (ft)
Distance From Headpin (ft)
0.75 - 0.84
0.25 - 0.33
0.67 - 0.75
0.17 - 0.25
0.58 - 0.67
0.08 - 0.17
0.50 - 0.58
0.01 - 0.08
0.42 - 0.50
0.00 - 0.01
0.33 - 0.42



These examples should demonstrate that for part of the flow range some life stages were not affected by use of conditional velocity simulations based on the criteria specified for either the maximum or minimum thresholds in conjunction with the user-specified scanning distances. The greatest impact on WUA across the entire range of discharges was obtained for the spawning life stage. Note that spawning was the only life stage where scan distance was set to >0'. The combination of threshold velocity and scan distances using the minimum threshold gave similar results to the standard velocity simulations for all life stages except spawning. This suggests that for most flows, HABTAE was able to find a velocity value above the threshold velocity within the specified scan distance for these life stages. This was not true at the very lowest discharges, but it is reasonable that fewer high velocity cells would be encountered at the very lowest flows.

Conversely, using the maximum threshold, there were more instances where HABTAE was not able to find a velocity that was less than the specified maximum (upper bound) within the scan distance for fry, adult, and spawning. Therefore WUA totals were reduced compared to the standard velocity simulations. Refer to the adjacent velocity calculation example in Chapter 4 of the manual if you have questions about the effect of these conditional velocity simulations. Again, the spawning life stage was most strongly affected due largely to the zero scan distance.

The degree to which conditional velocity simulations will affect WUA relationships will be a function of the form of the HSC curve for velocity, velocity limits specified, and the scanning distance supplied by the user. These factors will also result in either greater or lesser changes between target species and life stages. It is the responsibility of the investigator to justify his (her) choice of modeling options and, in particular, choice of velocity limits and scanning distances used for the species and life stages involved in each project analysis.

Step 5. Effects of Changing Threshold Velocities

To better illustrate the ideas discussed above, move to the **Adjacent Velocity** tab and change **VLIM** for Bull Trout juvenile and adult to 4.0 feet/second and select the **Minimum** radio button in the **Use VLIM as** box. From the comparison of simulation results in Step 4, relatively small differences between minimum and standard velocity simulations were obtained for juvenile and adult Bull Trout. To generate results for the higher VLIM, move to the **Output Options** tab and **Run** the simulation, then move to the **ZHAQF Results** tab and view the graph. Select Juvenile and Adult life stages only. You may also copy and paste the ZHAQF table into the adjvelhab.xls spreadsheet in the space identified as REVISED VLIM FOR JUVENILE AND ADULT, row 50.

By viewing the graphs to the right of the data table, it is apparent that setting the minimum threshold to a higher value has dramatically altered simulation results for both of these life stages. In fact, at lower discharges the results would indicate that velocities greater than 4.0 feet/second simply do not exist in the channel. Why? Confirm this is true by reviewing the velocity distribution plots for the lower discharges in either **\Models\Velocity Simulation\Results\Cross Section** or **\Reports\Graphs\Bed Profile with WSL/Velocities**. You should find there are no velocities greater than 4.0 fps until a discharge of 650 cfs is simulated.

The fact that WUA for Bull Trout juvenile (and adult) is 0.0 at discharges 250 cfs and below, means that HABTAE was unable to locate velocities greater than 4.0 feet/second within the given scan distance for each computational cell. Therefore set the computational cell WUA to zero (i.e. in **..\Habtae\Adjacent Velocity** the **WUA = 0** button was selected in the **WUA calculation when VLIM not found** box.) At simulated discharges of 650 cfs and 1,250 cfs, hydraulic predictions are generating velocities in at least some computational cells that are greater than
4.0 feet/second and, therefore, a small amount of conditional WUA is predicted for these life stages.

Step 6. Generation of Hydraulic Properties using Different Velocity Simulation Approaches

You have already run the VELSIM program to produce the four velocity simulation alternatives that will be used in this lab. For convenience, you will find them in the Sample folder as noted in Table L10-1 below:

Windows		DOS	Difference	% difference
Cell bed elevation	91.65	91.65	0	0.00
Water surface elevation	92.456	92.47	0.014	0.02
Depth	0.806	0.82	0.014	1.71
Depth Suitability Index	0.0708	0.096	0.025	26.25
Combined Suitability Index	0.0644	0.087	0.023	26.25
Weighted Usable Area	8.698	11.79	3.096	26.25

Table L10-1. Project names for different velocity simulation options.

To use any of these projects in PHABSIM for Windows, use **\File\Open Project** and move to the desired project directory using **Browse**. Once in that directory, the file *projectname.phb* will be visible in the Open File dialog box. Double click the project file to open the project.

In previous laboratory steps, effects of different conditional velocity simulation approaches were examined to

LABORATORY 10 – CONDITIONAL VELOCITY HABITAT SIMULATIONS

compare the HABTAE habitat predictions using these options. In this step, the effect of different hydraulic simulation approaches on conditional velocity simulations using a minimum threshold approach will be compared. First we will examine the effect of using the "best" velocity simulation by applying each of the three calibration velocity sets to their appropriate range of discharges.

Return to the **\Models\Velocity Simulation\Velocity Calibration Set Assignments** tab and assign the appropriate cal set 1 to all discharges up to 75.2 cfs and cal set 2 to 139 cfs. Run the velocity simulation again by clicking the **Run** button in the **..\Options** tab. Then move to the **\Models\Habtae\Adjacent Velocity** tab and remove the check from the **Scan for velocity in adjacent cells** check box. Click the **Run** button in the **..\Output Options** tab. Move to the **ZHAQF Results** tab and copy the Results table for Bull Trout. Paste these results into the range beginning at row 72 in the adjhabvel.xls spreadsheet.

Compare the results of the standard habitat calculation for bull trout juveniles and adults (using the three cal set velocity simulation) to the standard habitat calculation using a single cal set. Are the results significant? How might this change in velocity simulation affect the outcome of any decision being based on the habitat analysis?

What effect does use of three cal sets have on adjacent velocity calculations? To examine this, move to the **\Models\Habtae\Adjacent Velocity** tab and check the **Scan for velocity in adjacent cells** check box. Click the **Run** button in the **..\Output Options** tab. Move to the **ZHAQF Results** tab and copy the results table for bull trout. Paste these results into the range beginning at row 91 in the adjhabvel.xls spreadsheet.

Again, compare the results using the graphs provided. Comparing these results with the results generated earlier using a single cal set, you can see that the effect of the adjacent velocity condition is greater at low flows in both sets of results. For this particular data set, it appears that the habitat results are more strongly influenced by the adjacent velocity condition than by the choice of velocity calibration set.

What about the first decision you made in the hydraulic modeling process, the choice of hydraulic model? The results obtained to this point were based on the "best" water surface results we could obtain by combining models at the control and across the pool. To examine the sensitivity of the habitat simulation process to choice of water surface model, we will run the WSL simulation using STGQ for all combinations of cross section and discharge.

Return to the **\Models\WSL\Methods** tab, select the **STGQ** radio button, and click the **Select All** button followed by the **Run** button. Move to the **..\Velocity Simulation** window and click the **Run** button in the **Options** tab. Next, move to the **\Models\Habtae\Output Options** tab and click the **Run** button there. Move to the **ZHAQF Results** tab and copy the Results table for Bull Trout. Paste the results into the space provided in row 113 of the adjvelhab.xls spreadsheet.

Comparing the graphs in spreadsheet you will again find that the choice of hydraulic simulation option has less effect than the choice of adjacent velocity calculation.

At least two conclusions can be drawn from this exercise. First, in the particular circumstances of this study site, the choice of hydraulic simulation has less influence than the choice of adjacent velocity conditions for Bull Trout adult and juvenile. This may not be true for all study sites or all HSC. (You may wish to create spreadsheet graphs for the other life stages to see if they are more or less affected by these choices.) Second, use of the adjacent velocity simulation can be a good tool to help determine whic h ranges of flow produce substantial and/or insignificant amounts of habitat when adjacent conditions are important. This information may be very useful in the instream flow decision arena.

When using conditional velocity based habitat simulation, it is especially important to ensure that the various adjacent velocity conditions used have a strong biological basis. The IFIM process emphasizes obtaining agreement among stakeholders as to the form of the analysis prior to beginning the PHABSIM application. This ensures that the critical questions about use of habitat simulation options such as conditional velocity are asked before the analysis begins.

Step 7. Including Adjacent Velocity Conditions That Lie Just Outside The Search Distance

As a final step in this laboratory, the **Scan for initial velocity (VO) and interpolate** radio button in the **..\Habtae\Adjacent Velocity** tab will be checked to cause the program to interpolate a weight for suitable habitat if the threshold velocity is not found within the user-specified scanning distance. In previous simulations, the **WUA = 0** radio button was checked, which caused the WUA to be set to 0.0 if the threshold velocity was not found. Choosing the interpolation option directs the program to locate a velocity that is closest to the threshold velocity and less/greater than the user specified velocity (V_o) within the scanning distance. The program then interpolates a >combined suitability' between 0.0 and 1.0 to modify WUA in the computational cell rather than setting it to 0.0. Whether the program finds a suitable velocity which is less than (VLIM acts as a maximum) or greater than (VLIM acts as a minimum) V_o is determined by the option selected in the **Use VLIM as** box.

In PHABSIM for Windows, move to the **\Models\Habtae\Adjacent Velocity** tab and enter V_o values of 0.4, 0.5, 1.0, 1.0 for bull trout fry, juvenile, adult, and spawning life stages, respectively, in the input table. Set **VLIM**to act as a minimum, select **Scan for initial velocity (VO) and interpolate**, and be sure that the **Scan for adjacent velocity** box is still checked. Move back to the **Output Options** tab and click **Run**. Copy and paste the ZHAQF table to row 137 of the adjvelhab.xls spreadsheet.

Note that V_o values have been entered for each life stage to be analyzed and, in this particular application, the values are less than the VLIM values since the minimum threshold option is being used in the simulations. Remember the minimum threshold option directs the program to look for values greater than VLIM so a relaxed V_o must be less than VLIM to make sense. Refer to the example in Chapter 4 of the manual if you have questions about this.

Plots of the **Scan for initial velocity (VO) and interpolate** and the **WUA = 0** options for adult and juvenile Bull Trout are included in the spreadsheet at row 130. The results for all life stages show slightly greater habitat over part of the range of discharges with the **Scan for initial velocity (VO) and interpolate** option compared to the **WUA = 0** option. This is a result of including the additional interpolated WUA that had weighting factors assigned between VLIM and V_o when the interpolation option was selected.

Laboratory 11. Habitat Modeling - HABTAM

Objective

The objective of this laboratory is to illustrate the use of the HABTAM program where the investigator wishes to examine available habitat at two different flows and the species and life stage of interest can migrate laterally within a cross section.

Programs Used: . HABTAM

Data Files Used: Lab11.phb

Introduction

The HABTAM program is used to simulate conditions at a cross section where fish are allowed to migrate laterally to find suitable habitat when two separate flows are compared. The user supplies a starting flow, an ending flow, and an appropriate maximum migration distance. The program will compute the WUA for each pair of discharges and compute the amount of WUA that is used at the ending flow assuming that all the WUA (i.e., habitat) at the starting flow was used. The program can also be used with a maximum allowable migration distance of 0.0, which might be appropriate for incubation life stages or benthic invertebrates. In this latter case, the program will compute the minimum of the WUA of the starting or ending flow. The use of the HABTAM program should not be confused with "migration" analyses within a reach or river segment, since only lateral migration on a given cross section is considered in the HABTAM program. PHABSIM for Windows does not contain any reach or river segment migration analytical capabilities.

The required hydraulic and channel properties information for this lab has already been generated in previous exercises. We will use the Lab11 project that contains three calibration sets assigned to their representative discharge ranges as the starting point for this lab. The laboratory implements the following processes four steps:

- Ensure the best WSL and velocity simulations have been performed
- Set HABTAM Options
- Simulate habitat using HABTAM

Step 1. Open the Lab11 Project

Use /**File/Open** to move to the lab11 working directory and open the lab11 project file. You now have the sample project as it was at the end of Lab 6 with the velocity distribution determined by three velocity templates applied to three ranges of flow.

For later use, it is a good idea to open the project and make a note of the curve ID numbers and which life stage and species they represent. Table L11-1 contains the curve ID numbers in the project. Note that some have three digits for the species ID number.

Table

Windows		DOS	Difference	% difference
Cell bed elevation	91.65	91.65	0	0.00
Water surface elevation	92.456	92.47	0.014	0.02
Depth	0.806	0.82	0.014	1.71
Depth Suitability Index	0.0708	0.096	0.025	26.25
Combined Suitability Index	0.0644	0.087	0.023	26.25
Weighted Usable Area	8.698	11.79	3.096	26.25

Acknowledgements **i**

PREFACE **ii**

A Brief History of PHABSIM

Use of this Document

Changes Between PHABSIM Version 2 and PHABSIM for Windows

Conventions Used in this Document

Chapter 1, Introduction to the Physical Habitat Simulation System **1**

Objectives

Associated Laboratory Exercises

An Overview of IFIM

The Purpose of PHABSIM

The Structure of PHABSIM

Application of PHABSIM

L11-1. HSC ID numbers and life stages provided in the sample project.

Step 2. Set HABTAM Options

Go to **/Models/HABTAM/Options** and put a check in the boxes for **Write migration calculation details, Write cross section data, Write flow related data**, and **Write computational details**. Selecting these options will allow the examination of the computational details in the output file listing to better understand how the HABTAM program functions. Check that **Velocity Calculation Options** in the **Velocity Calculations** tab is set to **Mean column velocity** because the HSC curves used in the laboratory are based on mean column velocities. The remaining options can be left in their default condition. We recommend you compare the defaults with the option choices for a full understanding of the choices available in HABTAM.

Next, go to the **Migration** tab. Here you will find a table containing all species/life stages for which HSC have been entered in this project. You can supply the allowable migration distance for each life stage. For this lab we will use Brown Trout spawning, fry, and adults, HSC curve numbers 11300, 11301, and 11302. Enter migration distances of 0.0 for spawning, 5 for fry, and 15 for adults. Note that a distance of
0.0 is entered for spawning since incubating eggs cannot migrate.

In the **Options** tab you can enter starting and ending discharge pairs representing the range of flow to be considered in the analysis. In an actual application, you would enter flow ranges relevant to the purpose of your study. For example, the range of high and low flows due to a hydropeaking operation. For this lab, enter three sets of flow pairs: 15, 30, 75.2, 139, 250 versus 625; 15, 30, 75.2, 139, 250 versus 1,250 and 1,250 versus 15, 30, 75.2, 139, and 250. That is, enter a starting flow of 15 and an ending flow of
625. In the next row, enter a starting flow of 30 and an ending flow of 625, etc. For the third set, enter a starting flow of 1,250 and an ending flow of 15. Continue similar entries until finished.

Step 3. Simulate Habitat Using HABTAM

With these options selected, click the **Run** button. When the program finishes click **OK** and go to the **Migration Results** tab. There you will find a table of WUA values that reflect the amount of habitat area that was available to an organism that could migrate the specified distance when the flow changed over the ranges shown on the table axes. The **Graph** button provides 2- and 3-dimensional plots of the results. The entries in the **Migrations Results** table represent the habitat area derived for the species/life stage shown in the **Curve – species/life stage** box and the distance shown in the **Migration Distance** box. You may scroll through the possible entries for those boxes to view the results for all life stages and migration distances set in the options. For example, to view the table or graph for Brown Trout adults, scroll the species box to Brown Trout adults and the migration distance box to 15 ft. (We only specified a single entry of 15 feet for them earlier, so you must select that distance to fill the table with the Brown Trout Adult results.)

The ZOUTn file contains the selected output items and can be viewed using Wordpad. The Zout file contains computational detail summary tables for each cross section, a summary table output listing for the selected life stages for each set of paired flows for each cross section in sequence, and, following the final flow pair computational summary table for the current life stage, HABTAM provides reach level summary tables.

Examine the **Migration Results** tab summary table listing shown in Table L11-2 that contains the pair-wise flow comparisons for each life stage. It should be apparent from these results that the order of the paired flows can make a difference on program results. This should make sense since the initial flow is being compared to the ending flow and the actual difference is a function of not only the user-specified migration distance but also the combined suitability of available habitat cells at the ending discharge. Note that for both the adult and spawning life stages the "habitat used" areas are identical for these two sets of flow comparisons. For spawning, a migration distance of 0.0 should, by definition, produce the same result. In the case of adults, it is apparent that a migration distance of 15 feet is large enough to allow access to most, if not all, of the cross sections' computational cells between the changes in discharge. Now select the spawning life stage and 0 migration distance. What kind of changes do you see in comparison to the adult migration habitat?

Table L11-2. HABTAM weighted usable area results for Brown Trout adults for the study site with 15 feet search distance.

Windows		DOS	Difference	% difference
Cell bed elevation	91.65	91.65	0	0.00
Water surface elevation	92.456	92.47	0.014	0.02
Depth	0.806	0.82	0.014	1.71
Depth Suitability Index	0.0708	0.096	0.025	26.25
Combined Suitability Index	0.0644	0.087	0.023	26.25
Weighted Usable Area	8.698	11.79	3.096	26.25

Acknowledgements **i**
PREFACE **ii**
A Brief History of PHABSIM

Two- and 3-dimensional plots of the migration-based weighted usable area can be viewed by clicking the **Graph** button. The 3-D plot can be rotated for better viewing by holding down both mouse buttons and moving the mouse. It takes some trial-and-error experimentation to get familiar with the movement mechanism. Try it, and see.

The ZHAQF output from HABTAM contains the reach level summary results of WUA and can be accessed at the **ZHAQF Results** tab.

Step 4. Influence of Migration Distance on HABTAM Model Predictions

To illustrate the sensitivity of the HABTAM model to proper choices of migration distance, this step of the laboratory will alter the migration distance used for fry, juvenile, and adult life stages and compare the resulting computations at the 139 cfs and 15 cfs flow combinations. Change the migration distance for fry and adults to 3 feet and 25 feet respectively. The results of this change for Brown Trout adults are shown in Table L11-3.

What effect did changing the migration distances have on fry and adult life stages compared to the previous habitat simulations?

It should be apparent that sensitivity in model predictions occurs over a range of migration distance between 0.0 and some upper threshold that is dependent on the shape of the HSC criteria and, therefore, different for different species and life stages. The selection of an appropriate migration distance is a matter of professional judgment. Remember, this migration distance only applies to computational cells at a given cross section.

Table L11-3. HABTAM weighted usable area results for Brown Trout adults for the study site with 25 feet

Windows		DOS	Difference	% difference
Cell bed elevation	91.65	91.65	0	0.00
Water surface elevation	92.456	92.47	0.014	0.02
Depth	0.806	0.82	0.014	1.71
Depth Suitability Index	0.0708	0.096	0.025	26.25
Combined Suitability Index	0.0644	0.087	0.023	26.25
Weighted Usable Area	8.698	11.79	3.096	26.25

Acknowledgements **i**
PREFACE **ii**
A Brief History of PHABSIM

search distance.

Laboratory 12. Habitat Modeling - HABEF

Objective

The objective of this laboratory is to illustrate use of the HABEF program for simulation of effective habitat for each of six options available to the user. The HABEF program can be used to examine differences between available habitat for a given species and life stage at different flows or comparisons between different species and life stages at a specific flow.

Programs Used: HABTAE, HABEF

Project Used: Lab12.phb

Introduction

The HABEF program can be used to examine a number of relationships between habitat conditions at two stream flows and/or for two life stages at a specific discharge. In this laboratory, each of the six computational options available within the HABEF program will be examined.

In the HABEF program different hydraulic property arrangements can be used depending on the option selected. The HABEF program will compute two different indices of habitat. The first is WUA, which is derived from the combined suitability factor computed by the initial habitat simulation program. (You must have run HABTAE or HABTAM prior to using HABEF.) The second index, UA (usable area) is derived from the sum of computational cell areas where the combined suitability in the computational cell is >0.001. Usable areas can be considered to be a measure of the area where all of the HSC variables have suitability that is marginally greater than zero. Can you explain why this may not be the same as the wetted surface area of the stream?

The six steps in this laboratory guide the student through these basic options of the HABEF program:

- Union of Life Stage 1 with Life Stage 2
- Stream Flow Variation Analysis (Minimum WUA)
- Competition Analysis
- Stream Flow Variation Analysis (Maximum WUA)
- Effective Spawning Analysis
- Stranding Index Analysis

Step 1. Ensure Needed Hydraulic And Habitat Model Results Have Been Run

Habitat analysis results from HABTAE or HABTAM are required prior to executing HABEF. Open the Lab12.phb project in the Lab12 directory and note that **WUA Results** exist for Rainbow Trout adult. This indicates one or the other of these programs has produced results earlier. If you are uncertain which program was used, check the **Habitat Results** table. In this case, the **Habitat Results** table in the HABTAM window is filled with [NULL] entries while the table in the HABTAE window has numerical values. Hence, HABTAE was run.

Step 2. Set Appropriate Simulation Options and Run HABTAE Model

This step is provided as an example of the actions you would perform when the initial modeling steps have not yet been performed. For this laboratory, you may go directly to Step 3 as the HABTAE model has been run and the needed result files are already in the Lab12 folder.

Move to the HABTAE program window by clicking /**Models/HABTAE**. Go to the **Life Stages** tab and click as many life stages on or off until only the Brown Trout adult and Rainbow Trout adult (or other desired) life stages remain. Click the **Run** button to run the model. You will now have habitat results for adult Brown and Rainbow trout.

At this point, two files have been created in the Lab12 directory containing computational cell details at each cross section for each simulated discharge for each of the species and life stages used in the simulation. Those files have the naming convention: Projectname.HSCnr(e or m). The habitat suitability criteria number (HSCnr) is used to the identify species and life stage contained in each particular results file. The suffix „e' or „m' indicates whether the files were produced by HABTAE or HABTAM, respectively. The HABEF program uses these files for cell-by-cell computations. In this case, they should be named Lab12.11302e and Lab12.21115e, respectively, for Brown and Rainbow trout adult results produced by HABTAE.

Step 3. HABEF Simulations for Union (Option 1) and Competition (Option 3) Analyses

The HABEF program will now be used to simulate the union of two life stages and competition between two species. In the union analysis for two species and life stages (Option 1) HABEF computes total weighted usable area represented by combined habitat of the two species or life stages. The total habitat quantity computed at a specific discharge will always be greater than or equal to the highest amount for a single species or life stage but always less than or equal to the sum of the two habitat totals. Why is this? In answering this question, consider adding the largest WUA value regardless of species in each cell to the HABEF union sum. If species/life stage "a" has the dominant WUA in all cells and there are no cells where the species/life stage "b" alone has WUA greater than zero, then the WUA reported by HABEF will be equal to the WUA for species/life stage "a". If both species/life stages dominate in some cells, the sum will be greater than the sum for species/life stage "a" alone. Will this general statement still be true for two species/life stages that use very different habitats with little or no overlap?

The analysis of competition (Option 3) computes the amount of habitat for a particular species or life stage for two conditions. First, it calculates habitat for species/life stage "a" in cells where habitat for the species/life stage "b" is zero. This is combined with the amount of habitat occurring in computational cells where combined suitability is greater than 0.0 for both species but where species "a" has a higher combined suitability value than species "b". Thus, the competition option describes the total WUA for cells where a species dominates.

Select **/Models/HABEF** and enter a descriptive name for the comparison being run in the **Job Title** text entry box. This name will be used to label all output tables (both text files and on-screen). In the species/life stage 1 text entry box, click the down arrow button to the right and select Brown Trout adult. In the second text entry box, click the down arrow and select Rainbow Trout adult, then click the **Union of life stage 1 with life stage 2** radio button. Note that this assigns Brown Trout adults to species/life stage 1 and Rainbow Trout adults to species/life stage 2. Finally, click the **Run** button and view the **Results** tab. You may also produce a named HABEF results file using the **Text File** button in the **Results** tab and view it using Wordpad. PHABSIM for Windows does not retain subsequent sets of results in the database, so it is convenient to create result text files for

each run to allow later comparison when numerous HABEF options are generated in the course of an analysis. It is also wise to change the job title for each run to avoid later confusion among options where the numerical results are similar.

The table in the **Results** tab contains a summary for each life stage at each discharge of their respective UA and WUA values and the WUA associated with the union of the two life stages. Note that the WUA associated with the union of two life stages is less than the total WUA if the two life stages had been simply added together at a given flow. A comparison of the Total Area column (i.e., total stream surface area) and the respective UA columns for each life stage shows that at discharges below 139 cfs all computational cells have a combined suitability greater than 0.001. Why is this?

Table L12-1 contains an example of the union analysis output table. Click the **Graph** button at the bottom of the HABEF **Results** tab to view graphical results.

Windows		DOS	Difference	% difference
Cell bed elevation	91.65	91.65	0	0.00
Water surface elevation	92.456	92.47	0.014	0.02
Depth	0.806	0.82	0.014	1.71
Depth Suitability Index	0.0708	0.096	0.025	26.25
Combined Suitability Index	0.0644	0.087	0.023	26.25
Weighted Usable Area	8.698	11.79	3.096	26.25
Acknowledgements				**i**
PREFACE				**ii**
A Brief History of PHABSIM				
Use of this Document				

Table L12-1. HABEF output for union analysis.

You can see that the total amount of WUA in the union of two species is greater than that for either individual species WUA and less than their sum would be. You may wish to view the graph of results and print it for later reference.

Next, the HABEF program will be run again with the same input data but will be used to compute effective habitat based on selection of the competition analysis option.

Go to the HABEF **Options** tab and select the **Competition analysis** radio button. Make sure that the first input file is ZHCF1 and the second file is ZHCF2, as in the previous example. Change the **Job Title** to indicate the next results are for the competition analysis. Click the **Run** button and move to the **Results** tab.

Table L12-2 shows output from the competition analysis. Note that the HABEF output is different when selecting competition analysis versus union analysis (Table L12-1). The program shows summary results at each simulation discharge in terms of total stream area, UA and WUA where each species has the only suitable habitat. Summary output is also provided for amount of usable area for both species and area associated with habitat conditions where each species is dominant (i.e., combined suitability for species “1” is greater than the combined suitability for species “2”). The program also computes the amount of habitat area with equal worth for both species as noted earlier.

Table L12-2. HABEF output for competition analysis.

Windows		DOS	Difference	% difference
Cell bed elevation	91.65	91.65	0	0.00
Water surface elevation	92.456	92.47	0.014	0.02
Depth	0.806	0.82	0.014	1.71
Depth Suitability Index	0.0708	0.096	0.025	26.25
Combined Suitability Index	0.0644	0.087	0.023	26.25
Weighted Usable Area	8.698	11.79	3.096	26.25

Acknowledgements **i**
PREFACE **ii**
A Brief History of PHABSIM
Use of this Document
Changes Between PHABSIM Version 2 and PHABSIM for Windows

The competition results for 15.0 and 30.1 cfs show Brown Trout adults have more suitable habitat at the low flow range. However, from 75.2 cfs and up, Rainbows have significantly more habitat than Browns.

The dominance of Rainbow Trout adult habitat at higher discharges is related to their tolerance for lower depth as reflected in the depth HSC reaching 1.0 at a lower depth for Rainbows than for Browns. Go back and check the HSC to confirm this. For the 15 and 30.1 cfs discharges, Rainbow Trout adults have between 50% and 70% as much habitat as Brown Trout adults. However, from 75.2 cfs and up, the Rainbow habitat is three or more times as abundant as Brown habitat. Assuming the HSC have been verified to accurately describe behavior of the two species, from these results can you conclude that higher flows favor Rainbow Trout adults? How would the results be affected if the depth HSC for each species had a ±25% error and the full range of the uncertainty was considered in the analysis?

Step 4. Streamflow Variation Minimum and Maximum Analysis

Streamflow variation analysis for minimum and maximum WUA in HABEF can be used to explore which species and life stage has either the maximum or minimum WUA at each discharge on a computational cell-by-cell basis. When HABEF minimum variation is selected, the composite suitability factor used to compute WUA for a computational cell is the minimum composite suitability value in that computational cell in each of the two species/life stages being compared. The maximum streamflow variation HABEF option is identical except that the maximum composite suitability from the computational cell within the two ZHCF files is used to compute WUA.

Make sure that the first species/life stage you wish to consider is entered in the first dialog box and the second species/life stage is in the second box. Select the **Streamflow Variation Analysis (minimum WUA)** radio button, change the job title to indicate minimum WUA analysis, and click the **Run** button to execute the HABEF program. Move to the Results tab to view the output. You may wish to save the results for later comparison, click the **Save** button to do so.

For comparison, perform a maximum streamflow variation analysis. Enter a job title indicating maximum WUA, click the **Streamflow Variation Analysis (maximum WUA)** radio button, and click **Run**. Again, click the **Results** tab to review results.

A comparison of these streamflow variation results with the previous minimum analysis shows a marked difference in the relationship between minimum or maximum WUA and discharge. The minimum WUA analysis declines as discharge increases, while maximum WUA increases then decreases with flow.

When these results have been examined, return to the HABEF window.

Step 5. Effective Spawning Analysis Using HABEF

HABEF effective spawning analysis allows an investigator to examine the effects of flow alterations on spawning and incubation life stages. The program computes effective spawning habitat based on the concept that available habitat at an initial (spawning) discharge must also be available at the second (incubation) discharge. In this analysis, the HABEF program computes combined suitability in a computational cell at the starting and ending discharges (i.e., for each set of paired discharges in respective HABTAE or HABTAM results). If composite suitability at the second discharge is greater than 0.0, then the composite suitability factor for that computational cell at the first or starting discharge remains unchanged and WUA for that computational cell is added to the total for the cross section and, hence, the reach. Simply put, if the spawning area maintains minimal incubation conditions (stays wet with needed velocity) then the spawning area is accumulated in the total. However, if the composite suitability factor at the second discharge is 0.0, then suitability at the first discharge is set to 0.0 and that amount of available habitat is 'removed' from the total at the cross section. This is similar to using the minimum streamflow analysis option but differs in that WUA at the first flow is dependent on the analysis of the second flow.

To make this example of effective spawning more realistic, new results using Bull Trout spawning HSC will be generated with the HABTAE program.

Return **to /Models/HABTAE**, move to the **Life Stages** tab and click all of the Brown and Rainbow Trout life stages to turn them off. Now click the four Bull Trout life stages to turn them on. Click **Run** and return to the HABEF program when HABTAE is finished.

Change the job title to indicate you are performing an effective spawning analysis and select Bull Trout spawning in both species/life stage dialog boxes. Then click **Run** and move to the **Results** tab. Click the **Graph** button to view the results. Which combination of discharges produces the greatest effective spawning habitat values? Which produce the lowest values?

The plot also shows that if the starting flow is 1250.0 cfs and flows are reduced, the amount of effective spawning habitat is substantially reduced at 250.0 cfs and non-existent below 75.2 cfs. As the starting and ending flow difference is reduced, the effective spawning is less affected as would be expected (Why?). It should also be apparent that starting at a lower flow such as 75.2 and ending at a higher flow such as 139.0 cfs has less impact on effective spawning (Why?). If you have difficulty reading the 3-dimensional plot, return to the results table and examine it in drawing your conclusion.

Step 6. Stranding Index Analysis Using HABEF

Stranding analysis with the HABEF program employs essentially the same computational logic as described above for effective spawning analysis. The composite suitability of a computational cell at the second flow must be greater than 0.0 for composite suitability of the computational cell at the first flow to contribute to effective WUA. Thus, when evaluating stranding, one should only compare flow pairs that show a decrease in discharge. For this analysis, the same species and life stage is selected in both dialog boxes on the /HABEF/Options tab. Typically, the selected life stage would be one that has only a small capacity to move with changes in discharge, though the analysis can be conducted for any life stage.

While a stranding analysis will not be run in the laboratory due to time considerations, the following general approach can be used for all life stages. To ensure that the analysis is focusing on available depth alone, you can create a new set of suitability curves for stranding. To do so, make copies of the HSC in the **/Edit/Suitability Curves** window and edit suitability curve coordinates for velocity and channel index, setting all suitability values are 1.0. There is no need to change the number of coordinate pairs. Change depth suitability curve coordinates for depth such that depth suitability is 0.0 below some threshold (e.g., 0.5 feet) and then change the remaining depth SI values to 1.0.

Save these changes and run the new HSC in the HABTAE program. Then move to the HABEF program and run the stranding index analysis using the same HSC in both dialog boxes. The results will show the chance of stranding when depth for that species/life stage drops below the selected threshold value.

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Exhibit 14

Riverine Fish Flow Investigations

Federal Aid Project F-289-R6

Richard Anderson
Principal Investigator

and

Greg Stewart



Russell George, Director

Federal Aid in Fish and Wildlife Restoration

Job Progress Report

Colorado Division of Wildlife

Fish Research Section

Fort Collins, Colorado

June 2003

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Bill Owens, Governor

COLORADO DEPARTMENT OF NATURAL RESOURCES

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COLORADO DIVISION OF WILDLIFE

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State: Colorado

Project No. 7400 ENDG 0700 Name: Aquatic Nongame Research

Study No. SE-3-22 Title: Riverine Fish Flow Investigations

Period Covered: July 1, 1997 - June 30, 2002

Study Objective: To determine relationships between flow and habitat availability for warm-water riverine fish communities of Colorado.

Prepared by:_____
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Approved by:_____
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Date:_____

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TABLE OF CONTENTS

APPROVAL PAGE ii

LIST OF TABLES v

LIST OF FIGURES vii

LIST OF APPENDIX TABLES ix

LIST OF APPENDIX FIGURES x

INTRODUCTION 1

STUDY AREA 4

METHODS 12

- Fish Sampling 12
- Channel Topography 14
- Hydraulic Simulation 19
- Habitat Quantification 20
- Development of Meso-Habitat Suitability 20
- Determination of Habitat Availability 22

RESULTS 23

- Fishery Quantification 23
  - Fish Over 15-cm in Length 23
  - Fish Less Than 15-cm in Length 28
  - Size Structure for Native Fish 30
  - Density and Biomass Estimation 34
- Habitat Quantification 39
  - General Site Description 39
  - Habitat Composition and Diversity 40
  - Habitat Suitability 44
  - Habitat Availability Versus Flows 47

DISCUSSION 62

- Habitat Modeling, Flow Needs for Native Sucker 62
- Habitat Composition and Diversity 65
- Field Observation, Flow Needs of Native Fish 66
- Non-Native Fish Versus Flows 68
- Flow for Endangered Fish 69

FLOW RECOMMENDATIONS 70
Colorado River 70
Yampa River 71
Dolores River 72

SUMMARY 73

CONCLUSIONS 74

RECOMMENDATIONS FOR FUTURE RESEARCH 75

ACKNOWLEDGEMENTS 76

REFERENCES 77

APPENDIX TABLES AND FIGURES 82

LIST OF TABLES

1. Recommended mean monthly flows [Osmundson et al (1995)] for the 15-Mile Reach in cubic ft/sec. 10

2. Mean monthly and monthly minimum flows recorded at the Palisade gage, 15-Mile Reach, Colorado River for summer months during the three years of the study. 11

3. Dates for electro-fishing and flows on the day of the sample. 15

4. Depth and velocity criteria used to define meso-habitat types. 21

5. Species compostion for fish over 15 cm from all study sites. 25

6. Species composition from seine hauls at the Sevens and Duffy sites in 1999 and 2001, Yampa River. 29

7 Species composition for fish greater and less than 15 cm at the Big Gypsum site on the Dolores River, July 2001. 30

8. Mean lengths of bluehead sucker captured during the study period (1998 to 2001) in the Yampa, Colorado and Dolores Rivers. 31

9. Mean lengths of flannelmouth sucker captured during the study period (1998 to 2001) in the Yampa, Colorado and Dolores Rivers 33

10. Mean lengths of roundtail chub captured druing the study period (1998 to 2001) in the Yampa, Colorado and Dolores Rivers. 33

11. Density and biomass estimates in **fish per kilometer** and **kilograms per kilometer** for each study site. 36

12. Density and biomass estimates in **fish per hectare** and **kilograms per hectare** for each study site. 37

13. Physical attributes of each study site (mean velocity, length, mean width, surface area at modeled flows) 41

14. Meso habitat availability per kilometer at a reference flow typical of the base flow period. 42

15. Correlation between riffle meso habitat and total fish biomass.....43

16. Correlation between pool habitat and biomass for carp, white sucker and catfish 43

17. Correlation between deep riffle habitat and bluehead sucker biomass..... 44

18. The 1, 10, 20, 40, 60, 100 and 177 low flow day for the Maybell, Lily Park, Palisade and Bed Rock gages for years with fishery biomass data. 54

LIST OF FIGURES

1. Location of the three study sites for the Yampa River, Lily Park, Sevens and Duffy. 5

2. Peak flow during the study period recorded at the Maybell gage with exceedence frequency for the period of record....7

3. Minimum flow during the study period recorded at the Maybell gage with exceedence frequency for the period of record....7

4. Location of the two study sites in the 15-Mile Reach, Colorado River, Corn Lake and Clifton. 9

5. Location of the Big Gypsum (Big Gypsum Valley) study site on the Dolores River. 12

6. Example of digitized polygons for electro-fishing areas (photo of Clifton site). 22

7. Bluehead Sucker depth and velocity criteria used to model bluehead habitat availability. 45

8 Flannelmouth sucker depth and velocity criteria used to model flannelmouth habitat availability. 46

9 Bluehead sucker habitat availability at Corn Lake, Colorado River. 48

10. Bluehead sucker habitat availability at Clifton, Colorado River. 48

11. Bluehead sucker habitat availability at Lily Park, Yampa River. 49

12. Bluehead sucker habitat availability at Sevens, Yampa River. 50

13. Bluehead sucker habitat availability at Duffy, Yampa River 50

14. Bluehead sucker habitat availability at Big Gypsum, Dolores River. 51

15. Projected biomass (kg/ha) of bluehead sucker based on habitat availability over a range of simulated flows. 53

16. Projected versus observed bluehead biomass for five study sites....55

17 Flannelmouth sucker habitat availability at Corn Lake, Colorado River 56

18. Flannelmouth sucker habitat availability at Clifton, Colorado River 57

19 Flannelmouth sucker habitat availability at Lily Park, Yampa River.....57

20. Flannelmouth sucker habitat availability at Sevens, Yampa River 58

21. Flannelmouth sucker habitat availability at Duffy, Yampa River 59

22. Flannelmouth sucker habitat availability at Big Gypsum, Dolores River 59

23. Projected flannelmouth biomass as a function of flow for all study sites 60

24. Projected versus observed flannelmouth biomass for five study sites.....61

LIST OF APPENDIX TABLES

1. Density and biomass estimates for all species in **fish per kilometer** in **kilograms per kilometer** for each study site 83

2. Density and biomass estimates for all species in **fish per hectare** and **kilograms per hectare** for each study site 85

3. Corn Lake polygon area, polygon mean depth, polygon mean velocity and polygon density and biomass for bluehead and flannelmouth sucker 87

4. Clifton polygon area, polygon mean depth, polygon mean velocity and polygon density and biomass for bluehead and flannelmouth sucker 88

5. Lily Park polygon area, polygon mean depth, polygon mean velocity and polygon density and biomass for bluehead and flannelmouth sucker 89

6. Sevens polygon area, polygon mean depth, polygon mean velocity and polygon density and biomass for bluehead and flannelmouth sucker 90

7. Duffy polygon area, polygon mean depth, polygon mean velocity and polygon density and biomass for bluehead and flannelmouth sucker 91

LIST OF APPENDIX FIGURES

1. Longitudinal profile for Corn Lake site, Colorado River. 92

2. Longitudinal profile for Clifton site, Colorado River. 92

3. Longitudinal profile for Lily Park site, Yampa River....93

4. Longitudinal profile for Sevens site, Yampa River 93

5. Longitudinal profile for Duffy site, Yampa River....94

6. Longitudinal profile for Big Gypsum site, Dolores River....94

7. Corn Lake study site meso-habitat distribution at 1000 cfs, Colorado River....95

8. Clifton study site meso-habitat distribution at 1000 cfs, Colorado River....95

9. Lily Park study site meso-habitat distribution at 200 cfs, Yampa River 96

10. Sevens study site meso-habitat distribution at 200 cfs, Yampa River....96

11a. Meso-habitat availability for modeled flows at Corn Lake 97

11b. Shannon Diversity, Interspersion and Juxtaposition for modeled flows at Corn Lake....97

11c. Meso-habitat availability for modeled flows at Clifton....97

11d. Shannon Diversity, Interspersion and Juxtaposition for modeled flows at Clifton 97

12a. Meso-habitat availability for modeled flows at Lily Park 98

12b. Shannon Diversity, Interspersion and Juxtaposition for modeled flows at Lily Park....98

12c. Meso-habitat availability for modeled flows at Sevens 98

12d. Shannon Diversity, Interspersion and Juxtaposition for modeled flows at Sevens 98

13a. Meso-habitat availability for modeled flows at Duffy....99

13b. Shannon Diversity, Interspersion and Juxtaposition for modeled flows at Sevens 99

13c. Meso-habitat availability for modeled flows at Duffy.....99

13d. Shannon Diversity, Interspersion and Juxtaposition for modeled flows at Duffy 99

14. Sigma plot for bluehead (left) and flannelmouth (right) sucker, showing biomass at mean polygon depth (x-axis) and velocity (y-axis). 100

INTRODUCTION

Conservation and management of native species is now a major consideration within the Colorado Division of Wildlife (CDOW). This is especially true for species that are listed as federally threaten or endangered. Four species of fish in the Colorado River basin are listed as endangered by the U.S. Fish and Wildlife Service. The Upper Colorado River Recovery Program was established to identify and resolve problems, so these fish can eventually be down-listed (Wydoski and Hamill 1991). The state of Colorado and the Recovery Program share the same goal of recovering the fish, but their agencies may not share common strategies. A unifying approach for native fish management objectives is to agree on the scientific validity of data involved in identification of limiting factors.

In Colorado State government instream flow protection for fish via water rights has been a common practice in high elevation headwaters (Espregren 1998). Water rights adjudication, however, has become a rigorous legal process for high profile warm water rivers like the Colorado and Yampa Rivers where water is already highly over-appropriated. In response, U. S. Fish and Wildlife Service (USFWS) conducted studies for instream flow recommendations in regard to recovery of endangered fish species in the 15-Mile Reach of the Colorado River (Osmundson et al. 1995) and the Yampa River (Modde and Smith 1995). Modde et al. (1999) was a field-based study on the Yampa River, also sponsored by the Recovery Program. Even though the intent of these flow studies was the same, to determine stream flow requirements for endangered fish, recommendations were based on vastly different methodologies.

The goal of this project was to develop biologically based instream flow recommendations for the Colorado in the 15-Mile Reach and Yampa rivers based on habitat and flow requirements for non-endangered native fish. The identification and validation of flow needs for non-endangered native fish may assist in preventing listing these species in the future. This data may also be of value to the Endangered Fish Recovery Program by providing ancillary information concerning the overall fish community and descriptions of physical habitat availability.

Typically CDOW uses the R2Cross method (Nehring 1979) or PHABSIM (Bovee 1982) for making instream flow recommendations for protecting cold water habitats. However these two methods were not considered appropriate for the warm water sections of the Colorado and Yampa Rivers given the elevated levels of biological, geomorphic and social complexities for these rivers.

This study employed a Meso-Habitat approach that is similar in concept to PHABSIM. PHABSIM is widely used in North America to quantify impacts of altered flow regimes to habitat. PHABSIM consists of two modeling components. The hydraulic component is a series of one-dimensional cross-sections that are linked to produce a series of rectangular cells that form a grid. Mean depth and velocity conditions are calculated for each cell for a given flow. The biological component is a set of suitability index curves for depth and velocity criteria that are used to rate micro-habitat suitability for each cell in the cross-sectional grid. Habitat availability is measured by an

index called weighted useable area (WUA), the summation of cell areas weighted by its suitability index. When plotted versus discharge WUA typically peaks at a single flow that is considered the flow that maximizes habitat. PHABSIM has been criticized because of assumptions implicit with micro-habitat suitability curves, assumptions of positive relationships between habitat availability and fish abundance, and the tendency of users to recommend flows at the peak of the WUA-discharge relation regardless of natural flow occurrence. These assumptions have been obstacles for using PHABISM to model impacts of reduced flows on large warm water rivers of the west slope (Rose and Hahn 1989).

The Meso-Habitat method of this study is also an integration of hydraulic and biologic analyses. We used a 2-D flow model to simulate depths and velocity. Fish habitat suitability was derived from density estimates made at each site. Two-dimensional (2-D) flow models have been found to have high potential for application in instream flow studies (Leclerc *et al*., 1995; Bovee, 1996; Kondolf et al. 2000). Two-dimensional models offer a significant improvement over one-dimensional (1-D) modeling by increasing spatial resolution. This allows for a highly accurate quantification of the physical habitat for each flow of interest. 2-D models are not dependent on micro-habitat suitability curves for predicting habitat availability. Meso-habitat scale precision is more efficient for sampling biological data. Criteria can be established for individual species and also by guilds (sympatric species) (Parasiewicz 2001). A relationship between habitat availability to fish abundance assumes that fish distribute themselves in the river primarily as a function of habitat. A large part of this study was to develop meso-habitat criteria for two native suckers. This was accomplished by examining the relationship between their abundance and meso-habitat availability. The output of the meso-habitat methodology was the relationship among meso-habitat availability and the range of modeled flows.

Species Used for the Biological Analysis

The primary species used in the instream flow analysis were the bluehead sucker (*Catostomus discobolus*), flannelmouth sucker (*Catostomus latipinnis*) and roundtail chub (*Gila robusta*). These species, quite common in the Colorado River, comprised about 80 percent of fish sampled between Rifle and Palisade. Anderson (1977) speculated that fishery abundance was likely at carrying capacity set by the physical habitat. Samples made by the Recovery Program (ISMP) in the Colorado River downstream of Grand Junction to Loma found native fish were about 90% of the catch (Elmbald 2003). Osmundson (1999) reported high catch rates of native suckers in the Colorado River, with the highest catch rate in the 15-Mile Reach. The thriving populations of these three native species suggest that habitat, base flow alternations or non-native introductions have not negatively impacted their life history requirements in the river. In fact, studies suggest the Colorado River is an excellent location to study dynamics between these three native fish and physical habitat.

Conversely, these three native species have not maintained a historically abundant population or relative composition in the Yampa River. Miller (1982), Carlson (1979), Wick (1981 and 1986) and Prewitt (1977) reported that native suckers had become fairly rare in the Yampa River upstream of Maybell at River Mile (RM) 74. The most common species is the introduced white sucker (*Catostomus commersoni*). Elmblad (2003) reported native fish were only 24% and 35% of the catch during Interagency Standardized Monitoring Program (ISMP) surveys upstream of Maybell (River Mile 75). The Yampa River has experienced reduced base flows and has an established population of introduced nonnative predators, which obscure determination of the relationship between habitat and native fish density.

The bluehead sucker is a large fish (up to 45 cm in length) that remains abundant in most west slope rivers. Not a lot of data is available from life-history studies of the bluehead sucker. However, biologists who sample in the Colorado drainage strongly associate this species with a single meso-habitat. This makes the bluehead sucker an excellent species for flow and habitat evaluation studies. Adult fish are typically found in moderate to deep riffle habitat, which is a combination of fast flowing water over cobble-rubble substrate (Woodling 1985; Sublette 1990). The bluehead feeds on invertebrates, which have their highest densities in riffles. Because the bluehead is an obligate riffle species, it's meso-habitat suitability can be defined by the depths and velocities of the riffle habitats the sucker occupies.

The flannelmouth sucker is another large bodied fish that grows up to 60 cm long. The flannelmouth is abundant in most west slope rivers where hybridization with white sucker has not occurred. The flannelmouth is another species whose habitat requirements can be defined by depth and velocity combinations. Adults of generally occupy deeper run habitats (Woodling 1985). Runs are typically defined as areas with low to moderately fast currents. In the Colorado and Yampa Rivers, run habitat is generally more ubiquitous. Likewise, the flannelmouth tends to be more common in run dominated rivers. The flannelmouth's habitat overlaps with the bluehead's in the glide section of the river. Glides have similar depths and velocities as runs, but glides are located between the tail of the pool and the head of a riffle where bed elevation is rising.

The roundtail chub is a cyprinid that achieves a large body size (up to 45 cm in length) and is still fairly common in parts of its range in Colorado. The roundtail chub is a predator and has a much different life history and behavior than the two native suckers. These fish generally seek cover during the day and patrol or forage during the evening. These fish do not rely on one particular meso-habitat type; therefore, their habitat use can not be modeled by a simple range of depth and velocity criteria. This is a true multi-meso-habitat species. Factors that control their density may be more a function of forage availability than of meso-habitat availability.

The speckled dace (*Rhinichthys osculus*) is a small-bodied cyprinid that may attain a length of 12-cm (Woodling 1985). Speckled dace are generally very abundant and like the bluehead sucker are a riffle-obligate species. Since dace are small-bodied fish they can occupy shallow riffles, which means during periods of reduced flows

bluehead sucker habitat would become unsuitable long before dace habitat loss would become problematic. Therefore, meso-habitat availability for speckled dace and another small-bodied native fish, the mottled sculpin (*Cottus bairdi*) were not modeled in this study. It was necessary, however, to include these species in an ancillary analysis because the dace and sculpin populations have been noticeably impacted on the Yampa River during low-flow scenarios.

Study Objectives:

1). Quantify fish habitat on warm water sections of the Yampa, Colorado and Dolores rivers using 2-D flow models

2). Determine community structure, density and biomass for fish assemblages for the three study rivers

3). Determine relationships between habitat availability and fish abundance for the native species bluehead sucker, flannelmouth sucker and roundtail chub

4). Develop biologically based instream flow recommendations for the Yampa River and Colorado Rivers in the 15-mile reach

5) Provide validation for meso-habitat suitability values used in the 2-D model and for predicting habitat as a function of flow

STUDY AREA

Yampa River

There are three study areas on the Yampa River. The two sites established in 1998 are called the Sevens and Duffy stations. A third site at Lily Park was added in 2000. The Sevens station is located at River Mile (RM) 63 and is 1.8 mile in length. Duffy is at River Miler (RM) 109 and is 1.3 miles in length (Figure 1). Sevens and Duffy were electro-fished in 1998, 1999, 2000 and 2001. The habitat was mapped in 1999. The Lily Park site is located just below Cross Mountain Canyon and just above the mouth of the Little Snake River (Figure 1). The Lily Park site extends 19 miles from RM 52.7 to RM 54.5. The bridge on County Road (CR) 25 is located at RM 52.5.

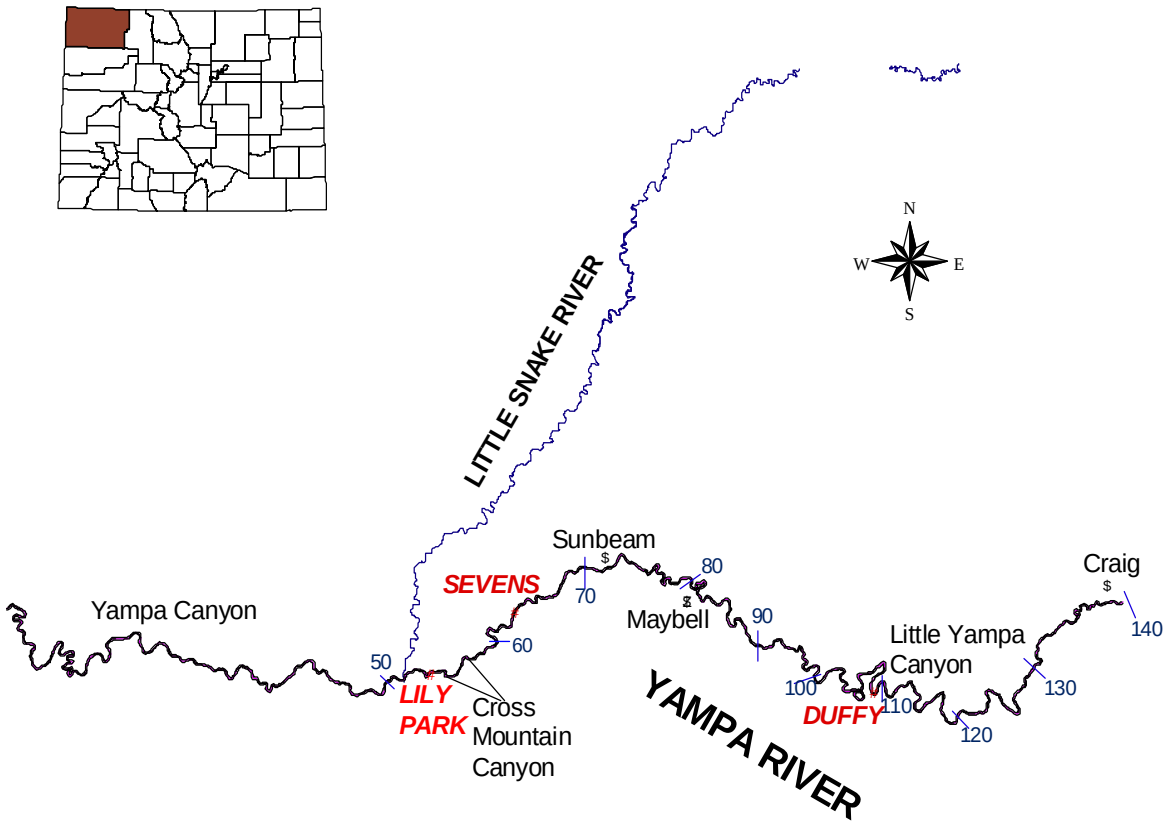


Figure 1. Location of the three study sites for the Yampa River, Lily Park, Sevens and Duffy.

The Cross Mountain Ranch is the landowner for most of the river at Sevens and Lily Park. The BLM is the primary landowner at Duffy. In general, each site on the Yampa River has distinctly different fish and habitat characteristics. Duffy is located in Little Yampa Canyon and has some deep pools with large boulders that provide cover. Duffy is low gradient. The primary habitat during the base-flow period consists of shallow pools. Sevens is also low gradient with gravel-sand substrate. At typical base flows, shallow, low-velocity pools and runs are the most common habitats. The Lily Park site is higher gradient with a cobble-boulder substrate. Faster flowing habitats (runs and riffles) dominate in Lily Park. The Lily Park site was added because of its better native fish composition than at Duffy.

Peak flows recorded at the Maybell gage were fairly similar for the years 1998, 1999 and 2000, at 10,040 cfs, 9,980 cfs and 9,830 cfs respectively. Peak flows in these three years are near the magnitude of the median peak flow of 9,980 cfs for the 86 year period of record (Figure 2). Peak flow in 2001 was 7,650 cfs, which has been exceeded in 77% of the years during the period of record. The peak flow in 1997 was 16,400, and has been exceeded in only 5% of the period of record (Figure 2). Andrews (1982) calculated bankfull flow for the Yampa from the Maybell gage to be 9,.000 cfs.

Determining impacts of low flows are one of the primary objectives of this study. Modde et al. (1999) used a cross section methodology (modified R2Cross) to identify habitat availability at low flows for endangered fish on the Yampa River. The result was a recommendation that 93 cfs be used as a reference flow that signals the beginning of severely degraded conditions. The 93-cfs reference flow was specifically not meant to be an instream flow recommendation since it was believed the endangered pikeminnow could likely survive severely degraded conditions for a short term.

Annual minimum flows recorded at the Maybell gage for 1997, 1998, 1999, 2000 and 2001 were 320 cfs, 115 cfs, 166 cfs, 30 cfs and 50 cfs respectively. The 86-year median minimum flow is 126 cfs (Figure 3). The 2000 minimum flow of 30 cfs was exceeded in 93% of the years, and the 2001 minimum flow of 50 cfs was exceeded in 83% of the years for the period of record (Figure 3). Flow did not drop below the 93-cfs reference flow in 1998 and 1999, but flow was less than 93 cfs for 34 days in 2000 and 17 days in 2001.

Two consecutive years of low flow may have more significant and lasting impacts on the aquatic community (carrying capacity) than a single low flow year. Stream flow was less than the 93-cfs reference flow for 0 days in 1997, 2 days in 1996, 0 days in 1995. In 1994, the minimum flow was 8 cfs and flow was less than 93-cfs for 73 days that year. Presumably habitat was severely restricted in 1994 and there were impacts to the fish community. The four-year interval between 1994 and the start of sampling in 1998 may have been enough time to allow the fish community to adjust back to normal flows. There were two days of flow below the 93 cfs in 1996. As of 2000, flow had not been below the 93 cfs for the previous three years. However, 2001 was a second consecutive low-flow year (Figure 3).

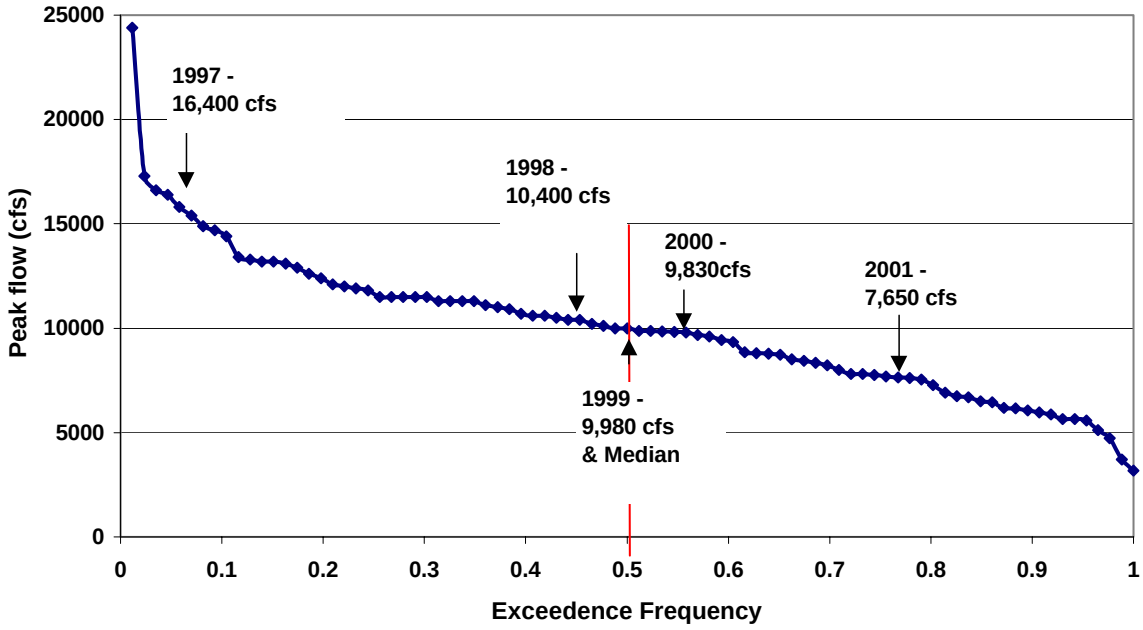


Figure 2. Peak flow during the study period at the Maybell gage with exceedence frequency for the period of record.

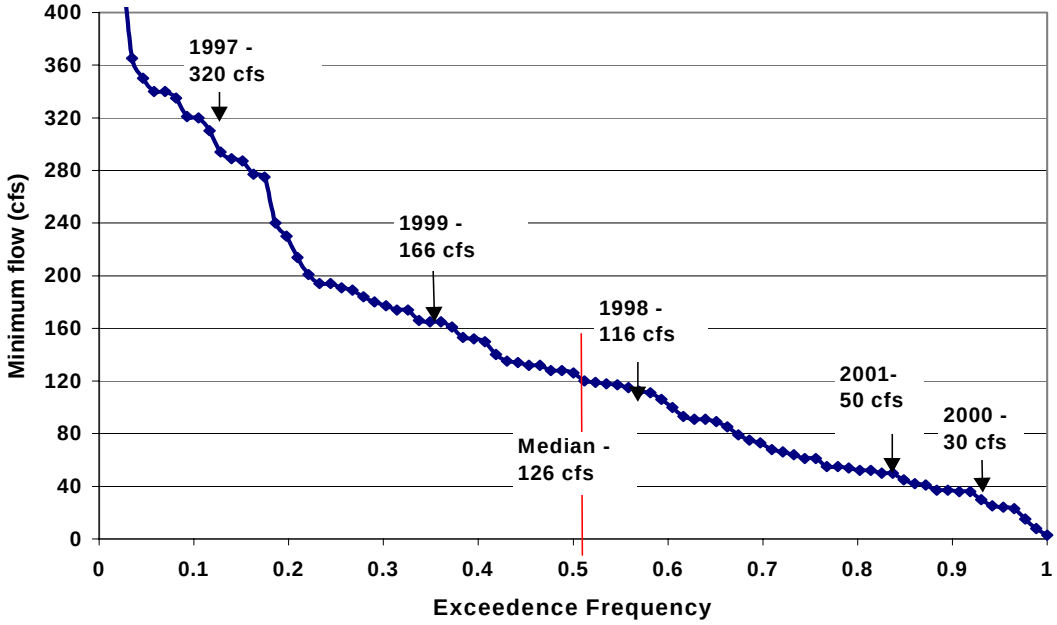


Figure 3. Minimum flows during the study period recorded at the Maybell gage with exceedence frequency for the period of record.

Colorado River – 15-Mile Reach

The 15-Mile Reach of the Colorado River extends from Palisade, Colorado (RM 185), downstream to the confluence of the Gunnison River at about RM 170 (Figure 4). The Colorado River Recovery Program (Osmundson et al. 1995) considers the 15-Mile Reach important for endangered fish recovery. Flows are an issue because of two major upstream diversions that divert flow from the river during the irrigation season (April 1 to November 1). The Government Highline diversion is located in lower Debeque Canyon (RM 193.7) and the Highline canal has a capacity of 1620 cfs. The Grand Valley diversion dam is at RM 185.4. The Grand Valley canal has a capacity of 640 cfs.

A USGS gage, which is located about 0.4 km downstream from the intake for the Grand Valley canal (Figure 4), began operation in 1990. Flows at the Palisade gage are typically 1200 to 1600 cfs less than above the diversion structures in spring and summer. Winter (November to March) flows in the 15-Mile Reach do not appear to create fishery concerns. Flows recorded at the Cameo gage (RM 199.9) appear to be at least at pre-development levels or higher due to senior water right calls at the Shoshone power plant in Glenwood Canyon. Also there can be additional releases for power generation from Green Mountain Reservoir (Per comm. Karen Flogequest (USBR). Flows recorded at the Palisade gage are usually higher than at Cameo between November and April because Plateau Creek joins the river at RM 193.3. Pitlick (1999) determined bankfull flow to be near 22000 cfs for the 15-Mile Reach.

There are two study sites in the 15-Mile Reach. In 1999, bed topography was mapped from the boat launch at Corn Lake (RM 177.5) downstream to RM 175.3 (Figure 4). This station is named the Corn Lake Site. The Corn Lake site length, which is 3.9 km long and has an average width of 55.2 m at a flow of 1400 cfs, was electro-fished in 1999, 2000 and 2001. The river in this section includes five small backwaters. Flow is generally confined within the main channel as opposed to a braided channel (Figure AF7).

The Clifton Site was added in 2000. This site is about 300 m upstream from the Corn Lake site. The Clifton site is from RM 177.7 to 180.4 and has a total length of 4.2 km. In this section, the river has split flow in two large sections of the channel. There is an old diversion structure located at RM 179.7. The dam backs up water along the north shoreline. There is a large backwater at lower flows. Smaller backwaters like those found in the Corn Lake are uncommon in this site (Figure AF8).

The peak flow for the Palisade gage in 1999 was 12700 cfs on June 10. The peak flow in 2000 was 13,500 cfs on May 31. In 2001 the peak flow was 8,410 cfs on May 21. The median peak flow for the 11-year Palisade gage history is 13,500 cfs indicating that peaks for 1999 and 2000 were near normal. Typically, flows in March are near 2000 cfs, but in some years flows can drop after April 1 due to diversions into the Government Highline and Grand Valley canals. In 1999, flows during the ascending limb (April and May) of the hydrograph flow dropped to 435 cfs on April 15, 1999. That was the minimum flow for the year. The minimum spring flow was 1110 cfs on April 5th, 2000 and 500 cfs on April 17th, 2001.

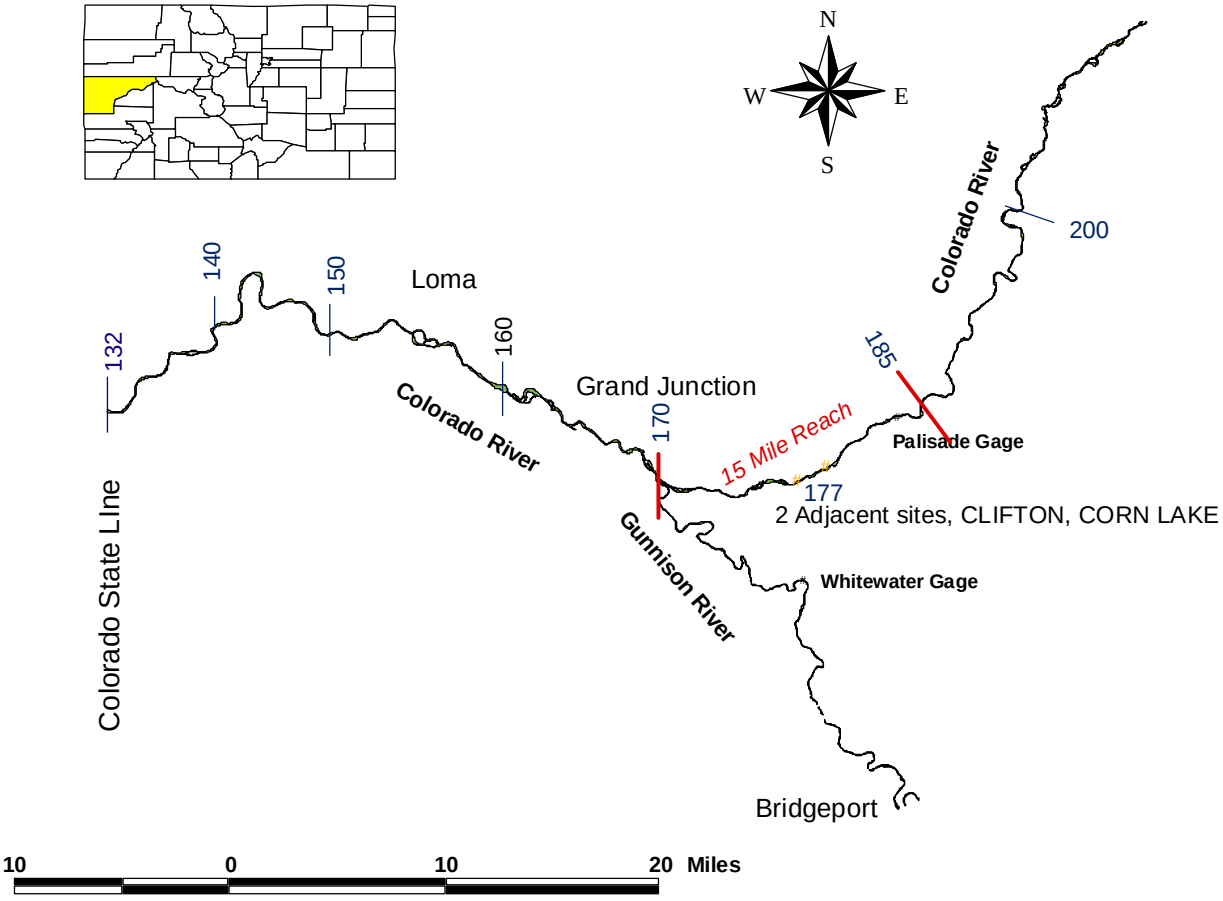


Figure 4. Location of the two study sites in the 15-Mile Reach, Colorado River, Corn Lake and Clifton.

Summer flows were much less in 2000 and 2001 than in 1999. They provided an opportunity to sample the fish population at different flows. Osmundson et al. (1995) made instream flow recommendations for the 15-Mile Reach based on a study of habitat availability for endangered fish. The recommendations from Osmundson et al (1995) were somewhat complex because they wanted to avoid using a single minimum flow. These instream flow recommendations were provided as mean monthly (not mean daily) minimums flows. They varied by season and depending on wet, average and dry flow-year categories determined from historic flow data. The lowest mean monthly flow recommendation was 810 cfs (Table 1), which should only occur at the same frequency as dry years, which was defined as two in ten years. In half the years, the mean monthly minimum flow for August to September should exceed 1630 cfs (Table 1).

Table 1. Recommended mean monthly flows [Osmundson et al (1995)] for the 15-Mile Reach in cubic ft/sec. The exceedence percent indicates frequency that the given flow should be met. For example, during a ten-year period, half the years should exceed a mean flow of 1630 cfs in August, September and October; three of the years should exceed 1240 cfs; and two years should exceed 810 cfs for a mean monthly flow.

Exceedence	**July Mean Monthly (cfs)**	**August Mean Monthly (cfs**	**September Mean Monthly (cfs)**	**October Mean Monthly (cfs)**
50% (Wet)	5,370	1,630	1,630	1,630
80% (Normal)	3,150	1,240	1,240	1,240
100% (Dry)	1,480	810	810	810

Since the recommendations from Osmundson et al. (1995) are presented as averages, minimum flows are not the primary consideration. For example, the minimum flow for 2000 was 542 cfs and it was 477 cfs in 2001. The median minimum summer flow for the period of record (11 years) was 588 cfs. Even though flows were less than 810 cfs for 32 days in both 2000 and 2001, these years do not violate Osmundson et al (1995) recommendations. Summer flows in 1999 exceeded the 50% exceedence (wet year) recommendations for all months except July (Table 2) indicating Osmundson considered flows in 1999 optimal. Summer flows in both 2000 and 2001 exceeded the 100% (dry year criteria) in all months except July (Table 2). The federal recommendations, however, will not be "met" if another "dry year" occurs before 2009.

Table 2. Mean monthly and monthly minimum flows recorded at the Palisade gage, 15-Mile Reach, Colorado River for summer months during the three years of the study.

Year		July (cfs)	August (cfs)	September (cfs)	October (cfs)
1999	Mean	4,721	2,221	1,752	1,837
	Minimum	2,500	1,380	1,180	1,430
2000	Mean	1,271	913	986	916
	Minimum	648	581	665	543
2001	Mean	995	1,133	1,014	809
	Minimum	477	686	754	535

Dolores River

The headwaters of the Dolores River lie in the San Juan Mountains. The river flows mostly northward about 200 miles to its confluence with the Colorado River in Utah. The McPhee Dam, which stores water primarily for irrigation, regulates flow for most of the river's course. The McPhee Dam has a capacity of 38 1000 acres/feet and began storing water in 1984. The magnitude of runoff and peak flows are much reduced compared to before 1984. The San Miguel River is of comparable size and joins the Dolores about 117 miles below the McPhee Reservoir. The San Miguel has a relatively unregulated flow.

Access points for boat launches and take-outs were found to be very limited over most of the Dolores River's length. A study site was located in the Big Gypsum Valley, which is 14 river miles downstream from the Slick Rock Bridge and 34 river miles upstream of the Bedrock boat launch (Figure 5). The Dolores River Guidebook (DeVries and Maurer 1977) starts with River Mile (RM) 0.0 at the Bradfield Bridge. The confluence of the Dolores with the Colorado River is RM 171. We used the river guide in reverse RM order to identify landmarks. Beginning at the confluence as River Mile 0.0, the Utah-Colorado State line is RM 22.4, and the **Big Gypsum Study Site is RM 107.1 to 109.9**. The study site starts at the BLM Gypsum Valley Recreation site and ends about 3.0 miles downstream at the 20R (county road) bridge crossing. The study station is about 70 river miles downstream from McPhee Reservoir.

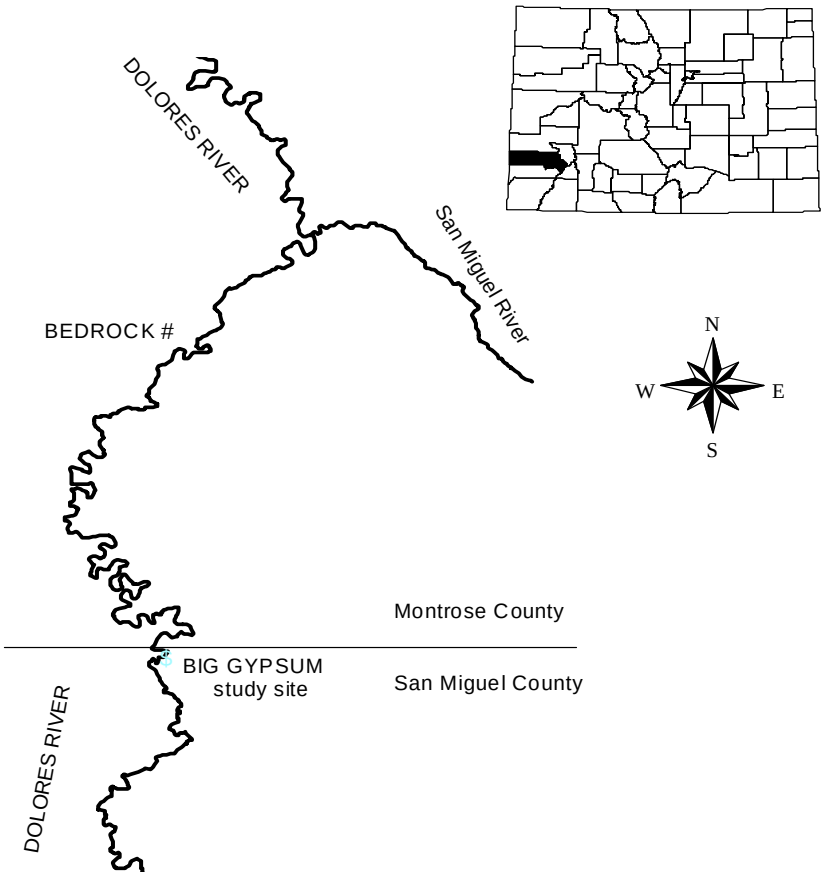


Figure 5. Location of the Big Gypsum (Big Gypsum Valley) study site on the Dolores River.

METHODS

FISH SAMPLING

Fish sampling was performed by electro-shock on the Yampa and Colorado Rivers between 1998 and 2001. Fish were electro-shocked and netted from a 15 ft Achilles raft between 1998 and 2000. A 16-ft Hyside self-bailer raft was equipped for electro-fishing in 2001 using the same Smith-Root electro-fisher, 5000-watt generator and anode array mounted on a forward boom as in the three earlier years. Flows below 120 cfs on the Yampa River were highly problematic for the Achilles boat because it had to be

frequently dragged in shallow reaches. Dragging became the case for the Hyside at flows less than 100 cfs on the Yampa. The boat was maneuvered by either oars or by a battery powered 40-pound thrust trolling motor. Two netters caught as many fish as they could while the shocker was in operation. All fish were measured to the nearest millimeter. Only fish over 150 mm were marked and therefore used for mark and recapture population estimates. Density estimates were made for the each study site on the Yampa, Colorado and Dolores.

The Darroch multiple mark method (Everhart and Youngs 1981) was used to make the population estimate with ninety-five percent confidence intervals. A total fish estimate was made for all species and for each species. Recapture rates generally varied between species and size-groups. For our samplings larger suckers had the highest recapture probabilities. Species with appreciably lower recapture probabilities included catfish, bass, pike and carp (the lower group). The total fish estimate was a blend of recapture probabilities, but should produce reliable comparisons for total fish abundance between years, when species and size composition was consistent. For rare species (pikeminnow, etc) with zero or one recapture in the sample, abundance was estimated by dividing the number in the sample by the mean recapture probability of the lower group.

The z-test with an alpha of 0.05 ($z = 1.96$) was used to test for significant differences in density estimates between years at each station. At stations with three or more years of sampling, the Bonferroni inequality was also used to control the overall significance level (.05) for the simultaneous comparison of all pairs of years (Dr. David Bowden, CSU, pers. communication). At stations with 4 years of data, (Duffy and Sevens) the z value (2.631) corresponds to an alpha of 0.05 divided by six (0.0083).

On the Yampa River, a different mark was used for each run-riffle sequence, which allowed for determining if recaptured fish had moved up, down or had not moved between captures. The dates and the flow for each field trip during the four-year period 1998 to 2001 for Sevens and Duffy are given in Table 3. The Lily Park Site was electro-fished for two years in 2000 and 2001 (Table 3). Flow readings were taken from the Maybell gage. Flows recorded from the Lily Park gage tended to be somewhat higher than Maybell and are included in Table 3 parenthetically.

On the Colorado River, fish in both study sites within the 15-Mile reach were marked to designate the upper, middle and lower sections of the site to give a general idea of movement between passes within the station. A total of eight electro-fishing passes were made at the Corn Lake station in 1999. Four passes were made on the left half and four on right half of the river. The Clifton site was added in 2000 and fish from Clifton were given a unique mark so they could be distinguished from fish marked downstream at the Corn Lake station. The sampling strategy was modified in 2000. The total number of electro-fishing passes was six at both Corn Lake and Clifton. Instead of sampling left and right sides, the river was divided into three longitudinal zones, i.e., right shoreline, left shoreline and mid channel so that fish caught in shallow shoreline habitat were distinguished from the deeper channel habitat. The electro-fishing boat sampled each zone (right and left shoreline and mid channel) twice. In 2001, the same

sampling scheme was used as in 2000 except a seventh pass was performed in the mid-river zone. The additional mid- river pass was found necessary to improve the recapture probabilities for large fish mid-channel. The dates and the mean daily flow (Palisade gage) for that day for the period of sampling is given in Table 3.

The Dolores River was electro-fished in July 2000 and 2001. In both years on the first pass block nets were placed at the downstream end of each run (upstream of riffles). Also, each run was repetitively electro-fished three to five times. Fish from each pass were held in nets, then marked and released into the same run of capture. This process was continued over the entire reach. Block nets were not used on recapture passes. Dates of electro-fishing and flows from the Slick Rock gage is given in Table 3.

CHANNEL TOPOGRAPHY

Global Positioning Systems and Sonar

In 1999 and 2000, bathymetric surveys of the channel were taken of the six study sites using Global Positioning Systems (GPS) and sonar technology. The channel surveying technique previously described in Anderson and Stewart (2000) was performed from a moving boat. A large amount of bathymetry data was gathered in a short amount of time. The GPS system was a Javad Oddessy L1/L2 RTK GPS with Glonass and Multi-path reduction options turned on. The system had a published vertical accuracy of 15mm +/- 1.5 mm. The sonar unit was an ODOM Hyrographic Systems, Hydrotrac - Single Frequency, Portable Survey Sounder. The sonar unit used a 200kHZ frequency with a published accuracy of 1cm +/- 1% of depth and an output resolution of 1cm. The sonar unit pinged and logged ten depth readings per second. The RTK GPS logged one position per second. The RTK GPS system output a NMEA GGA string at a rate of 1Hz while the sonar output text strings indicated depth at a rate of 10Hz. Data from these instruments were sent to a laptop computer and recorded using the COMLOG software from ODOM Hydrographic. Because the RTK GPS and Sonar data were received at different rates, all data entries collected by the COMLOG software were time-tagged to the millisecond using the computer's clock. The depth readings immediately before and after the RTK GPS reading were interpolated by the computer clock time (nearest millisecond) to produce the XYZ coordinates used to map bed topography of the river channel.

Bathymetric data were collected from longitudinal runs and cross-sectional surveys. Special care was taken to ensure that the transducer and GPS antenna were mounted in such a way as to remain nearly vertical during each run.

Table 3. Dates for electro-fishing and flows on the day of the sample.

SEVENS	DATE OF ELECTROFISHING			FLOW IN CFS		
	August	September	October	August	September	October
1998		18, 23, 29	1		222, 189, 163	172
1999	30	1, 14, 16		315	280, 219, 201	
2000		28	4, 9		334	240, 206
2001	24, 30	4		114, 70	64	

DUFFY	DATE OF ELECTROFISHING			FLOW IN CFS		
FULL STAT	August	September	October	August	September	October
1998		16, 22, 24, 30			264, 174,194, 162	
1999	25	2, 15, 17		237	247, 212, 180	
2000		12, 26	10		69, 518	199
2001	21, 23, 28	6		105, 98, 77	57	

DUFFY	DATE OF ELECTROFISHING			FLOW IN CFS		
DEEP RUN	August	September	October	August	September	October
1998		3, 14, 15			209, 261, 287	
1999	23, 24, 31	7		284, 282, 329	357	
2000		11, 19, 25			79, 57, 632	
2001	20, 27			123, 94		
LILY PARK	DATE OF ELECTROFISHING			FLOW IN CFS		
	August	September	October	August	September	October
2000		13,27	3, 5		70, 420	260, 215
2001	22, 29	5		91, 85 (151, 110)	61 (96)	

CORN LAKE	DATE OF ELECTROFISHING			FLOW IN CFS		
	Aug.	September	October	Aug.	September	October
1999		28(2x), 29, 30	5, 6, 8, 12		2060,2000,1990	1660,1420, 1740,1860
2000	15, 17 22, 24	5, 8		903, 821 1110, 907	1100, 1090	
2001		16,19,24 26,28	2,4		701, 915, 857, 859, 790	715, 689

CLIFTON	DATE OF ELECTROFISHING			FLOW IN CFS		
	August	September	October	August	September	October
2000	16, 18, 23 25, 30	6		853, 902, 1020 856, 1290	1080	
2001		20, 21, 25, 27	1, 3, 9		904,901,891,824	735, 684, 543

DOLORES	DATE OF ELECTROFISHING		FLOW IN CFS	
Big Gypsum	July		July	
2000	11, 12, 13, 18, 19, 20, 27		52, 53, 55, 58, 53, 53, 52	
2001	16, 17, 18, 19, 23		66, 68, 68, 53, 50	

Waterline Surveys

One hindrance to using sonar to map the channel bottom involved the equipment's minimum depth limitation. In order for the sonar to get a reading off the bottom of the channel, the transducer had to have at least half a meter of water underneath it. The transducer was located approximately 15cm underwater to allow for the pitch and roll of the boat and to minimize air entrainment under the transducer head. Thus, the minimum depth to gather sonar data was 75 cm.

In areas that were too shallow for data collection by the boat-mounted GPS/sonar method, additional topographic data was collected using RTK GPS in what we referred to as the "walking method". In this method, the Javad RTK GPS was mounted on a range pole and individual RTK GPS positions were recorded with a Psion data collector running Field Face software. After 2001, a TDS Ranger was used for collecting individual survey points.

Reference Sites

Data collected in the 15-mile reach of the Colorado River were geographically referenced to the Mesa County GPS Survey System (www.co.mesa.co.us, GIS section). Aerial photography of the 15-Mile Reach was purchased from Mesa County to aid in identification of landmarks and waterline boundaries.

The web page of the Mesa County Dept. of Public Works Engineering Division/Survey Section showed the locations of the county markers. Using the latitude and longitude of the brass marker at the intersection of 31 and C Road as a known reference point, we placed secondary rebar survey pins at two places along the 15-Mile Reach. One pin was placed near river mile 175. This pin was used as the reference point for the entire Corn Lake survey. The other pin, located on a bluff just upstream of the 32 Road Bridge on property owned by the Meso County Highway Department, was used for the Clifton surveys.

On the Yampa and Dolores, initial surveys markers were placed using only uncorrected GPS coordinates. Base pins located by the GPS were then used for all subsequent surveys at each of the sites.

Corn Lake, Colorado River

The Corn Lake site was mapped during a seven-day period beginning June 27th and ending July 7th. Flows were generally between 8,000 and 10,000 cfs. About 38,880 usable bathymetric survey points were collected along a 4.0-km reach. Water edge shots were obtained in October 1999 and July and August, 2000 using the walking method.

Clifton, Colorado River

The Clifton site is located 0.4 km upstream of Corn Lake and is 4.25 kilometer in length. A total of 45,000 usable bathymetric survey points were collected using the GPS/sonar method on May 31, and June 1, 2, 4 and 5, 2000. Flows during this period varied between 10,000 and 13,000 cfs. Waterline/water surface measurements were made by the walking method on August 1, 2 and 3, 2000; January 23, 24, 25 and 26, 2001; and (the final set) June 18,19 and 20, 2001.

Duffy, Yampa River

Bathymetric data was collected along a 2.25 km section of the Yampa River near the Duffy Tunnel using the GPS/sonar method during the period of July 9th to July 11th, 1999. From July 27th through July 29th 1999, the walking method was used to survey waterlines and shallow riffles.

Sevens, Yampa River

On July 12, 1999, bathymetric data were collected using the GPS/sonar technique along a 1.3-km section of the Yampa River at the Sevens study section. The length of this site was believed to be to short given the nature of the associated fish data and the habitats represented in this reach. The Sevens site was enlarged on June 23, 2000, by surveying another 1.3 km immediately upstream and overlapping the site mapped the previous year. These surveys used the same boat and GPS/sonar equipment. To compare bed and water surface elevations between years, three longitudinal profiles were obtained in the 1999 site and water lines and were recorded for the entire 2.6 km station. Collection of bathymetric data was hampered in 2000 by the low and unusually short runoff period.

The base pin established in 1998 was used as the reference position for both the 1999 and 2000 surveys. Shoreline and water surface shots were made using the walking method. Waterline shots for the entire reach were surveyed on October 30 and 31, 2000. Another series of water edge/surface shots were made in June 26 & 27 and July 5 & 6 2001.

Lily Park, Yampa River

Bathymetric data were collected using the GPS/sonar technique along a 3.3-km section of the Yampa River at Lily Park on June 12, 13 and 14, 2000. Collection of bathymetric data was hampered in 2000 by the low and unusually short runoff period. There was a large, wide and shallow riffle near mid-station that could not be surveyed by boat. Therefore, walking method was employed to survey shallow riffles on August 8 and 9 and again on October 19 and 20, 2000. Waterline shots were made on June 27 and 28, 2001, and at a lower flow on July 31 and August 1.

Big Gypsum, Dolores River

Over a three-day period, May 16, 17, and 18, 2000, bathymetric data was collected using the GPS/sonar methodalong a 3-km section of the Dolores River in the Big Gypsum Valley. As was the case with the Yampa River, the lower than normal runoff flows made data collection using sonar more difficult. Also, certain parts of the river were too shallow for the sonar. Several days were spent in June and July 2000 logging additional points by the walking method. Waterline/water surface shots were made on July 6 and 7, 2000, and on June 13 and 14, 2001.

Velocity Measurements

To calibrate modeled data, it is necessary to have obtained field measurements of depth and velocity at known flows. While depth can be gathered using the same technologies that are used in determining bathymetry, velocity measurements require another set of instruments. Two different technologies were used for measuring velocities in this project.

In 1998, a Marsh McBirney Flo-Mate Portable Flowmeter was used in conjunction with the total station to determine point velocities. The Marsh McBernie had a published accuracy of 1.5cm/s +/- 2 percent. This flowmeter was based on the electrical principle known as Faraday's Law. Here the flow rates were determined by passing a conductive fluid through a magnetic field. A wading rod that held the meter head was placed at a depth chosen to represent average velocity (usually 0.6 of total depth). Locations were recorded by shooting the point with the total station and then recording the average of three 10-second averages. After 1999, locations were recorded by locating the position with the RTK GPS and then recording the velocity of that point.

At high flows it is often not practical to use a wading rod to measure velocities. In May of 2000, a 3MHZ Sontek River Surveyor Acoustic Doppler Profiler (ADP) was used to gather calibration data at the 15-mile reach. The ADP measured the velocity of water using a physical principle called the Doppler shift. This principle stated that if a source of sound was moving relative to the receiver, the frequency of the sound at the receiver was shifted from the transmit frequency. By determining the Doppler shift using three beams, it was possible to determine the relative speed and direction of the flow. Using the Doppler shift from the river bottom to determine the boat speed and direction, we computed absolute velocity and direction. The ADP measured velocities in 15 cm vertical increments down to the river bottom. These velocities were averaged over a specified time interval.

Data Reduction and Preparation

The GPS/sonar technique produced a large number of data in a short amount of time. It generally was not possible to perform any quality control as the data was being collected. Data reduction and quality control were accomplished using an Excel- macro that stripped out non-sensible or incomplete points so only points that met a set of

standard criteria were used in the final survey. The Excel-macro eliminated all non-RTK hits as indicated by the GGA string. This eliminates false spikes in the sonar data sometimes caused by fish or woody debris. Spikes were identified by making a running average of the six nearest sonar pings (three prior and three after). An individual depth reading was marked as "bad" if the difference in between the moving average and the individual ping was greater than 15 cm. If an RTK GPS reading had a "bad" sonar ping recorded directly before or after it, that GPS reading was ignored. For those RTK GPS signals with "good" sonar recordings before and after them, the depth for that GPS position was determined through a linear interpolation of the sonar data based on the time tags. Topographic data were also visually examined by creating Triangular Irregular Networks (TIN).

HYDRAULIC SIMULATION

In the first two years of the project, hydraulic simulation and 2-D flow modeling was contracted with the Earth Resources Department of Colorado State University (CSU). Greg Stewart, a CSU graduate student, collected and input the data to the RMA2-hydraulic model. He performed the analysis during the time period June 1998 to June 2000. Stewart (2000) gives details on hydraulic methods, problems and innovations used for making flow simulations at 15-Mile Reach (Corn Lake) and the Duffy Tunnel site.

Stewart performed most of the installation and operation of technical equipment and data handing for the 2-D modeling. Following his departure, no 2-D modeling was performed until a new contractor was found. In 2002, a new contract was finalized with Utah State University. Dr. Craig Addley, contract administrator for 2-D modeling at Utah State University (USU), supervised modeling for the remaining four sites and some new modeling on Corn Lake. The USU lab used a 2-dimensional, quasi-3-dimensional model developed by Jonathan Nelson of the USGS. The technical description of this model and underlying equations can be found in Nelson (1996), Thompson et al. (1998), Nelson et al. (1995), McLean et al. (1999), Topping et al. (2000).

The 2-D model flow simulations for the Yampa River were meant to cover the range of flow typical in the base flow period, which typically varies between 125 and 200 cfs. Flows simulations at Sevens and Lily Park were produced at 40, 60, 80, 100, 125, 150, 200, 250, 300, 400, 500 and 600 cfs by USU. The Duffy site modeled by Stewart was at flows of 60, 80, 100, 125, 150, 200, 250, 300, 400, 500 and 600 cfs. On the Colorado River base flow was typically much higher than on the Yampa and did not commonly fall below 600 cfs. Stewart ran flow simulations at Corn Lake at 600, 700, 800, 900, 1000, 1200, 1400, 1600, and 1800 cfs. The same flows were modeled for the Clifton site by USU, with additional simulation at flows of 200, 250, 300, 350, 400, 450, 500 and 2000 cfs. Some follow-up modeling was done on the Colorado River so that both sites were modeled down to 100 cfs. Flows on the Dolores River ranged from a low at 10 cfs and a high of 500 cfs.

Site Characterization

Length, mean width and wetted area for each simulated flow were determined for each site using the two-dimensional modeling output data. Station lengths were measured along the channel thalweg. Widths were determined by dividing the wetted channel area at 600cfs (100cfs for Big Gypsum) by the station length. Longitudinal profiles were generated in ArcInfo by sampling channel bathymetry at two-meter intervals along the channel thalweg.

HABITAT QUANTIFICATION

A primary objective of this study was to objectively quantify changes in meso-habitat composition over a range of flows at each site. Meso-habitat is defined at the reach level and includes pools, runs, riffles and rapids. Pools have low velocity, runs have moderate velocity, riffles are swift areas and rapids have the fastest current. For modeling purposes pools were given a velocity of zero to 0.15 m/sec, runs ranged from 0.15 to 0.6 m/sec, riffles had velocity ranging from 0.6 to 1.5 m/sec and rapids had velocities over 1.5 m/sec (Table 4).

Habitat suitability for fish was also a function of depth. Very shallow areas were of high value to small fish, but they had no habitat value to large fish. Pools and runs had five depth categories, riffles had four and two depths categories for rapids (Table 4).

Using only depth and velocity, we defined 16 different non-overlapping meso-habitat types for use in this study. These 16 meso-habitat types provided a general representation of habitat diversity that was inclusive for a fish community composed of a variety of size-classes and species. These 16 meso-habitat types were then mapped using data provided by the 2-D flow models. In each case, solution files (2-D model output) were imported into ArcInfo and then linearly interpolated into 1 x 1-meter grids representing depth and velocity for a given flow. Depth and velocity grids were then sampled to create 1x1-meter meso-habitat grids. The abundance of meso-habitat was determined by counting the number of grids of each meso-habitat type. Surface maps of meso-habitat were created either in ArcView or by importing 2-D plotfiles into SMS (the 2-D modeling package by Boss International).

DEVELOPMENT OF MESO-HABITAT SUITABILITY

Meso-habitat suitability was developed using the fish sampling data. The electro-fishing data was summarized for individual electro-fishing sub-reaches (polygons). The total density and biomass calculated over the entire station did not indicate how fish were distributed within a station, whereas the electro-fishing sub-reaches provided much more detail on fish distribution within the stations. Electro-fishing sub-reaches had the same starting and end locations between passes and years and were digitized on the aerial photos of the study stations using ArcView. The sum of the area and fish from all electro-fishing sub-reaches equaled 100% of the entire station.

Table 4. Depth and velocity criteria used to define meso-habitat types.

	Habitat Types	Depth	Velocity
		(m)	(m/s)
1	Wetted-pool	0.01 – 0.2	< 0.15
2	Shoal-pool	0.2 - 0.5	< 0.15
3	Shallow-pool	0.5 - 1.0	< 0.15
4	Medi–pool	1.0 - 2.0	< 0.15
5	Deep-pool	> 2.0	< 0.15
6	Wetted-run	.01 - 0.2	0.15 - .6
7	Shoal-run	0.2 - 0.5	0.15 - .6
8	Shallow-run	0.5 to 1.0	0.15 - .6
9	Medi-run	1.0 to 2.0	0.15 - .6
10	Deep-run	> 2.0	0.15 - .6
11	Shallow-riffle	< 0.2	0.6 - 1.5
12	Riffle	0.2 to 0.5	0.6 - 1.5
13	Deep-riffle	0.5 to 1.0	0.6 - 1.5
14	Very-deep-riffle	> 1.0	0.6 - 1.5
15	Shallow-rapid	< 0.5	> 1.5
16	Deep-rapid	> 0.5	> 1.5

The meso-habitat suitability analyses used the 2-D hydraulic modeling simulation runs to determine physical attribute metrics for each polygon. This included surface area, mean depth, mean velocity, maximum depth and maximum velocity. Species density and biomass data were calculated based on the percent of fish captured in each sub-reach times the total-reach estimate. Polygons with zero biomass were considered unusable habitat. Polygons that supported high biomass indicated higher habitat quality. Biomass was determined for the flannelmouth sucker, bluehead sucker and roundtail chub over 20 cm in length.

The polygon data was used to create four functional meso-habitat types for bluehead and flannelmouth suckers. The biomass and mean depth, and mean velocity data was imported into Sigma Plot and then smoothed using a running median function. The result was a regular matrix showing estimated polygon biomass as a function of mean depth and mean velocity. The biomass data were graphed using Sigma Plot software at the scale of 0.1 m, which was used for both axes. For example, bluehead sucker had low biomass in the cell with a depth of 0.6 m and 0.3 m/s, but higher biomass for the cell with 0.6 depth and 0.7 m/s. The data was validated by regression analysis of projected biomass versus observed biomass.

Four levels of suitability were determined from the polygon biomass. Polygons with zero biomass were called Unusable habitat. Unsuitable, Marginal and Optimal were the other meso-habitat types. Each contained roughly about one-third of the total sample size. The lower third or Unsuitable polygons represented about 15% of the total biomass. Marginal represented about 25% Optimal contained about 60% of the total biomass of the total electro-fishing station.

Biomass data for the Colorado River was also examined as a function mean depth and velocity from the electro-fishing done along the shoreline. Shoreline sampling was done in 2000 and 2001 to determine species composition of the shoreline habitats. Shoreline habitats are typically shallow and low velocity and very adult flannelmouth and bluehead sucker were captured from shoreline habitats. The shoreline electro-fishing results were similar to the criteria for Unusable habitat determined by the Sigma Polt analysis.

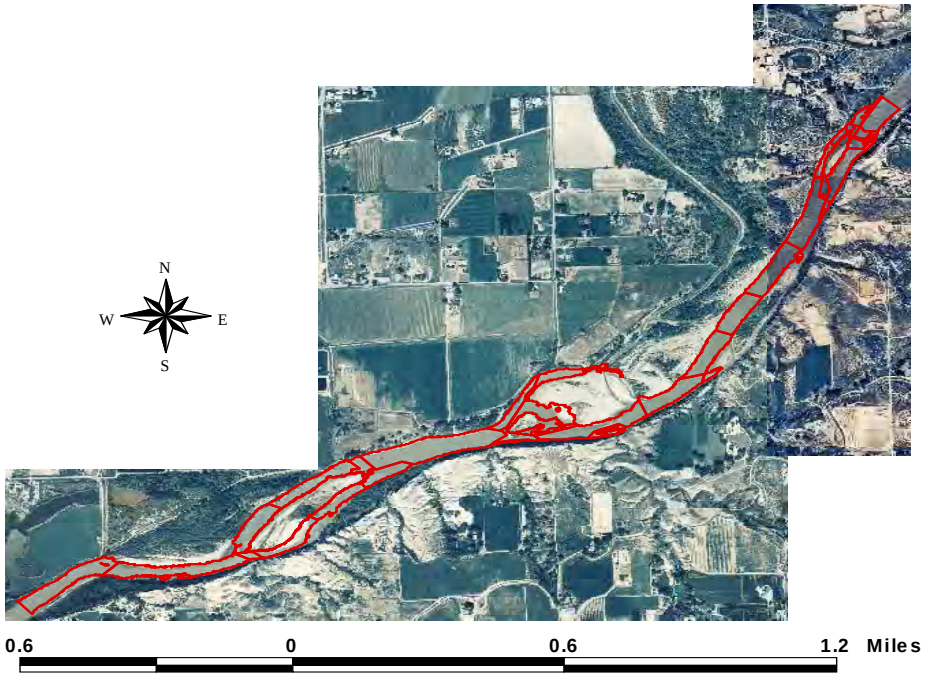


Figure 6. Example of digitized polygons or electro-fishing areas (photo of Clifton site).

DETERMINATION OF HABITAT AVAILABILITY

Once meso-habitat biomass (suitability) criteria for each species of interest were determined, habitat surface area for each of the four meso-habitat types (Unusable, unsuitable, marginal and optimal) was calculated with ArcInfo using the same process as described for the 16-meso habitat types. The surface area of unusable, unsuitable, marginal and optimal habitat was multiplied by the observed mean biomass to give a biomass estimate for both bluehead and flannelmouth suckers for each of the simulated flows.

RESULTS

FISHERY QUANTIFICATION

To determine the role flows have on fish community structure it is necessary to quantify both the fishery and habitat availability and then to establish the relationship between habitat and flow. The fishery was characterized by three different attributes for each of the study sites: 1) species composition, 2) size distribution and 3) density and biomass estimation. Since a complete summary of the fish data was in the job progress report, Anderson (2002), not all fish data is presented in this report.

In general, each annual progress report compares species composition, size and density data to the prior year's data. Length frequency histograms for each station sampled in 1998 and 1999 are available in Anderson and Stewart (2000). Histograms for the 2000 sample are given in Anderson and Stewart (2001) and histograms for the 2001 sampling are in Anderson (2002). Length data can also be obtained from the author in spreadsheet format. Seining data is presented in Anderson and Stewart (2000) and Anderson (2002).

Data for the Yampa River was organized by two periods, the first two years (1998 and 1999) had above normal base flows, while base flows during 2000 and 2001 were well below normal. Differences in the fishery between these two periods probably were attributable to differences in base flows. At the Duffy station, fish population sampling was done in a 4.5-mile reach (Long Reach), but only the upper 1.8 miles of the long reach was modeled for habitat composition (habitat reach). The Long Reach fish data was used for making comparisons between years.

Fish Over 15-cm in Length

Native species composition was highly consistent between years at the Sevens station with native fish comprising 73% (four-year mean) of the fish over 15 cm. The four-year mean for flannelmouth-sucker composition at Sevens was 49% with a range of 46% to 53%. The four-year mean for bluehead sucker was 19% and it was 4% for roundtail chub (Table 5). Colorado pikeminnow were rare or absent at Sevens for the four-year period. The greatest inconsistency for a native species at Sevens was a drop in bluehead and a small increase in flannelmouth composition in the 2001 sample compared against the three prior years (Table 5).

Native fish species were uncommon to rare at Duffy, averaging only 13% of fish over 15 cm for the four years. The data showed a downward trend in native fish at Duffy with highest native fish composition in 1998 (15%) and the lowest in 2001 (10%) (Table 5). Flannelmouth suckers were consistently at 5% in the first three years, but were only 2% in 2001. Bluehead suckers comprised about 4% and roundtail chub were 3% over the study period. Colorado pikeminnow were uncommon at Duffy. They comprised between 0.6 to 1.5% of the total catch.

Lily Park had by far the largest sample size for fish over 15 cm, and also the largest variation between years (Table 5). Flannelmouth was the most common species found at Lily Park. Its composition was 68% in 2001 and 48% in 2000 (Table 5). The 2001 data was probably a more accurate description of species composition at Lily Park because of the extraordinary number of catfish caught in 2000 decreased the relative abundance of other species that year. Bluehead sucker, roundtail chub and Colorado Pikeminnow composition were similar between years (2001 versus 2000) at Lily park: (9% versus 7%), (0.02% versus 0.03%) and (0.1% versus 0.0%) respectively (Table 5).

Within-station native fish species composition on the Yampa River was quite consistent over the four years of sampling. The differences observed were likely related to either sampling variability between years or difference in flows between years. There were large differences in species composition between stations. Flannelmouth composition was about 50% at Sevens, 5% at Duffy and 70% at Lily Park. Bluehead sucker composition was about 20% at Sevens, 4% at Duffy and 8% at Lily Park. Roundtail chub composition was at 4% at Sevens, 3% at Duffy and 0% at Lily Park.

Nonnative fish comprised 85 to 90% of the fish captured at Duffy Tunnel. White sucker and hybridized white sucker averaged 71% of the catch for the first three years (Table 5). The white sucker group dropped to 50% in 2001. At Sevens, the white sucker group was consistent at 15% of the population for the four years. White sucker or hybrids were very rare at Lily Park at 0.03%. Statistics indicate that the white sucker was better suited to conditions upstream of Sevens and native suckers were better competitors at the lower two sites.

There are three non-native predator species in the Yampa River that influence species composition independent of habitat availability. The northern pike was fairly commonly caught during the first two years of sampling (1998 and 1999) at Sevens and Duffy, but were uncommon in the last two years (Table 5). The trend for smallmouth bass was the reverse with the highest composition occurring in the last year, 2001 (Table 5). The most dramatic shift in smallmouth bass was at the Duffy site, from 10% in 2000 to 33% in 2001.

Channel catfish were non-native predators that had a low composition at Sevens (5%) and Duffy (4%). However at Lily Park, channel catfish composition was 40% in 2000 and 18% in 2001 (Table 5). Low flows were identified as problematic for channel catfish migration in 2000, inflating their numbers relative to normal flow years. A composition of 18% for catfish was a more likely representation for this species. In 2000, smallmouth bass comprised only 0.8% of the fish over 15 cm, but in 2001 smallmouth bass were 5 percent (Table 5).

Table 5. Species composition for fish over 15 cm from all study sites. Composition is from total number of fish measured.

YAMPA RIVER	SEVENS	SEVENS	SEVENS	SEVENS	MEAN	MEAN
Species	1998	1999	2000	2001	98,99,00	4 years
Flannelmouth Sucker	48%	46%	50%	53%	48%	49%
Bluehead Sucker	23%	18%	22%	13%	21%	19%
Roundtail Chub	5%	4%	4%	3%	4%	4%
Colo. Pikeminnow	0.20%	0.20%	0.25%	0.00%	0%	0.2%
White S. + Crosses	11%	15%	17%	16%	14%	15%
Channel Catfish	7%	7%	2%	5%	5%	5%
Carp	4%	5%	4%	4%	4%	4%
Smallmouth Bass	1.0%	2.5%	0.5%	5.0%	1%	2%
Northern Pike	1.3%	1.9%	0.2%	0.3%	1%	1%
Sample size	1391	1026	807	676		
YAMPA –REACH	DUFFY	DUFFY	DUFFY	DUFFY	MEAN	MEAN
Species	1998	1999	2000	2001	98,99,00	4 years
Flannelmouth Sucker	5%	5%	5%	2%	5%	4%
Bluehead Sucker	4%	6%	4%	4%	5%	4%
Roundtail Chub	3%	3%	4%	3%	3%	3%
Colo. Pikeminnow	1.5%	0.6%	0.8%	0.6%	1%	1%
White S. + Crosses	69%	72%	73%	50%	71%	66%
Channel Catfish	3%	4%	3%	4%	3%	4%
Carp	3%	1%	1%	2%	2%	2%
Smallmouth Bass	8%	6%	10%	33%	8%	14%
Northern Pike	2.8%	2.3%	0.9%	1.1%	2%	2%
Sample size	1653	2092	1294	856		
YAMPA RIVER			Lily Park	Lily Park		MEAN
Species			2000	2001		2 years
Flannelmouth Sucker			48%	68%		58%
Bluehead Sucker			9%	7%		8%
Roundtail Chub			0.02%	0.03%		0.03%
Colo. Pikeminnow			0.1%	0.0%		0.1%
White S. + Crosses			0.3%	0.2%		0.3%
Channel Catfish			40%	18%		29%
Carp			2.1%	2.1%		2.1%
Smallmouth Bass			0.8%	5%		3.0%
Northern Pike			0.2%	0.2%		0.2%
Sample size			4058	2989		
COLORADO RIVER		CORN L.	CORN L.	CORN L.		MEAN
Species		1999	2000	2001		3 years
Flannelmouth Sucker		38%	31%	40%		36%
Bluehead Sucker		35%	36%	38%		36%
Roundtail Chub		3%	4%	3%		3%
Colo. Pikeminnow		0.10%	0.04%	0.03%		0.06%

Razorback Sucker		0.20%	0.30%	0.06%		0.19%
White S. + Crosses		6%	5%	6%		6%
Channel Catfish		4%	6%	5%		5%
Carp		11%	14%	6%		11%
Sunfish (all species)		0.9%	1.5%	0.7%		1.0%
Trout (all species)		0.0%	0.1%	1.4%		0.5%
Bullhead		1.3%	0.6%			1.0%
Sample size		3499	2784	3463		
COLORADO RIVER		CLIFTON	CLIFTON	CLIFTON	MEAN	MEAN
Species		1999	2000	2001	2 Years	3 years
Flannelmouth Sucker		33%	33%	42%	37%	36%
Bluehead Sucker		23%	41%	27%	34%	30%
Roundtail Chub		7%	5%	6%	6%	6%
Colo. Pikeminnow		0.50%	0.03%	0.09%	0.06%	0.21%
Razorback Sucker				0.04%	0.04%	0.04%
White S. + Crosses		5%	4%	4%	4%	4%
Channel Catfish		14%	5%	6%	5%	8%
Carp		16%	12%	14%	13%	14%
Sunfish (all species)		0.9%	1.2%	1.1%	1.2%	1.1%
Trout (all species)		0.5%	0.1%	0.2%	0.2%	0.3%
Bullhead		0.5%	0.2%	0.4%	0.3%	0.4%
Sample size		575	3276	4485		
DOLORES RIVER			BIG GYP	BIG GYP	MEAN	MEAN
Species			2000	2001		2 years
Flannelmouth Sucker			16.0%	57.5%		36.8%
Bluehead Sucker			2.2%	5.8%		4.0%
Roundtail Chub			54.9%	24.5%		39.7%
Channel Catfish			15.8%	8.3%		12.1%
Carp			3.4%	1.7%		2.6%
Green Sunfish			2.0%	1.4%		1.7%
Bullhead			5.2%	0.6%		2.9%
Sample size			501	636		

Native species composition was also consistent between years for the Colorado River stations. At Corn Lake, native fish comprised 76% (three-year mean) of the fish over 15 cm with an even split of 36% for flannelmouth and bluehead suckers (Table 5). The three-year mean for roundtail chub was 3% (Table 5). Colorado pikeminnow were very rare at 0.06 percent. All razorback sucker caught were stocked fished. The greatest inconsistency for a native species at Corn Lake was for flannelmouth sucker composition in 2000. This was probably resulted from a different sampling effort that year.

In 1999, a two-pass effort was made at the Clifton station to see if marked fish from Corn Lake would be recaptured outside the site (Anderson and Stewart 2000). This data allowed for three years of species composition data to be collected on the Clifton reach. At Clifton, native fish comprised 76% (two-year mean) of the catch.

Flannelmouth composition averaged 36%, bluehead 30%, and roundtail chub 6 percent. Colorado pikeminnows were very rare at 0.2 percent.

Both Colorado River sites had 76% native fish and 36% flannelmouths. Clifton had a lower abundance of bluehead, but higher numbers of roundtail chub, suggesting subtle habitat differences for these species between these two sites.

Relative abundance of flannelmouths, blueheads and roundtail chub remained stable over three years at the two Colorado River sites. Minor fluctuations in community composition between years were well within the range of sampling error. They, therefore, probably do not reflect any real change in species composition. Sampling efficiency was influenced by a number of factors including flow, water clarity, effort and ability of netters. Flow conditions during sampling were fairly similar in 2000 and 2001, but were much higher in 1999. In 2000, sampling after thunderstorms or during periods of reduced water clarity was more common. There were fewer passes made in 2000 than in 1999 and 2001. Also, shoreline habitats received proportionally more effort in 2000 than in the other years.

Nonnative fish comprised 24% of the fish community over 15 cm at the two sites in the 15-Mile Reach. Common carp was the most frequently occurring nonnative species collected at both sites. The three-year mean for carp was 11% at the Corn Lake site and 14% at Clifton (Table 5). Carp displayed the most movement between stations based on recapture locations. Carp composition was much higher in the Colorado River that in the Yampa River, suggesting the Colorado River has better carp habitat.

The mean composition of white suckers, plus white sucker hybrids with flannelmouth and bluehead suckers, was 6% at Corn Lake and 4% at Clifton in 2001 (Table 5). The white sucker catch was much higher in backwater habitats than in the main channel. On the Yampa River, white sucker was a main channel species in the Duffy and Sevens sites while white sucker were very rare at Lily Park (0.3%). The other common nonnative fish in the 15-Mile Reach was the channel catfish, which was 5% at both stations. Unlike the Yampa River, there appears to be local reproduction of catfish in the 15-Mile Reach.

The Dolores River site at Big Gypsum was sampled in 2000 and 2001. Species composition differed greatly between the two years. In 2000, flannelmouth sucker represented 16% of fish over 15 cm. That rose to 58% in 2001 (Table 5). Roundtail chub represented 55% in 2000 and 25% in 2001 while bluehead sucker was 2% of the sample in 2000 and 6% in 2001. Native fish comprised 73% of the fish population in 2000 and 86% in the 2001 sample. The most common non-native fish in 2000 was channel catfish at 16%, but represented 8% in 2001.

The Big Gypsum stations had the highest composition of roundtail chub of all sites and the highest composition of native fish in general. However, there was instability in species composition between years at Big Gypsum. This instability was probably related to the much different flow conditions between years, with lower flows in 2001.

Even though native fish composition was high at the Big Gypsum site, other fishery factors indicate that the habitat conditions at this site were severely degraded.

Fish Less Than 15 cm in Length

The speckled dace and the mottled sculpin, two small-bodied native species that are associated with riffles or swift current habitats, were commonly observed at the Duffy station in 1998 (13%; 19%) and 1999 (8%; 27%). Conversely, both species were very rare in 2000 (1.2%; 5%) and 2001 (0.2%; 0.8%). The reduced number coincided with reduced flows in 2000 and 2001.

A large increase in young-of–year (YOY) smallmouth bass composition was observed in 2000 and 2001 (lower flow years). Species composition for YOY smallmouth bass at the Duffy station was 45% in 1998 and 42% in 1999. In these higher flow years, most YOY smallmouth bass were collected from shoreline habitats. YOY smallmouth bass composition was 84% in 2000 and 98% in 2001. Also during those years, YOY smallmouth bass occupied riffles as well as the shoreline habitats. The shift from speckled dace to YOY smallmouth bass in riffle habitats was also observed at Sevens in 2000 and 2001. This suggested the shift occurred river-wide.

Shoreline seining done in 1999 and 2001 gave a more quantitative count of fish less than 15 cm. The number of speckled dace collected by seine in 1999 at Duffy was 538 for 24% of the total, whereas seining in 2001 collected zero speckled dace (Table 6). The number of white suckers collected in seines in 1999 was 497 (22% of the total catch), but only 11 (1%) white suckers were caught in 2001. Smallmouth bass numbers were 35 (1.5%) in 1999 and 540 (67%) in 2001. Increases in YOY smallmouth bass during 2001 appeared to be related to the low flow conditions during that year as compared to higher base-flow conditions in 1999.

Low densities or abundance of speckled dace and mottled sculpin were also observed at Sevens. Speckled dace species composition (n) in 1998, 1999, 2000 and 2001 was 38% (123), 13% (10), 2% (11) and 2% (3) respectively, and for mottled sculpin, 5% (16), 0%, 0%, and 0% respectively (Table 6).

Speckled dace appeared to be very common during sampling on the Colorado River. Since other agencies were doing concurrent fish sampling in the 15-Mile Reach, no special effort was made to sample small-bodied fish. Miller et al (2003) made a density estimate of 2.36 dace per square meter for riffles and 0.50 in runs. Based on habitat availability, Miller et al. (2003) estimated speckled dace at 34,000 dace per km in the 15-Mile Reach.

In addition, no special effort was made to quantify non-native cyprinds (NNC; red shiner, sand shiner and fathead minnows) since this fish group was not involved in instream flow recommendations. These species were very abundant in shoreline and backwater habitats (Valdez 1999, Bundy and Bestgen et al. 1999, and McAda et al. 1997, and other annual ISMP reports).

Table 6. Species composition from seine hauls at the Sevens and Duffy sites in 1999 and 2001, Yampa River.

STATION	**SEVENS**	**SEVENS**	**DUFFY**	**DUFFY**
YEAR	**1999**	**2001**	**1999**	**2001**
TOTAL (n)	2165	2026	2272	803
	% (n)	% (n)	% (n)	% (n)
Flannelmouth sucker	1.1 (23)	5.4 (109)	1.0 (23)	0
Roundtail Chub	1.4 (34)	2.2 (45)	34 (733)	1.4 (11)
Speckled Dace	3.8 (83)	1.9 (39)	24 (538)	0
Sand Shiner	57 (1241)	82 (1662)	13.9 (315)	29.5 (237)
White Sucker, &crosses	27 (588)	4.3 (88)	21.9 (497)	1.2 (11)
Smallmouth bass	0.4 (9)	1.5 (30)	2.5 (57)	67 (540)
Fathead minnow	3.6 (77)	2.5 (50)	0.4 (10)	0.1 (1)
Carp	4.3 (93)	0	1.5 (35)	0.2 (2)
Stickleback	0.7 (16)	0.1 (3)	0.4 (9)	0
Redside shiner	0.05 (1)	0	0.04 (1)	0
Plains Killifish	0.05 (1)	0	0	0

All small green sunfish sighted were netted, and most were captured in backwater habitats. Removal of sunfish species was attempted in 2001 and 2000, but not in 1999, since the Recovery Program was conducting centrachid removal in some of the same backwaters during that time. In general, green sunfish numbers were higher during years of lower flow (2001) than during the high year (1999). However, the magnitude of flows observed during the study period did not appear likely to give sunfish species a competitive advantage in the Colorado River as was observed on the Yampa River.

YOY and juvenile flannelmouth and bluehead suckers and roundtail chubs were collected in the Colorado River in all years indicating that suitable habitat was available and that predation was not problematic for younger life stages. In contrast, YOY and juvenile flannelmouth and bluehead suckers were very rare on the Yampa River.

The sample size for fish less than 15 cm was highest in 2001. This could reflect increased sampling efficiency in backwaters and shorelines or an actual increase in small fish numbers. Small fish numbers can increase during low flow conditions because of increased habitat and water temperatures. A longer growing season and more primary productivity is usually associated with higher water temperatures. Flow conditions in both 2000 and 2001 may have been more conducive for small fish than in 1999.

Table 7. Species composition for fish greater and less than 15 cm at the Big Gypsum site on the Dolores River, July 2001.

	Big Gypsum 2001	**Big Gypsum 2000**	**Big Gypsum 2001**	**Big Gypsum 2000**
Species	**>15 cm**	**>15 cm**	**<15 cm**	**<15 cm**
Flannelmouth Sucker	57.5%	16.0%	9.9%	5.2%
Bluehead Sucker	5.8%	2.2%	14.2%	0.0%
Roundtail Chub	24.5%	54.9%	16.5%	48.0%
Channel Catfish	8.3%	15.8%	0.4%	1.4%
Carp	1.7%	3.4%	0.0%	0.2%
Green Sunfish	1.4%	2.0%	1.5%	5.7%
Pumpkinseed	0.0%		0.5%	
Brown trout		0.6%		
Black Bullhead	0.6%	5.2%	0.5%	0.2%
Speckled Dace	0.0%		17.5%	33.8%
Mottled Sculpin				
Red Shiner	0.0%		36.3%	5.2%
Sand Shiner	0.0%		2.3%	0.2%
Fathead minnow	0.0%		0.5%	0.2%
Native species	87.9%	73.1%	58.1%	87.0%
Sample size	636	501	2159	577

The number of fish less than 15 cm was much higher in 2001 (2,159) than in 2000 (577) in the Dolores River (Table 7). Many more red shiners were observed in 2001. This was the most common species at 36% in the less than 15-cm group. Speckled dace was the next most common fish under 15 cm at 18 percent. Young flannelmouth suckers, bluehead suckers and roundtail chub were also common in the small fish group at 10%, 14% and 17% respectively in 2001. Native fish comprised 58% of the less than 15-cm fish sample in 2001 compared to 87% in 2000 (Table 7).

Size Structure for Native Fish

Length frequency histograms for each station sampled in 1998 and 1999 are available in Anderson and Stewart (2000). Length frequency histograms for the 2000 sample are given in Anderson and Stewart (2001) and histograms for the 2001 sample are found in Anderson (2002). There are no length frequency histograms given in this report, but summaries presented herein are based on data from the progress reports. Readers can refer to these progress reports for comparison between stations and between years. Some histograms from 2000 at Sevens are incorrect (bluehead, flannelmouth and catfish) or not included (Lily Park, smallmouth bass). Corrected histograms are found in Anderson (2002).

The Yampa site Sevens had a decrease in mean size of the bluehead sucker in 2000 and 2001 compared to 1998 and 1999 (higher flow years). Both mean length and sample size were smallest in 2001 at Sevens (Table 8). The 30.0-cm mean length was the smallest mean size for any site on the Yampa and Colorado. Duffy was the only site where mean lengths were not significantly different between years (Table 8). Bluehead suckers under 34 cm were rare at Duffy, likely due to predation. The bluehead's mean length of 36 to 38 cm was the highest for any site on the Yampa or Colorado River (Table 8). At Lily Park, bluehead under 28 cm were rare in both years and the means were similar (Table 8).

The length frequency for bluehead suckers on the Colorado River contained juvenile and adult–size fish. Mean length of the bluehead sucker was 33 to 35 cm (Table 8).

Mean lengths of the bluehead sucker on the Dolores River were noticeably different from all other sites with no collected bluehead sucker being over 28 cm in either sampling year. A very high number of yearling (325) bluehead sucker were caught at Big Gypsum in 2001, but no fish in that size-group was collected in 2000 (Table 8**).** About the same number of fish between 19 cm and 28 cm were collected in both years (11 in 2000, 18 in 2001).

Table 8. Mean lengths of bluehead sucker captured during the study period (1998 to 2001), Yampa, Colorado and Dolores Rivers.

	1998,a	1999,b	2000,c	2001,d
	Mean length of bluehead sucker in cm			
Sevens	33.5,cd	33.6,cd	31.3,abd	30.0,abc
Duffy	36.5	37.9	37.6	36.2
Lily Park			34.4,d	33.5,c
Corn Lake		36.5,cd	33.3,bd	34.8,bc
Clifton			31.8,d	33.5,c
Dolores			23.6	12.1
	Total number in sample - Number less than 15 cm			
Sevens	314 - 0	187 – 0	180- 0	89 – 0
Duffy	56 – 0	102- 0	45 – 0	41 – 3
Lily Park			347 – 3	212 – 0
Corn Lake		1212 –3	1010 –16	1283 –31
Clifton			1374 – 51	1228 – 35
Dolores			11-0	343-308

*a, b, c, d following a mean length indicates significant difference (2 tail test) at @=0.5.

The length frequency histograms and mean sizes were very similar for the flannelmouth sucker for the first three years at Sevens. But, their size decreased in 2001 compared to prior years. The mean length (43.8 cm) was significantly lower (Table 9).

Because the number of flannelmouth was low at Duffy in 2001 (n = 17) (Figure A8), the 2001 mean lengths (47.5 cm) were not significantly different from prior years (Table 9). The mean lengths of flannelmouth at Sevens (46 cm) and Duffy (49 cm) (Table 9) were high because there were no juvenile fish at these sites. This was most likely a result of predation. At Lily Park, mean length was significantly less in 2001 (38.4 cm) than in 2000 (41.5 cm) (Table 9) due to more fish less than 29 cm in 2001 (153) than in 2000 (4).

At Corn Lake, mean length of the flannelmouth was 39 to 41 cm (Table 9). The size structure of flannelmouth in the Colorado River ranged from 7 to 55 cm with modes representing all age groups. This suggested abundant habitat and no predation or competition.

On the Dolores River only three adult flannelmouth sucker were collected in 2001. The low mean length was representative of a population that had either poor habitat or limited forage availability for adult size fish. There was apparently very good reproductive success among flannelmouth in the Dolores River, since the vast majority of fish were between 9 and 19 cm in 2001. In 2000, most flannelmouth were between 16 to 26 cm in 2000.

Size structures of roundtail chub at Sevens and Duffy in 2001 were very similar (not significantly different) to prior years, but sample sizes were less at both sites (Table 10). The small decrease in mean lengths in 2001 (Table 10) was due to only one or two additional small fish in the sample, not a shift in size distribution. The high mean lengths at Sevens (38 to 40 cm) and at Duffy (43 to 44 cm) for the study period were due to few yearling and juvenile fish in the sample. Only one chub was collected at Lily Park in 2000 and in 2001. On the Colorado River, both large and small roundtail chub were present in 2000 and again in 2001 at Corn Lake and at Clifton. Mean lengths were not significantly different between Corn Lake (23.5, 20.9 cm) and Clifton (25.0, 22.1 cm) in the same year, but the differences were significant between 2000 and 2001 at both sites. On the Dolores River, roundtail chub ranged in size from two cm to 27 cm with only one large chub at 40 cm.

The length frequency data contained a lot of information about these fish populations. When smaller fish appeared as modes on the graph it was an indication of successful reproduction and survival of younger year-classes. On the Yampa River at Sevens and Duffy very few fish were collected in the size range of 15 to 35 cm, but fish larger than 40 cm were common. This indicates that predators in the Yampa River, primarily northern pike, have had a heavy impact on 15 to 35 cm fish. On the Colorado River, lengths were evenly distributed and showed the presence of multiple year-classes. The lack of predation in the Colorado River apparently allowed a natural length distribution to develop that was based on limits set by habitat availability.

Table 9. Mean lengths of flannelmouths captured during the study period (1998 to 2001), Yampa, Colorado and Dolores Rivers.

	1998a	1999b	2000c	2001d
	Mean length of flannelmouth sucker in cm			
Sevens	45.7,d	46.5,d	45.8,d	43.8,abc
Duffy	48.9	49.0	49.8	47.5
Lily Park			41.5,d	38.4,c
Corn Lake		41.2,cd	38.9,bd	40.6,bc
Clifton			38.3	38.8
Dolores			18.8d	14.2c
	Total number in sample - Number less than 15 cm			
Sevens	668 –0	476 – 0	404 – 1	359 – 0
Duffy	90 – 0	79 – 0	65 – 0	17 – 0
Lily Park			1,935 – 0	2,022 – 0
Corn Lake		1,384 –46	928 – 65	1,495 – 39
Clifton			1,106 – 55	1,934 – 53
Dolores			110 – 30	580 – 271

- a, b, c, d following a mean length indicates significant difference (2 tail test) at @=0.5 for those years.

Table 10. Mean lengths of roundtail chub captured during the study period (1998 to 2001), Yampa, Colorado and Dolores Rivers.

	1998a	1999b	2000c	2001d
	Mean length of roundtail chub in cm			
Sevens	39.0	40.0,d	39.2	37.9,b
Duffy	43.5	44.5	44.2	43.4
Lily Park			40.3	18.0
Corn Lake		23.3,d	23.5,d	20.9,bc
Clifton*		28.9	25.0,d	22.1,c
Dolores			14.1,d	10.9,c
	Total number in sample - Number less than 15 cm			
Sevens	73 –0	39 – 0	31 – 0	23 – 0
Duffy	55 – 1	44 – 0	46 – 0	27 – 1
Lily Park			1 – 0	1 – 0
Corn Lake		188 – 78	145 – 26	193 – 89
Clifton*		47 – 4	196 – 29	446 – 186
Dolores			275 – 277	145 – 367

* a, b, c, d following a mean length indicates significant difference (2 tail test) at @=0.5 for those years.

The Dolores River displayed yet a third pattern in length frequency. In the Dolores River, small fish (<15 cm) were abundant, but large fish (> 25 cm) were very rare. The Dolores does not have obvious predation impacts. The channel catfish was the only non-native predator species and typically small sized fish disappeared by predation. The lack of large fish was likely a function of a lack of habitat. The Dolores River

appeared to be a model of small fish having the advantage in the shallower pools and runs of this site. The Colorado River was a model of larger fish occurring in big the deeper and faster habitats typical of this river.

Density and Biomass Estimation

The biomass estimate included both size and density and was the best measurement of fish productivity for a river reach. Species composition and length frequency analysis provided necessary information about factors that may be influencing the biomass estimate. It was assumed that the carrying capacity (potential biomass) of a community and for individual species was set by a combination of habitat and forage availability. Other factors that reduced a particular species biomass below the habitat potential included predation, competition and hybridization as were described above for each site. Native fish biomass on the Colorado, Dolores Rivers and the Lily Park (Yampa River) was likely a good estimated of carrying capacity. The Sevens site was found to be less impacted by predation and hybridization than Duffy. The other primary variable in the carrying capacity equation was forage availability. Riffles were the most productive habitats for aquatic invertebrate production. Therefore, riffle habitat availability may also have influenced fish biomass. Given these background variables, biomass (fish productivity) at each site was used to indicate habitat potential for native fish between years and between sites.

In 1998 and 1999 at the **Duffy** Reach, total fish density and biomass estimates were similar at 378 and 403 fish/km and 73 and 65 kg/ha respectively (Table 11). Density estimates were not significantly different (alpha = .05) for 1998 and 1999. The 2000 density estimate of 316 was significantly lower (alpha = .05) than prior years. The total biomass estimate at Duffy in 2000 was 49 kg/ha. It was 42 kg/ha in 2001. Density and biomass estimates were down for all species except smallmouth bass in 2000 and 2001 (A-Table 1 and 2). The base flows during 2000 and 2001 were much less than in 1998 and 1999. Reduced fish biomass during the low flow years was also found at the other Yampa River sites. This was consistent with reduced carrying capacity in those years.

The density estimate for both white sucker and hybrids in 2001 was the lowest of the study period and was significantly different from the three prior years (A-Table 1). At **Duffy** large-bodied species decreased in density in 2001 compared to years with higher base flows. The only species to increase in density and biomass in 2001 was the smallmouth bass, a smaller bodied species that can utilize shallow habitats.

Total density estimates at **Sevens** were similar in 1998 (1,147 km) and 1999 (1,115/km) (Table 11). Biomass was 183 and 162 kg/ha in those years (Table 12). The density estimates dropped in 2000 (778/km) and 2001 (653/km). The biomass estimate in 2000 was 102 kg/ha. It was 79 kg/ha in 2001 (Table 12). The lower biomass was again associated in the years with the lower base flows, an indication of reduced carrying capacity at the flows of those years. Also consistent with Duffy is the lower estimate for

northern pike in 2000 and 2001. That suggests the risk of predation by this species was higher in 1998 and 1999.

Flannelmouths were the most common fish greater than 15 cm collected in all four years at **Sevens.** This species had the highest density estimates except in 2000. Flannelmouth sucker estimates were similar for 1998 and 1999, and similar for 2000 and 2001, but the periods differed from each other. The lowest numbers of bluehead were caught in 2001, but the estimate was not significantly different than in other years because of the lower number of recaptures (higher variance). The electro-fishing effort was roughly equal between years at Sevens and, based on effort, it appeared bluehead suckers were more scarce in 2001. The same applied to roundtail chub. Sample size was small for roundtail chub in all years and recapture rates were not high enough to produce tight confidence intervals. In 2001, fewer fish were caught given a similar sampling effort, but it was not statistically significant. The fact that total fish and native sucker density was less in 2000 and 2001 at both Sevens and Duffy indicates a common cause (likely flows) at both locations.

Lily Park was added to the study in 2000 so data is not available for the higher base flow years. The two years (2000 and 2001) of data were strikingly different. Anderson (2002) explained that channel catfish and flannelmouth sucker estimates were highly biased in 2000 as a result of very low summer flows and that the 2001 data was better for comparing density and biomass with other stations.

In 2001, **Lily Park** had by far the highest total fish density of 3,168 fish/km (Table 11) at the three Yampa Sites. Total biomass (kg/ha) at Lily Park was 3.7 times higher than at **Sevens** and 7.0 times higher than at **Duffy** (Table 12). These data strongly indicated that Lily Park had higher total productivity than the upstream sites. Lily Park was only ten river miles downstream of Sevens, suggesting similar temperature and water quality attributes. Also, there appeared to be a larger predator population of northern pike and smallmouth bass at Lily Park (Table 11). Most of the differences in fish density between Lily Park and Sevens were likely habitat related.

Flannelmouth biomass at **Lily Park** was 3.6 times higher and bluehead sucker density was 3.9 times higher than **Sevens**. The 37% decrease in bluehead density at **Lily Park** between 2000 and 2001 indicated reduced abundance between years. Roundtail chub density for fish over 15 cm was highest at Sevens. The near zero chub density at Lily Park (Table 11) indicated a lack of habitat there. It seemed more likely spawning or YOY habitat was missing for chub at Lily Park. Hybridization at **Duffy** did not allow for comparing native sucker density and biomass to other sites. Also predation at Duffy may have been reducing the density and biomass estimates below the potential for this site.

In spite of the problems identified with the 2000 **Lily Park** density data, the sampling effort was beneficial for documenting habitat used at this location. Many flannelmouths were collected from deep eddies and pools on September 13, 2000, at 114 cfs (Lily Park gage). But, on subsequent passes at higher flows (September 27, October 3 and 5) flannelmouth were not captured from those backwaters, but in runs with suitable

depths. These observations directly showed that flannelmouths occupied habitats at low flows (100 cfs) that were not used at higher flows (over 120 cfs). This

Table 11. Density and biomass estimates in **fish per kilometer** and **kilograms per kilometer** for each study site.

	no./km	no./km	no./km	no./km	kg/km	kg/km	kg/km	kg/km
YAMPA RIVER				**SEVENS**				
Species	1998	1999	2000	2001	1998	1999	2000	2001
Total Fish	1147	1115	778	**653**	1136.7	1004.5	633.1	491.9
Flannelmouth Sucker	395	376	296	**263**	413.4	411.6	361.4	227.7
Bluehead Sucker	274	238	309	**120**	110.5	93.5	26.0	30.1
Roundtail Chub	73	41	54	**29**	43.8	26.6	13.6	14.9
LONG REACH				**DUFFY**				
Species	1998	1999	2000	2001	1998	1999	2000	2001
Total Fish	387	403	316	430	509.6	453.8	340.5	291.9
Flannelmouth Sucker	25	15	11	5	34.2	19.3	15.6	6.1
Bluehead Sucker	24	23	16	19	14.0	9.5	10.1	12.1
Roundtail Chub	12	25	5	10	12.0	26.6	5.1	9.6
MAPPED REACH				**DUFFY**				
Species	1998	1999	2000	2001	1998	1999	2000	2001
Total Fish	435	343	467	716				
Flannelmouth Sucker	13	5	9	9				
Bluehead Sucker	21	10	12	3		2.6	4.1	2.1
Roundtail Chub	16	7	7	3		3.1	1.2	0.5
YAMPA RIVER			**Lily Park**				**Lily Park**	
Species			2000	2001			2000	2001
Total Fish			**6279**	**3168**			2369	1760
Flannelmouth Sucker			**2238**	**1667**			1316	801
Bluehead Sucker			**552**	**346**			195	114
Roundtail Chub			**2**	**2**			3.0	0.1
COLORADO RIVER		**CORN LAKE**				**CORN LAKE**		
Species		1999	2000	2001		1999	2000	2001
Total Fish		3962	3417	4007		2761	2854	2605
Flannelmouth Sucker		1550	999	1662		1261	1269	1281
Bluehead Sucker		1573	1182	1272		806	504	596
Roundtail Chub		192	357	171		57	68	41
COLORADO RIVER		**CLIFTON**				**CLIFTON**		
Species			2000	2001		1999	2000	2001
Total Density estimate			3766	4547			3207	3341
Flannelmouth Sucker			1822	1563			1280	1075
Bluehead Sucker			1138	1164			452	496
Roundtail Chub			437	357			100	94
DOLORES RIVER			**Big Gypsum**				**Big Gypsum**	
Species			2000	2001			2000	2001
Total Density estimate			196.6	231.7			259.0	49
Flannelmouth Sucker			35.8	105.9			89	1.5
Bluehead Sucker			3.0	12.7			7.0	0.3
Roundtail Chub			81.0	65.1			14.9	4.5

Table 12. Density and biomass estimates in **fish per hectare** and **kilograms per hectare** for each study site.

	no./ha	no./ha	no./ha	no./ha	kg/ha	kg/ha	kg/ha	kg/ha
YAMPA RIVER	**SEVENS**							
Species	1998	1999	2000	2001	1998	1999	2000	2001
Total Fish	185.2	180.0	125.6	105.4	183.5	**162.1**	**102.2**	**79.4**
Flannelmouth Sucker	63.8	60.7	47.8	42.5	66.7	**66.4**	**58.3**	**36.7**
Bluehead Sucker	44.3	38.4	49.8	19.4	17.8	**15.1**	**4.2**	**4.9**
Roundtail Chub	11.8	6.6	8.6	4.7	7.1	**4.3**	**2.2**	**2.4**
LONG REACH	**DUFFY**							
Species	1998	1999	2000	2001	1998	1999	2000	2001
Total Fish	55.3	57.7	45.3	61.4	72.9	64.9	48.7	41.7
Flannelmouth Sucker	3.6	2.1	1.6	0.7	4.9	2.8	2.2	0.9
Bluehead Sucker	3.5	3.3	2.3	2.7	2.0	1.4	1.4	1.7
Roundtail Chub	1.7	3.6	0.7	1.4	1.7	3.8	0.7	1.4
MAPPED REACH	DUFFY	DUFFY	DUFFY	DUFFY				
Species	1998	1999	2000	2001				
Total Fish	85.9	67.8	92.3	141.4				
Flannelmouth Sucker	2.6	1.1	1.8	1.7				
Bluehead Sucker	4.1	1.9	2.3	0.7				
Roundtail Chub	3.1	1.3	1.4	0.7				
YAMPA RIVER			**Lily Park**				**Lily Park**	
Species			2000	2001			2000	2001
Total Fish			1047.6	528.5			395.2	293.7
Flannelmouth Sucker			373.3	278.1			219.5	133.7
Bluehead Sucker			92.1	57.7			32.5	19.0
Roundtail Chub			0.3	0.3			0.5	0.0
COLORADO RIVER		**CORN LAKE**				**CORN LAKE**		
Species		1999.0	2000.0	2001.0		1999	2000	2001
Total Fish		765.1	659.9	773.8		533.2	551.2	503.1
Flannelmouth Sucker		299.4	192.9	320.9		243.6	245.1	247.3
Bluehead Sucker		303.8	228.3	245.7		155.7	97.4	115.1
Roundtail Chub		37.0	68.9	32.9		11.1	13.1	8.0
COLORADO RIVER			**Clifton**				**Clifton**	
Species			2000	2001			2000	2001
Total Density estimate			600	724			511	532
Flannelmouth Sucker			290	249			204	171
Bluehead Sucker			181	185			72	79
Roundtail Chub			70	57			16	15
DOLORES RIVER			**Big Gypsum**				**Big Gypsum**	
Species			2000	2001			2000	2001
Total Density estimate			116.3	137.1			153.2	28.8
Flannelmouth Sucker			21.2	62.6			52.5	0.9
Bluehead Sucker			1.8	7.5			4.2	0.2
Roundtail Chub			47.9	38.5			8.8	2.6

habitat-switching pattern was also observed in 2001 when flows were dropping. Flannelmouths did not occupy the eddies and pools when flow was above 120 cfs (August 22, 2001), but they were captured in these habitats as flows dropped to near 100 cfs on August 29th and September 5th, 2001.

Smallmouth bass was the only species in **Lily Park** to increase in 2001 (A-Table 1). This increase was believed to reflect a true increase in abundance, as all three Yampa sites displayed bass increases in lower-flow years. The bass density estimate at Lily Park in 2001 (501/km) was the highest of any of the sites on the Yampa River (Table 11).

The Colorado River **Clifton** site was added in 2000 because of differences in channel morphology compared with the Corn Lake site. Total density and total biomass estimates for fish/km and kg/km were similar between Corn Lake and Clifton in both years. But because Clifton was wider, the number of fish per hectare was less than Corn Lake. The total area at Clifton was 27.4 hectares compared to Corn Lake's 20.7 hectares. Both sites had a common flow of 1000 cfs. Clifton and Corn Lake were separated only by 0.2 km. So, it was possible to pool data from the sites and get larger sample sizes for testing estimates there between 2000 and 2001.

The **Clifton** site had the highest estimate of any site for total fish density per kilometer (4007/km) and biomass (3498 kg/km) (Table 11), but **Corn Lake** had the highest density 773/ha and 551 kg/ha biomass estimates by area (Table 12). The mean total fish biomass for both sites in the **15-Mile Reach** was 486 kg/ha. Biomass in the15-Mile Reach was much higher than the Yampa River, except for the Lily Park section where it was 1.4 times higher in 2001. Biomass in the 15-Mile Reach was three to five times higher than at **Sevens** and seven to ten times higher than at **Duffy**.

The **Corn Lake** estimate in 1999 for bluehead sucker was higher than in 2000 and 2001. The density estimate for bluehead and flannelmouth suckers were very similar between Corn Lake and Clifton in 2001. Bluehead sucker density was 1,272/km at **Corn Lake** and 1,206/km at **Clifton**. Flannelmouth-sucker density was 1,662/km at Corn Lake and 1,619/km Clifton (Table 11).

Bluehead-sucker density and biomass estimates were higher in the 15-Mile Reach than in the Yampa and Dolores River. The bluehead sucker's mean kilogram per hectare in the **15-Mile reach** was 3.6 times higher than blueheads at **Lily Park,** 5.5 times higher than **Sevens,** and 22 times greater than **Big Gypsum** (2000 data).

Flannelmouth-sucker density estimates per hectare were higher at **Lily Park** than the **15-Mile Reach.** But, because fish were smaller at **Lily Park**, **Corn Lake** had a higher biomass/ha. These data indicated that flannelmouth sucker habitat at **Lily Park** was nearly as good as the 15-Mile Reach. Flannelmouth sucker biomass at Lily Park was three times higher than **Sevens** and about four times higher than **Big Gypsum**.

Roundtail chub density estimates per kilometer were lower at Corn Lake (171/km), than at Clifton (370/km) (Table 11).

The largest difference between Corn Lake and Clifton in 2001 was in carp abundance (Table 11 and 12). Carp were found to be more mobile than other species between sampling trips. Near the end of sampling in 2001 when flow was lowest, habitats that formerly had a large number of carp at Corn Lake were vacant of carp and it appeared relatively more carp were found in Clifton. In spite of minor differences in density for carp, catfish and white suckers, productivity was very similar between the Corn Lake and the Clifton Stations.

Total fish density and biomass were very different between years at the **Big Gypsum Site** on the **Dolores River.** Base flows were similar between 2000 and 2001 (50 to 60 cfs), but there was a large difference in spring flows. Runoff flows were mild in 2000 with a peak flow of 1170 cfs on May 1, 2000, and peak flow was 533 cfs in 2001. The mean flow for the period April 17 though May 30 was 522 cfs in 2000, but was only 170 cfs in 2001. Reduced spring flows probably caused the lower biomass in 2001.

Dolores River density estimates for native fish >15 cm were low compared to the Colorado and Yampa (Table 11 and 12). The bluehead-sucker estimate was higher in 2001 (13 fish/km) than in 2000 (3 fish/km) due to a higher number of yearling fish in 2001. The Dolores had the lowest bluehead-sucker density estimate of all sites in 2000, but was higher than Duffy in 2001.

Flannelmouth density at Big Gypsum was significantly higher in 2001 at 106/km than 2000 at 36/km (Table 11). The higher flannelmouth abundance in 2001 resulted from a strong yearling group (13 - 18 cm), which was not as high the year before. The low density of adult size native fish in the Dolores River did not appear to be due to lack of recruitment, since juvenile fish were extremely abundant.

It appeared that the Dolores river was a much higher availability of YOY and yearling habitat than it had habitat for adult-sized (>28 cm) fish. Density estimates of roundtail chub were less in 2001 (65/km) than in 2000 (81/km). In 2000, there was a very high number of yearling chub (12 – 19 cm) collected, but the number of yearling fish caught in 2001 was much lower. Either there was poor survival of yearling chub or zero growth in chub since the number of larger fish did not increase.

HABITAT QUANTIFICATION

General Site Description

The Clifton reach on the Colorado River was the longest of the sampling sites followed by Corn Lake, Big Gypsum, Lily Park, Sevens and Duffy Tunnel (Table13). The Clifton reach had a riffle run morphology with a mean slope of 0.2%. An abandoned diversion dam, in the lower part of the site, backed up sediment and created an astomosting channel morphology through much of the Clifton site. Downstream of the dam, the channel was straight and narrow where it entered the Corn Lake reach. The mean width at Clifton was 59 m at 600 cfs (Table 13).

The Corn Lake Reach was located immediately downstream of the Clifton Reach on the Colorado River. Corn Lake had the same riffle run morphology, but was narrower and more constrained than the Clifton Reach. The slope of the Corn Lake was 0.15 percent. The site had the highest mean velocity of all sites. Aerial photograph analysis of the entire 15-mile reach revealed that Clifton site was slightly wider than most of the 15-Mile Reach while the Corn Lake site was slightly narrower. Mean width of Corn Lake was 48 meters at 600 cfs (Table 13)

The Duffy Tunnel on the Yampa River was the widest station with a mean width of 68 m at 600 cfs. Diffy had a low gradient riffle run / pool riffle (slope 0.06%) (Table 13). A significant feature of the Duffy Tunnel Reach was the "Duffy Tunnel" itself, a water diversion in the middle of the sampling reach. Large boulders were located in the channel just downstream of the diversion. In this area the channel widened considerably into an island complex. The Duffy Tunnel Reach was comprised of four runs and three riffles, each riffle being associated with an island complex.

The Sevens site had a mean width of 60 m at 600 cfs, with a slope of 0.05 percent (Table 13). Sevens mirrored the same low gradient riffle run / pool riffle morphology as Duffy Tunnel. The Sevens Reach had a single-thread channel with the upper portion of the channel consisting of tightly spaced pools and riffles (~7.5 channel widths between riffles). The lower 900 meters was one large run.

Lilly Park was steeper, faster, and narrower (Table 13) than the other Yampa River sites and had a characteristic change in morphology between the upper and lower sub-reaches. The upper portion of the reach was shallow with riffle-run morphology. Half way through the reach was a large bend. Below that point the river had tightly spaced pool-riffle sequences (~5 channel widths between riffles).

Mean bed slope was determined from the longitudinal profiles for each site. Negative slopes on the profile occurred in riffles and runs. Positive or up-slopes occurred in glides or in the tail out of pools. The Corn Lake and Clifton longitudinal profile see Appendix-Figures 1 and 2. Lily Park has the highest bed slope and the highest standard deviation suggesting higher variability at this station (A-Figure 3). Longitudinal profiles for Sevens, Duffy and Big Gypsum are presented in (A-Figure 4, 5 and 6 respectively).

Habitat Composition and Habitat Diversity

The surface area of the 16 meso-habitats types was used to determine habitat composition at each site for each simulated flow. The 16 meso-habitat types were composed of five pools, five runs, four riffles and two rapids (Table 4). The flow at the time of fish sampling was used to compare habitat composition and diversity between rivers. For the Colorado River this flow was 1000 cfs. Only about 7% of the habitat was in the pool category (Table 14). Clifton had about 17% pool and backwater at 1000 cfs. Lily Park was 19% pool habitat at 250 cfs (Table 14). At 250 cfs Lily Park, Sevens and Duffy were dominated by run habitats. Pools were common in the main channel (Table 14).

Table 13. Physical attributes of each study site (mean velocity, length, mean width, surface area at modeled flows).

	Big Gyp	Clifton	Corn Lake	Duffy	Lilly	Sevens
*Mean Velocity (m/s)	0.28	0.44	0.54	0.39	0.51	0.38
Length (km)	3.3	4.2	3.9	2.1	3.1	2.9
*Width (m)	22	59	50	68	57	60
Percent Slope	0.15%	0.20%	0.16%	0.06%	0.20%	0.05%
Flow (cfs)	Area (ha)					
10	6.0					
20	6.3					
30	6.5					
40	6.7				12.9	11.8
50	6.8					
60	6.9			10.8	12.9	13.1
80	7.0			11.2	12.9	13.7
100	7.1	16.4	11.2	11.6	13.1	14.3
125				11.9		
150		18.5	15.5	12.2	14.4	15.1
200	7.6	19.6	16.3	12.6	14.9	15.6
250		20.6	17.0	12.9	15.1	15.9
300	7.8	21.3	17.7	13.2	15.1	16.2
350		21.9	18.1			
400	8.0	22.4	18.5	13.6	16.7	16.7
450		22.9	18.8			
500	8.2	23.3	19.2	13.9	17.0	17.1
600		24.2	19.8	14.2	17.6	17.4
700		25.3	20.2			
800		26.0	20.7			
880						18.1
900		26.8	20.4			
1000		27.4	20.7			
1200		28.5	22.1			
1400		29.3	22.7			
1600		30.2	23.3			
1800		31.0	23.8			
2000		31.8				

Velocities and mean width calculated at 600cfs, except for Big Gypsum which were calculated at 100cfs

Meso-habitat composition varied with discharge, since meso-habitats were defined by depth and velocity criteria. At Corn Lake and Clifton, pool composition was highest (40% and 60%) at the lowest modeled flow of 100 cfs and quickly decreased as flows increased to 800 cfs (A-Figures 11a and 11c). At 1000 cfs, Corn Lake had the highest composition of riffle habitat at 53% while Clifton had 39% (Table 14, and A-Figures 11a and 11c). At 250 cfs, the Yampa River had a low amount of riffle habitat compared to the Colorado River. Lily Park had more riffle habitat at 250 cfs (10%) than Sevens (2%) and Duffy (6%) (Table 14, A-Figures 12a, 12c, 13a).

Base flows on the Dolores River at the time of electro-fishing were about 50 to 60 cfs. Habitat composition at this flow was 51% pools and only 5% riffle (Table 14, A-Figure 13c).

The lowest of amount of riffle habitat per kilometer was at the Big Gypsum Site. The highest amount of riffle habitat was at Clifton (2.58 ha) (Table 14). These two sites also had the lowest (Big Gypsum, 259) and the highest (Clifton, 3,440) total fish biomass (kg/km). The R-square value for a simple linear regression between riffle area and total fish biomass was 0.85 (Table 15). Riffle habitat at the Duffy site was intermediate to Sevens and Lily Park. Yet, total fish biomass was much less at Duffy. Fish biomass at Duffy was likely reduced by higher predation rates. Habitat data there suggested a higher total fish biomass potential than was observed.

Table 15. Correlation between riffle meso habitat and total fish biomass

		Clifton	Corn	Lily Park	Sevens	Duffy	Big Gypsum
Riffle		2.58	2.08	0.55	0.12	0.30	0.09
Total biomass		3440	2740	2064	1071	482	259
R Square	0.847535						

Deep pools were found to be uncommon habitats in all sites. At low flows velocities are low. At high flow when depths are higher, low velocity areas are confined to backwaters. Deep pools seemed to be used primarily by larger fish including larger predators. Small fish tended to occupy shallow pools or shorelines. Species that appeared to require deep pools and runs (over 1-meter depth) included mostly channel catfish, carp and white suckers. The Clifton station, with the most deep-pool and deep-run habitat, also had the greatest combined biomass of catfish, carp and white suckers (Table 16). The R-square value for this regression was 0.89.

Table 16. Correlations between pool habitat and biomass for carp, white sucker and catfish.

		Clifton	Corn	Lily Park	Sevens	Duffy	Big Gypsum
Deep pool & deep run		1.53	1.07	0.76	0.88	0.46	0.17
tot biomass		1581	767	740	492	373	95

R Square 0.8854

The bluehead sucker is a native fish and one of the primary species of interest for this study. Habitat requirements of this fish indicate a relationship between bluehead sucker biomass and deep-riffle meso-habitat availability. The Colorado River sites had much greater deep-riffle meso-habitat than either the Yampa and Dolores Rivers. The R-square value for deep-riffle habitat and total bluehead biomass was 0.92 (Table 17). It appeared that a lack of deep and swift habitat (deep-riffle) in the Yampa River explained why blueheads tended to be smaller at Lily Park. The Duffy site had lower bluehead sucker biomass relative to the other Yampa River sites and relative to riffle habitat availability. This was explained by hybridization with the white sucker.

Table 17 Correlation between deep riffle habitat and bluehead sucker biomass

	Clifton	Corn	Lily Park	Sevens	Duffy	Big Gypsum
Deep riffle	1.53	1.41	0.05	0.02	0.01	0.00
Bluehead biomass	497	550	195	102	12	7
Bluehead R Square	0.9158					

Habitat diversity based on the 16 meso-habitat compositions varied greatly among sites. The Shannon Weaver diversity at the base flow representative of the fish surveys was highest at Clifton followed by Corn Lake, Big Gypsum, Lily Park, Sevens and Duffy (Table 14). A visual display of habitat diversity for each simulated flow is given in Appendix Figures 11, 12 and 13.

The maximum Shannon-Weaver value for 16 meso-habitats was 2.776. Habitat diversity (Shannon-Weaver) peaked at 1000 cfs at Clifton (2.47) and at 1200 cfs at Corn Lake (2.23), which were typical of flow conditions during the fish-sampling period. Since flows were not modeled above 600 cfs for the Yampa River, the flow that habitat diversity peaked was not identifiable. However, at 600 cfs Lily Park had the greatest habitat complexity according to Shannon-Weaver diversity (2.22) followed by Sevens (1.92). Duffy was the least complex (1.73). This order of habitat complexity matches the order of fishery diversity found on the Yampa River.

Habitat Suitability

We used the finer scale (Polygon) method to determine fish habitat suitability criteria based on how fish distributed themselves within the study site. Polygons were sub units of a study site and possessed both electro-fishing and habitat data. The polygon analysis referred to the process where biomass was used to identify suitable and non-suitable habitats. Habitat suitability for bluehead and flannelmouth suckers was calculated at Corn Lake, Clifton, Lily Park and Sevens (A-Table 3, 4, 5, and 6 respectively). Polygon data from Duffy was not included due to the very low occurrence of native suckers there (A-Table 7). Polygon data from the Big Gypsum site was not included because the 2-D model simulations were not available when this analysis was performed. Inclusion of the Big Gypsum data would likely not alter results because at 50 to 60 cfs the Big Gypsum site lacked both habitat and biomass diversity.

In 2000 and 2001, shoreline electro-fishing was done at Corn Lake and Clifton to sort out bank habitat from mid-channel habitat. Very few adult bluehead and flannelmouth suckers were collected along from the shoreline making it unnecessary to keep shoreline polygons for these fish. The adult bluehead and flannelmouth sucker did not occupy bank habitat. This was another indication that these fish avoid areas with depths less than 0.3 m and velocities less than 0.35 m/s.

The polygon analysis found that bluehead sucker biomass increased in polygons with higher velocities (A-Tables 3, 4, 5, 6 and 7; A-Figure 14a). Polygons that had velocities over 0.6 m/s had much higher biomass than polygons with velocities less than 0.5 m/s. There were no polygons with a mean velocity over 0.6 m/s on the Yampa River.

All polygons with higher velocity criteria were on the Colorado River data. The bluehead sucker Sigma plot (A-Figure 14a) also showed mean depths of 0.5 to 1.0 m having higher biomass than shallower depths.

The sigma plot for flannelmouths showed these fish were more abundant in polygons with mean velocities over 0.5 m/s and depths over 0.6 m (A-Figure 14b).

The sigma plot representation was simplified into four functional meso-habitat types based on depth and velocity characteristics. The poorest habitat for blueheads was classified as **Unusable** (Figure 7) and represented the river areas that blueheads did not occupy. Polygons with the highest biomass were used to indicate **Optimal** habitat conditions (depths and velocities). Optimal polygons accounted for about 60% of the total bluehead biomass. The mean biomass for all optimal biomass polygons was found to be about 243 kg/ha (Figure 7). **Marginal** habitat represented about 25% of the total biomass. The mean biomass for polygons in the marginal category was 116 kg/ha. The remaining 15% of the total biomass represented the **Unsuitable** category (Figure 7). Unsuitable habitat had a biomass value of 31 kg/ha.

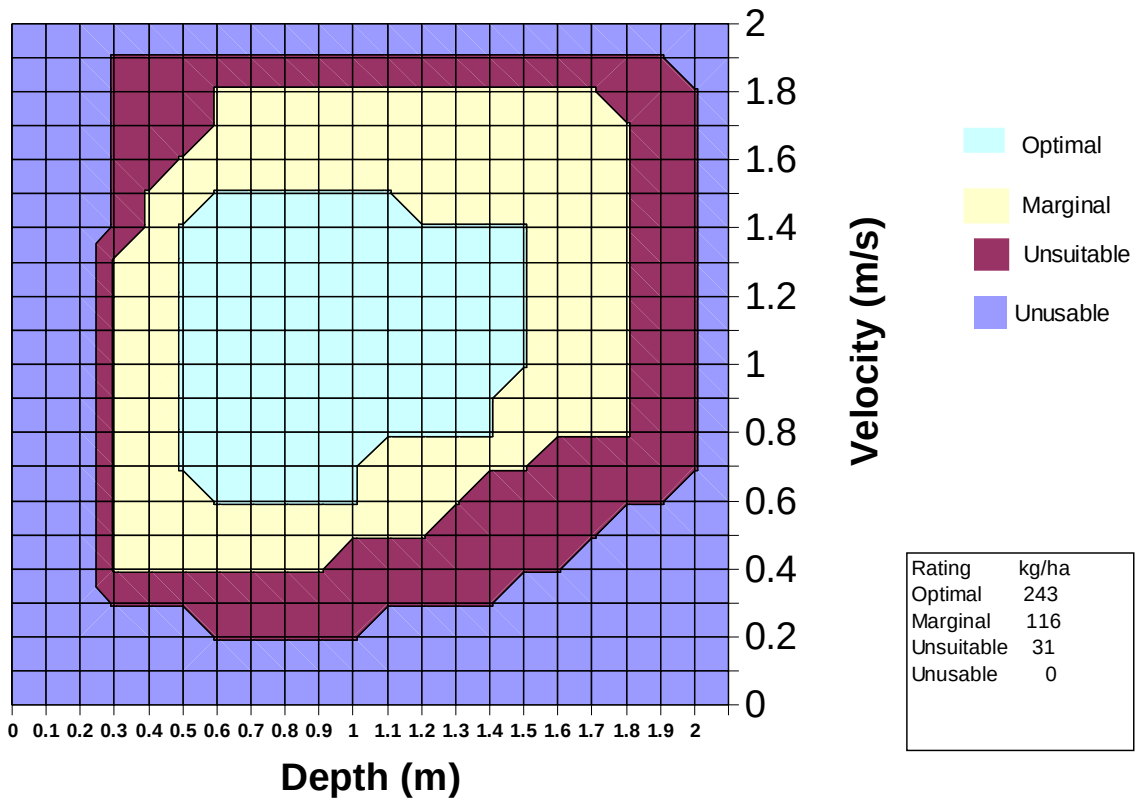


Figure 7. Depth and velocity criteria used to model bluehead habitat availability.

Habitat suitability criteria for flannelmouths were also developed using the above-described polygon analysis approach. The sigma plot for flannelmouths showed biomass associated with mean depths and velocities for that polygon (A-Tables 3, 4, 5, 6, and 7). Very few flannelmouth were observed from habitats with velocities less than (0.3 m/s) (A-Figure 14b). **Unusable** habitat for flannelmouths represented the river areas where they were not found. **Optimal** polygons accounted for about 60% of total biomass. The mean biomass for all optimal biomass was found to be about 496 kg/ha (Figure 8). **Marginal** habitat represented about 25% of the total biomass and was 253 kg/ha. **Unsuitable** was about 15% of the total biomass and was a value of 123 kg/ha.

The higher biomass for flannelmouths resulted primarily from their larger body size. Larger flannelmouths were more frequent in the Colorado River than in the Yampa. Also flannelmouth and bluehead densities were fairly similar in the Colorado River. But, in the Yampa River flannelmouths had much greater density than the bluehead.

Development of biologically based habitat suitability criteria made it possible to determine the relationship between flow and habitat availability. The suitability criteria were validated by the high R-square value for the regression between observed and predicted biomass values for the bluehead (0.91) and flannelmouth (0.93).

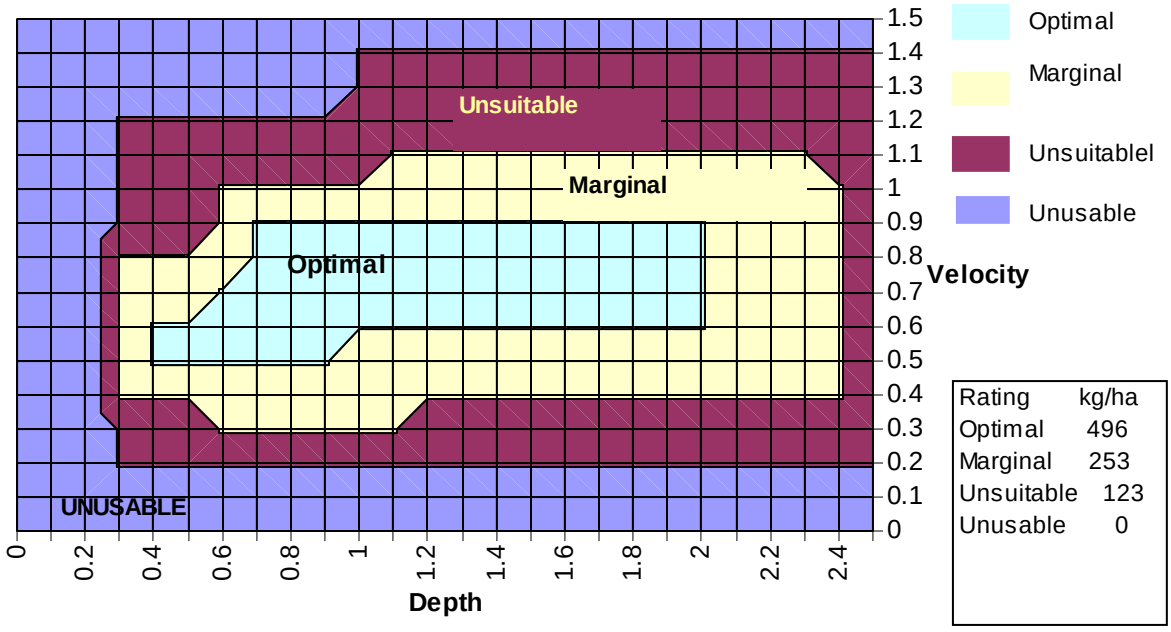


Figure 8. Flannelmouth sucker depth and velocity criteria used to model bluehead habitat availability.

HABITAT AVAILABILITY VERSUS FLOWS

Habitat availability for each of the four functional meso-habitat types (Optimal, Marginal, Unsuitable and Unusable) was calculated using the 2-D flow model data for simulated flows at each site. The habitat suitability graphs were the final product in the Meso-Habitat methodology and showed how total habitat was related to flow. The functional meso-habitat graphs were for adult (>20 cm) bluehead and flannelmouth suckers. Optimal habitat represented about 60% and Marginal habitat represents about 25% of the total biomass. The Unsuitable habitat represented about 15% of the biomass and Unusable supported zero biomass. At low flows, Unusable habitat always increased the area and percentage of blueheads and flannelmouths since both depths and velocities decreased.

– Bluehead sucker

Flows modeled at **Corn Lake** ranged from 100 to 1800 cfs. Unusable habitat decreased rapidly from 150 to 800 cfs and was fairly constant from 1000 to 1800 cfs. Optimal habitat increased with increasing flow upt to 1200 cfs. Above 1200 cfs optimal habitat increased at a slower rate. Both marginal and unsuitable peaked at near 500 cfs (Figure 9).

The range of flows modeled at **Clifton** ranged from 100 to 2000 cfs. Clifton had more total surface area than Corn Lake. There was about four ha more of the Unusable habitat at Clifton than at Corn Lake. The wider channel and higher amount of pool habitat at Clifton did not to translate to increased habitat or abundance of blueheads. The Unusable area peaked at 16 ha, remaining high at 10 ha at 1500 cfs (Figure 10). Optimal habitat increased linearly from 300 to 1800 cfs. At 1000 cfs, Optimal habitat was near six ha while Marginal habitat was also near six ha, similar to Corn Lake. Marginal habitat had an inflection point at 700 cfs. Unsuitable habitat had an inflection point at 300 cfs (Figure 10).

Flows modeled at **Lily Park** ranged from 40 to 600 cfs. At the start of the project we believed that 600 cfs would be high enough to be inclusive for making instream flow recommendations. Nonetheless, relationships between flow and the functional meso-habitat types would have been clearer if flows had been modeled up to at least 1000 cfs. Unusable habitat decreased fairly linearly from 40 (12.5 ha) to 600 cfs (six ha). Unsuitable habitat peaked at about 250 cfs and was fairly constant above this flow. Below 250 cfs, Optimal habitat availability was very low. At 600 cfs, Optimal habitat increased to two ha, which was very similar to availability on the Colorado River (three ha at Corn Lake and two ha at Clifton). Marginal habitat was near zero at 100 cfs and increased to five ha at about 500 cfs (Figure 11), which was also similar to the two Colorado River sites.

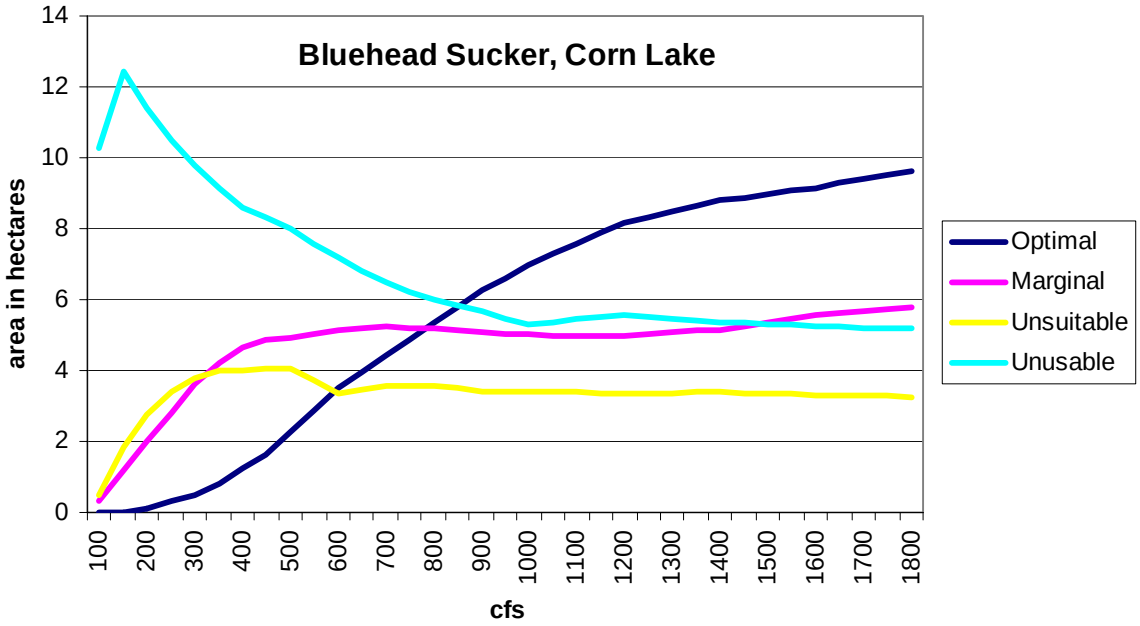


Figure 9. Bluehead sucker habitat availability at Corn Lake, Colorado River.

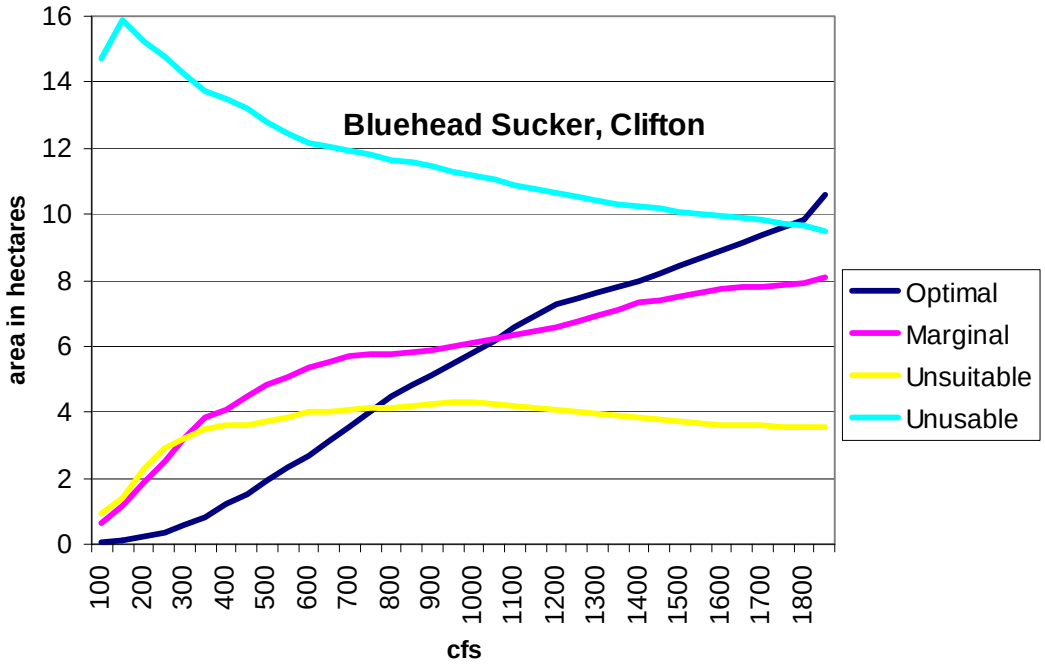


Figure 10. Bluehead sucker habitat availability at Clifton, Colorado River.

Flows modeled at **Sevens** ranged from 40 to 880 cfs. At flows less than 100 cfs nearly 100% of the river was in the Unusable habitat category. Unusable habitat was about six ha at 550 cfs. Marginal habitat peaked near 5.5 ha at 550 cfs (Figure 12). Optimal was only one ha at 600 cfs, about half that found at Lily Park and the Colorado River sites. Optimal habitat availability increased to over four ha at the highest modeled flow of 880 cfs and the rate of increase was faster above 600 cfs. The rapid increase in Optimal habitat indicated that depths and velocity increased more quickly above 600 cfs than below 600 cfs. Flows less than 250 cfs produced a very low amount of adult bluehead sucker habitat in the Marginal and the Optimal categories (Figure 12)

Flows modeled at **Duffy** ranged from 40 to 600 cfs. At 600 cfs, marginal habitat was at 3.9 ha and Optimal was less than 1 ha. Like Sevens, Duffy has a flat slope and did not appear to have high potential for a large bluehead-sucker population at flows less than 250 cfs. Unusable habitat at Duffy peaked at 125 cfs and was the most common habitat type until flows reached 500 cfs (Figure 13).

Flows modeled at **Big Gypsum** ranged from 10 to 500 cfs. These ranges appeared adequate to bracket curve breaks for both higher and lower base flows. Curve breaks for Unusable, Unsuitable and Marginal were all near 200 cfs (Figure 14). Flows less than 80 cfs provided less than 0.6 ha Optimal habitat. Wetted width at Big Gypsum was less than half that of the Yampa and Colorado rivers, so hectare per unit discharge was less.

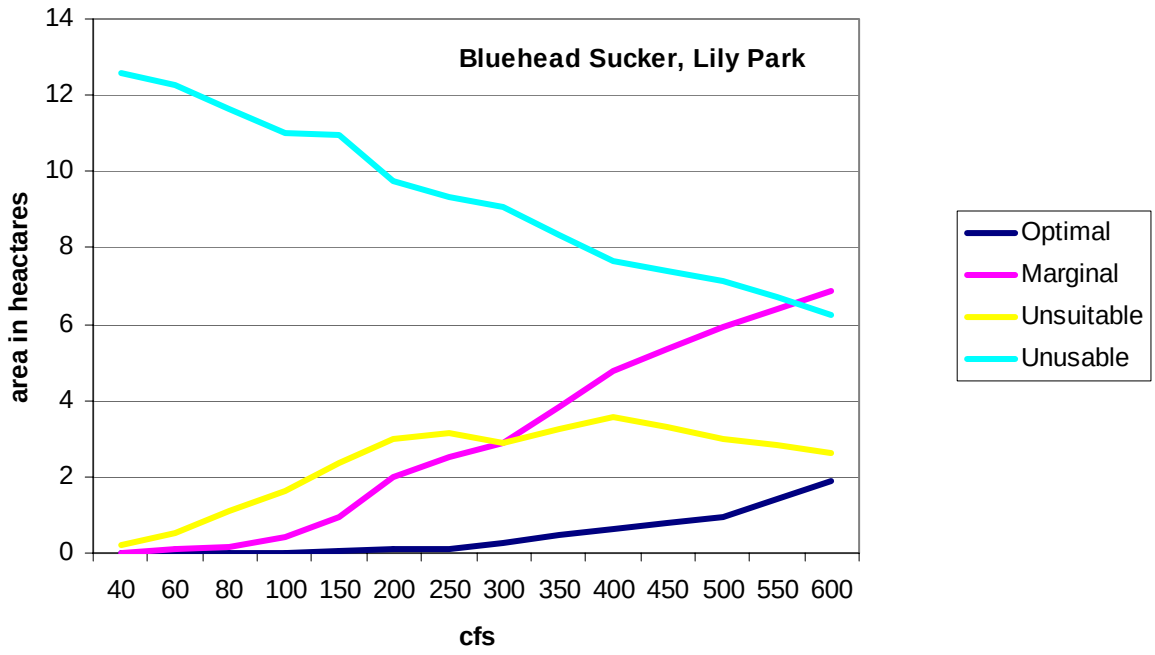


Figure 11. Bluehead sucker habitat availability at Lily Park, Yampa River.

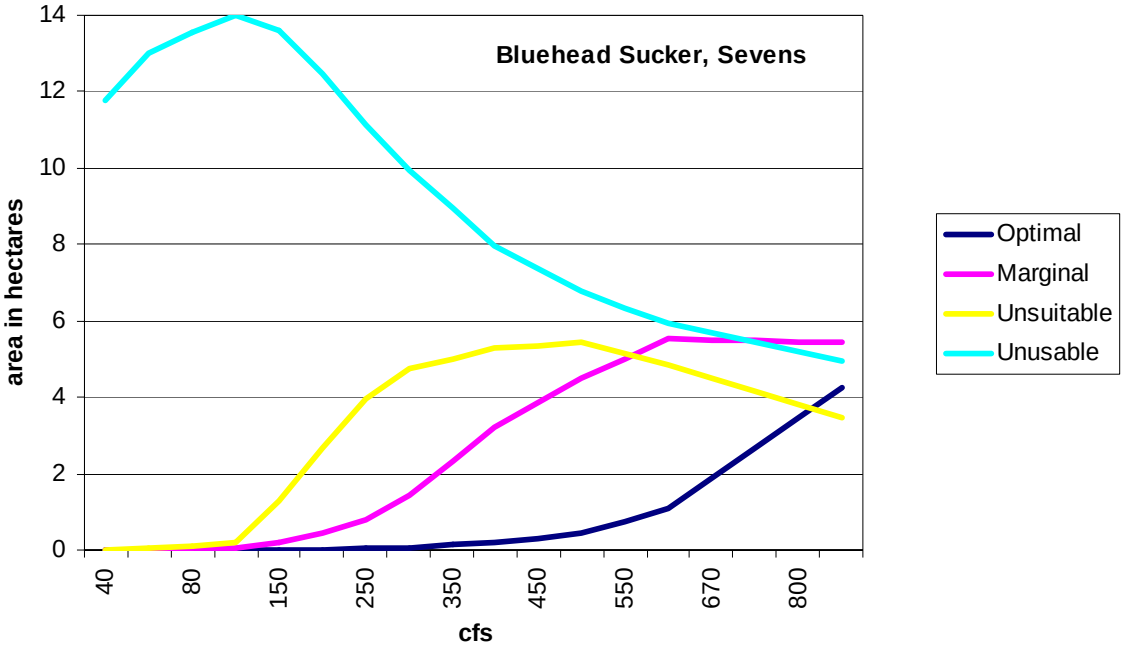


Figure 12. Bluehead sucker habitat availability at Sevens, Yampa River.

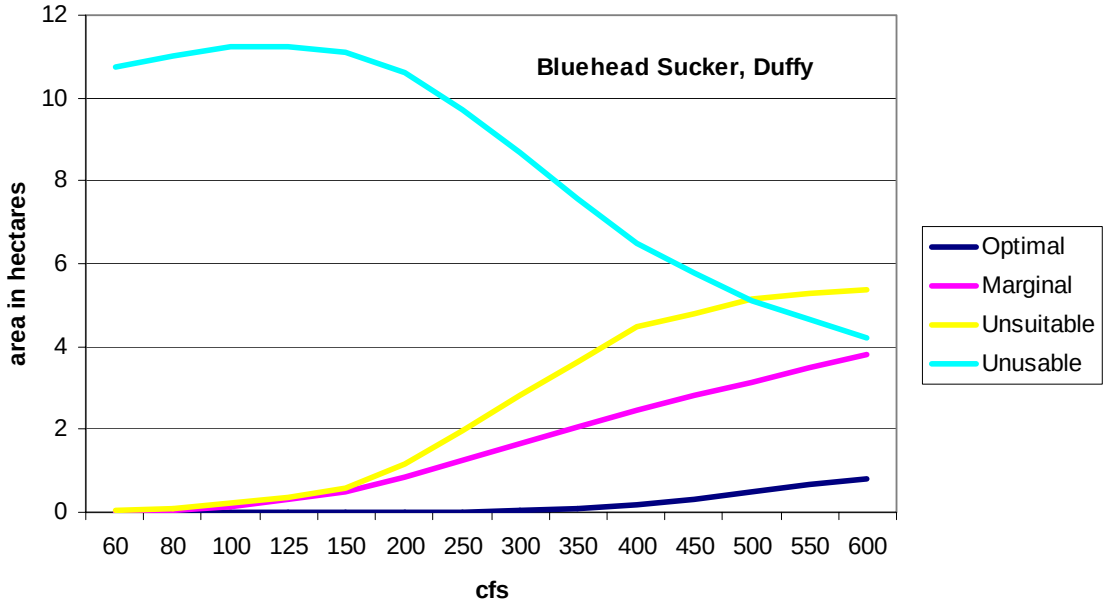


Figure 13. Bluehead sucker habitat availability at Duffy, Yampa River.

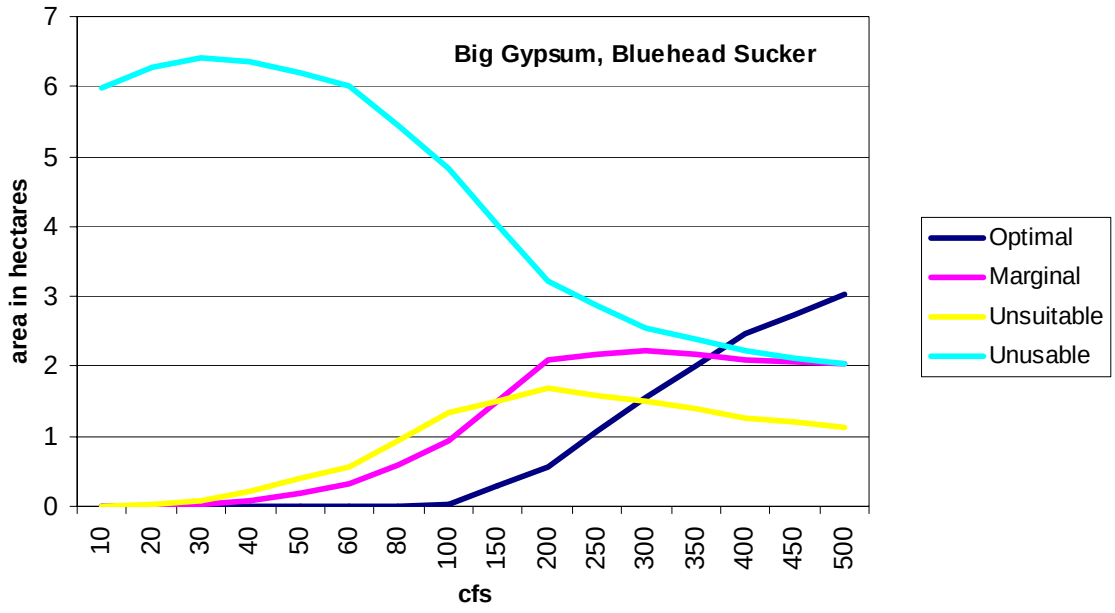


Figure 14. Bluehead sucker habitat availability at Big Gypsum, Dolores River

When habitat availability (Figures 9 to 13) in hectares is multiplied by the mean biomass associated with each habitat type (Optimal, Marginal and Unsuitable) the product represents a biomass projection for each simulated flow. The mean biomass for blueheads was zero in Unusable habitat (polygons), 31 kg/ha for Unsuitable polygons, 116 kg/ha in Marginal and 243 kg/ha in Optimal polygons (Figure 7). The biomass projection curve was therefore a composite of the four functional meso-habitat types, which simplified comparisons of habitat availability between sites.

The Big Gypsum site had higher projected biomass at lower flows than the other sites (Figure 15). Big Gypsum had a much narrower wetted width (18.5 m) and a fairly high bed slope of 0.15%. The smaller channel meant suitable depths and velocities were achieved at lower flows. Big Gypsum also had the highest projected bluehead biomass of 121 kg/ha at 500 cfs (Figure 15). There was a curve inflection in the Big Gypsum projection curve at 80 cfs and another at 200 cfs. Below 80 cfs, bluehead biomass was computed to be less than 5 kg/ha, which was near the flow and biomass observed during data collection.

The Corn Lake site had the highest projected biomass for flows over 250 cfs for the large rivers (Figure 15). Corn Lake has a narrowest stream width (48 m) of the Colorado and Yampa River sites and a higher bed slope of 0.15%. Since discharge equalled width x depth x velocity, the narrower width at Corn Lake produced higher mean depth and/or velocity values for the higher range of flows. The Corn Lake

bluehead biomass curve had its steepest slope below 600 cfs. At base flows of near 1000 cfs, biomass at Corn Lake was projected to be near 115 kg/ha. Corn Lake was sampled during three years and bluehead biomass was observed to be near 110 kg/ha at base flows of near 900 to 1000 cfs.

Lily Park had the highest projected biomass of blueheads at flows less than 250 cfs (Figure 15). The higher mean bed slope (0.2%) accounted for more biomass potential at lower flows than at Corn Lake. The projected biomass curves at Lily Park and Corn Lake were very similar, which meant physical habitat was very similar for these two sites. The most obvious physical difference between these two sites was the level of their base flows. Given similar base-flow scenarios, the two sites were expected to have similar bluehead population characteristics. The deeper and faster habitats and larger-sized bluehead suckers, common at Corn Lake, were lacking at Lily Park. In 2001 the bluehead biomass estimate was about 32 kg/ha at Lily Park.

The Clifton site had the third highest predicted bluehead biomass for flows from 100 cfs to 600 cfs among the large rivers studied. Wetted width (60 m) and mean bed slope (0.2%) were also high at Clifton. Even though bluehead population characteristics were nearly identical between Clifton and Corn Lake, biomass projections were less at Clifton because of higher total surface area there. The greater amount of off-channel or backwater habitat at Clifton was found to be unusable habitat for adult blueheads. Figure 15 indicates that at a flow of 600 cfs, bluehead biomass was expected to be very similar for Clifton, Sevens and Duffy.

Sevens and Duffy had similar wetted widths of 60 m and 68 m respectively and the lowest mean bed slopes (0.05% and 0.06% respectively) of the six study sites. The flatter nature of the two sites was reflected in a reduced amount of bluehead potential. At 400 cfs, the bluehead biomass was projected to near 35 kg/ha. It quickly dropped to six kg/ha at a flow of 150 cfs for both sites (Figure 15).

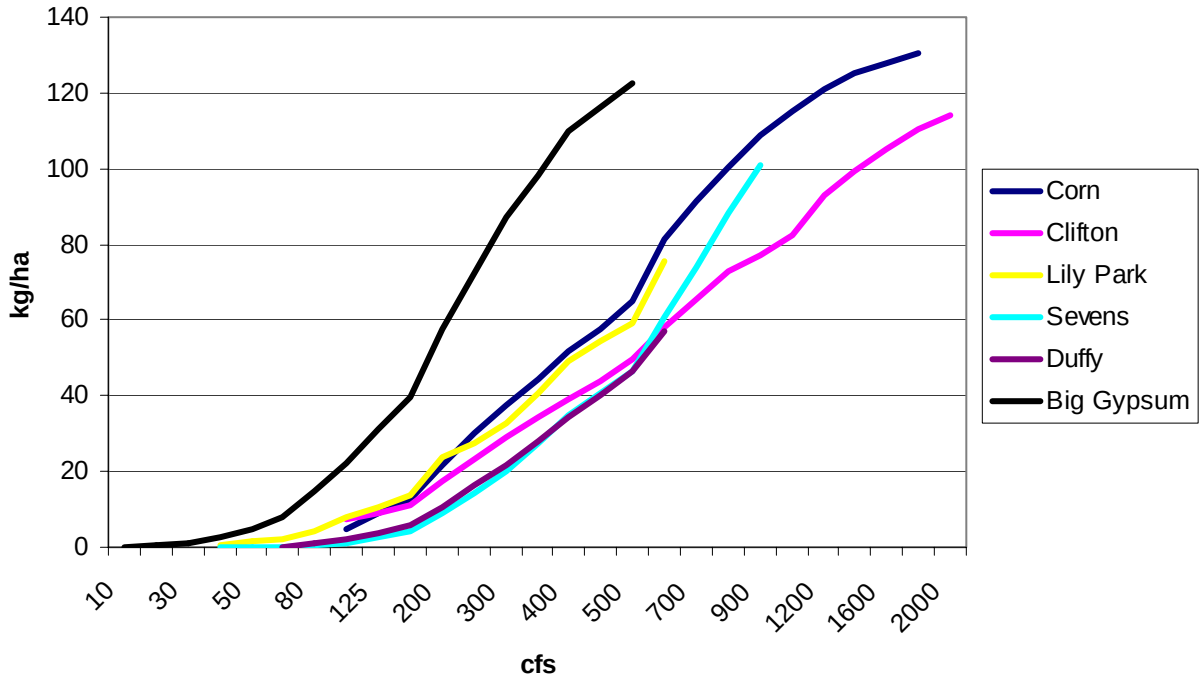


Figure 15. Projected biomass (kg/ha) of blueheads based on habitat availability over a range of simulated flows.

The projected adult bluehead biomass was regressed against the measured biomass for all stations with data except for Duffy. Duffy was excluded because non-hybridized blueheads were very rare at that site, a condition amplified by predation and not due strictly to habitat availability. Measured biomass was the kg/ha of blueheads determined by fall electro-fishing. To make the comparison between measured and predicted biomass, it was necessary to select a flow that represented the base flow for that year's sample. Some years have higher base flows than others, but the minimum flow likely does not set carrying capacity for the entire year since it only occurs for a singe day (Table 19). The median flow (177) had an even number of days above and below this level (Table 19). The 60-day low-flow was selected as the flow to use for the comparison between measured and projected biomass. The 60-day low-flow day meant there were 59 days in the water year with less flow and 305 days with higher.

Table 18. The 1, 10, 20, 40, 60, 100 and 177 low-flow days for the Maybell, Lily Park, Palisade and Bed Rock gages for years with fishery biomass data.

1998	1	10	20	40	60	100	177
Maybell	115	170	194	280	350	500	808
Lily Park	157	210	241	340	433	540	802
1999	1	10	20	40	60	100	177
Maybell	110	176	212	247	290	362	469
Lily Park	110	210	226	274	327	400	490
Palisade	435	710	1190	1380	1510	1720	1970
2000	1	10	20	40	60	100	177
Maybell	30	50	67	113	199	275	352
Lily Park	30	70	99	125	196	303	364
Palisade	581	694	749	901	1090	1620	1880
Bed Rock	25	33	37	48	52	54	59
2001	1	10	20	40	60	100	177
Maybell	50	70	94	123	160	210	255
Lily Park	67	95	126	160	201	240	280
Palisade	477	580	690	828	927	1080	1340
Bed Rock	26	32	36	38	42	45	52

The R square value for the project versus measured biomass of 0.91 indicated that this analysis gave a good reflection of the measured data (Figure 15). The highly significant relationship was due to the wide range of flow conditions used in development of the Meso-habitat model. Flows less than 800 cfs during the base flow period were not common on the Colorado River and base flows were generally less than 300 cfs on the Yampa River. Additional data for this validation approach will become available when fish sampling is conducted at the Colorado and Yampa River sites in 2003 and when a site on the Gunnison River is added in 2005.

– Flannelmouth sucker

Flannelmouth habitat data was analyzed in the same manner described for bluehead sucker. In general, flannelmouths were found to prefer habitats with somewhat less velocity and greater depths than blueheads. Flannelmouth and bluehead density estimates were similar for the Colorado River, but biomass estimates for flannelmouths were higher because these fish achieve a larger body mass. On the Yampa River, flannelmouths had higher density and biomass estimates than bluehead sucker at all three sampling sites.

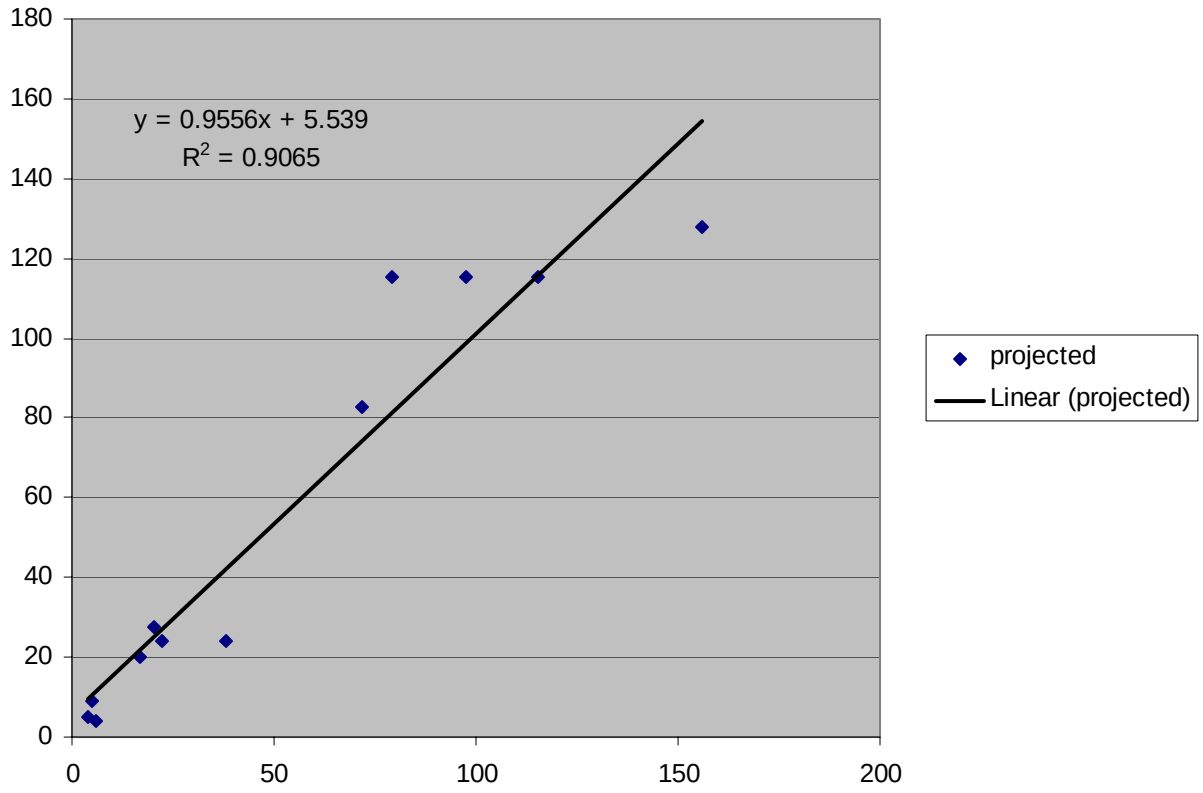


Figure 16. Projected versus observed bluehead biomass for five study sites.

The flows modeled at **Corn Lake** ranged from 100 to 1800 cfs. Unusable flannelmouth habitat was minimized near 5 ha in the flow range of 800 to 1000 cfs. Sampling on the Colorado River in 2000 and 2001 was performed at flows in the 900 to 1000 cfs ranges. These flows appeared to provide near maximum habitat for flannelmouths. Flows over 1200 cfs do not improve habitat availability for flannelmouths. Optimal habitat was highest at about 5.5 ha (1000 cfs), while Marginal habitat peaked at 7 ha at 1200 cfs. There was an inflection of the Marginal habitat curve at 500 cfs indicating a rapid decline in flannelmouth habitat when flows drop below 500 cfs (Figure 17).

The flows modeled at **Clifton** ranged from 100 to 2000 cfs. Clifton had about 4 to 5 ha more of the Unusable category than Corn Lake at similar flows. Unusable area peaked at 15 ha at 100 cfs and was at its minimum, 10 ha, at a flow of 800 cfs (Figure 22). Optimal habitat increased linearly from 10 to 1100 cfs. At flows of 1200 to 1500 cfs, flannelmouth habitat was maximized at the Clifton station. At 1500 cfs, both Marginal and Optimal habitats were near 7 ha. Marginal habitat had an inflection point at 700 cfs and Unsuitable habitat had an inflection point at 300 cfs (Figure 18).

Flows modeled at **Lily Park** ranged from 40 to 600 cfs. Unusable habitat decreased fairly linearly from 40 (12 ha) 600 cfs (5 ha). Unsuitable habitat peaked from

250 cfs to 400 cfs. The maximum optimal habitat likely occurred at a flow higher than 600 cfs. At 600 cfs, Optimal was four ha and Marginal was five ha. At 600 cfs Lily Park was very similar in habitat availability to both Colorado River sites. Below 200 cfs, Marginal habitat decreased and Optimal habitat became rare. Below 100 cfs Marginal habitat was very poor and Optimal was near zero (Figure 19).

Flows modeled at **Sevens** ranged from 40 to 880 cfs. At flows less than 100 cfs, nearly all habitat was in the Unusable category at 12 to 14 ha. Unusable habitat was below four ha at flows over 600 cfs. Marginal habitat peaked near 6 ha at 600 cfs (Figure 20). Only one ha of Optimal habitat occurred at 450 cfs. There were less than 3 ha at 600 cfs. At flows over 600 cfs, Optimal habitat increased at a faster rate and was about 6 ha at the highest modeled flow of 880 cfs. At flows less than 200 cfs, very little river area was in either the Marginal or Optimal categories for flannelmouths.

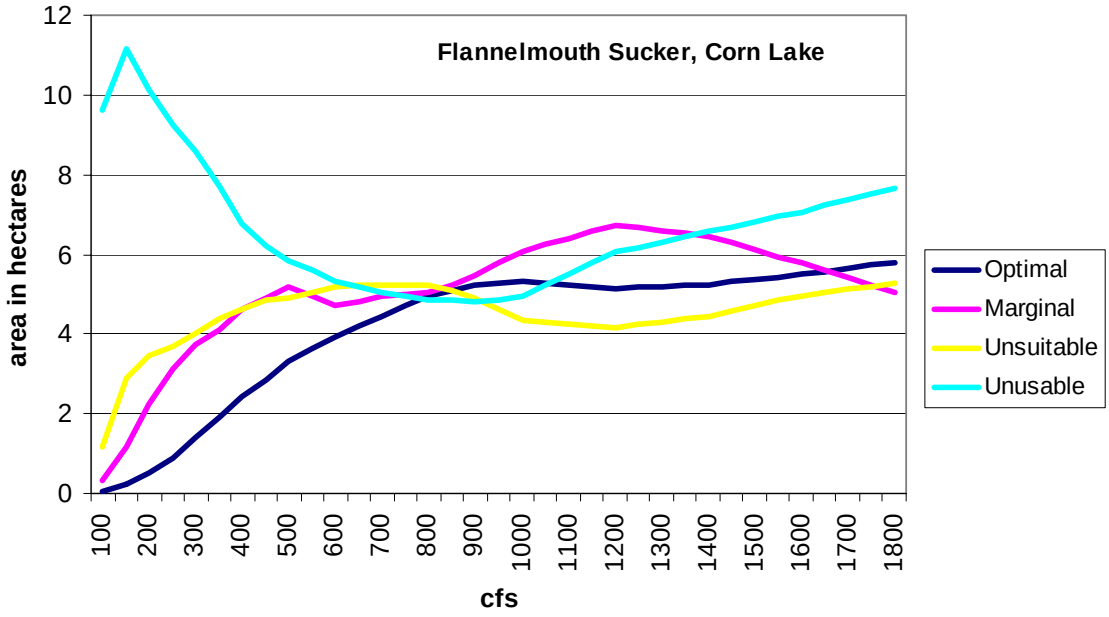


Figure 17. Flannelmouth sucker habitat availability at Corn Lake, Colorado River.

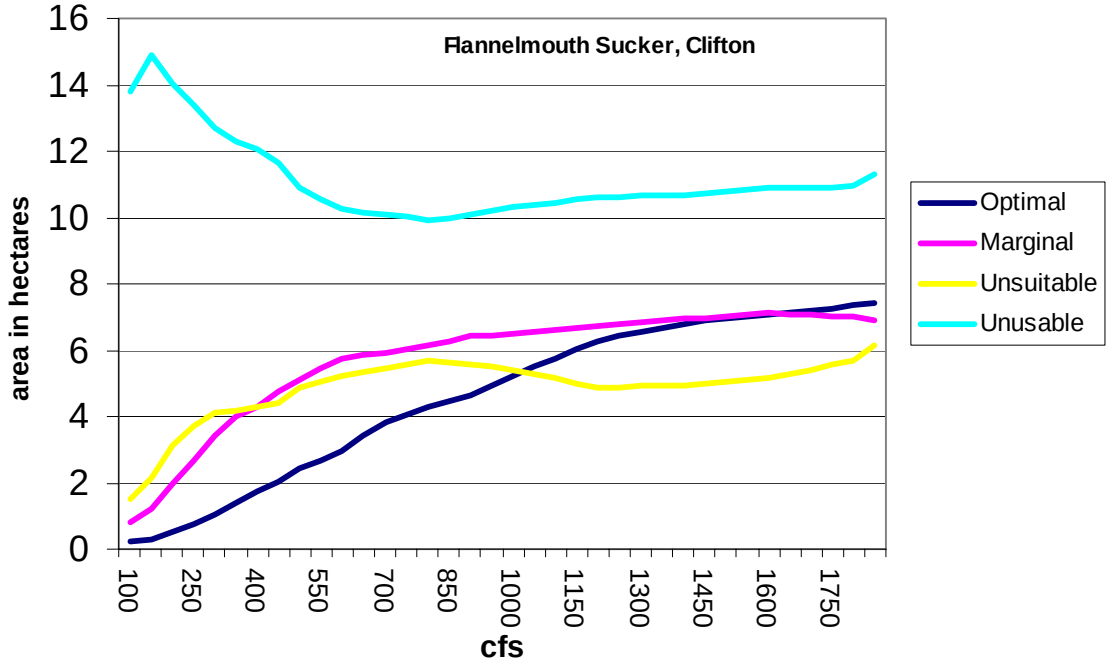


Figure 18. Flannelmouth sucker habitat availability at Clifton, Colorado River.

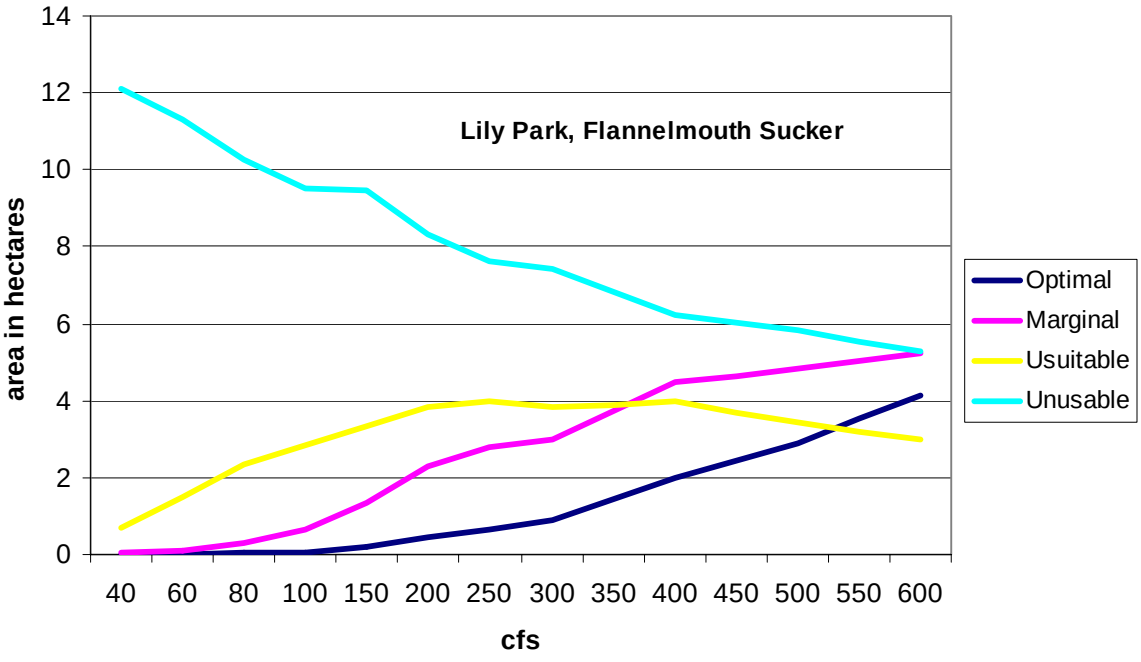


Figure 19. Flannelmouth sucker habitat availability in ha at Lily Park, Yampa River.



Figure 20. Flannelmouth sucker habitat availability in ha at Sevens, Yampa River

Flows modeled at **Duffy** ranged from 40 to 600 cfs. Unusable habitat at Duffy peaked at about 11 ha at 100 cfs and was the most common habitat type until flows reached 400 cfs (Figure 21). At 600 cfs unusable habitat was less than 3 ha. Unsuitable habitat was highest at 400 cfs. Marginal habitat increased slowly from 60 to 300 cfs. Optimal habitat was about 1.5 ha at 600 cfs. Duffy appeared to have the least amount of flannelmouth sucker habitat of the study sites in the lower ranges of flows

Flows modeled at **Big Gypsum** ranged from 10 to 500 cfs. Unusable habitat dropped from a high of 6 ha to about 1.7 at 150 cfs. Optimal habitat increased steadily from 100 to 550 cfs (Figure 22). Flows over 150 cfs did not improve marginal habitat. Flows less than 80 cfs did not provide optimal flannelmouth habitat. Flows less than 40 did not provide marginal habitat. The Big Gypsum station was sampled at a flow near 60 cfs, but flows can get well below 60 cfs in some years.

Adult flannelmouth (>20 cm) biomass was projected for each simulated flow by multiplying habitat availability (ha) times the mean biomass for each type. Unusable habitat had a zero biomass value. Unsuitable had a mean biomass of 123 kg/ha. Marginal had a mean biomass of 253 kg/ha Optimal was 496 kg/ha. The projected biomass curve was a composite of these four functional meso-habitat types.

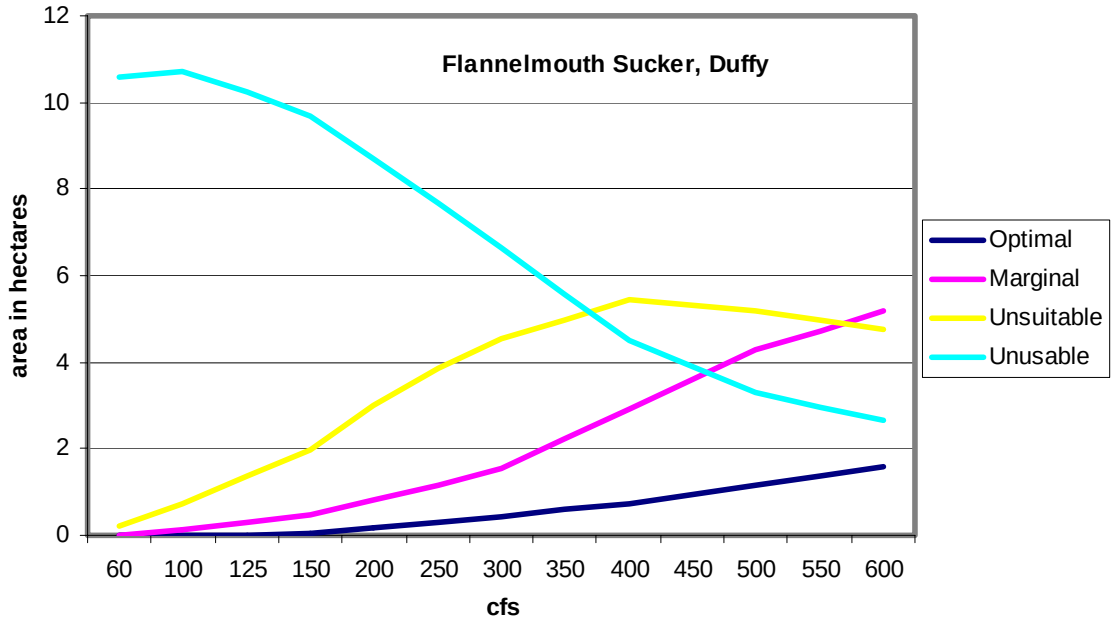


Figure 21. Flannelmouth sucker habitat availability at Duffy, Yampa River.

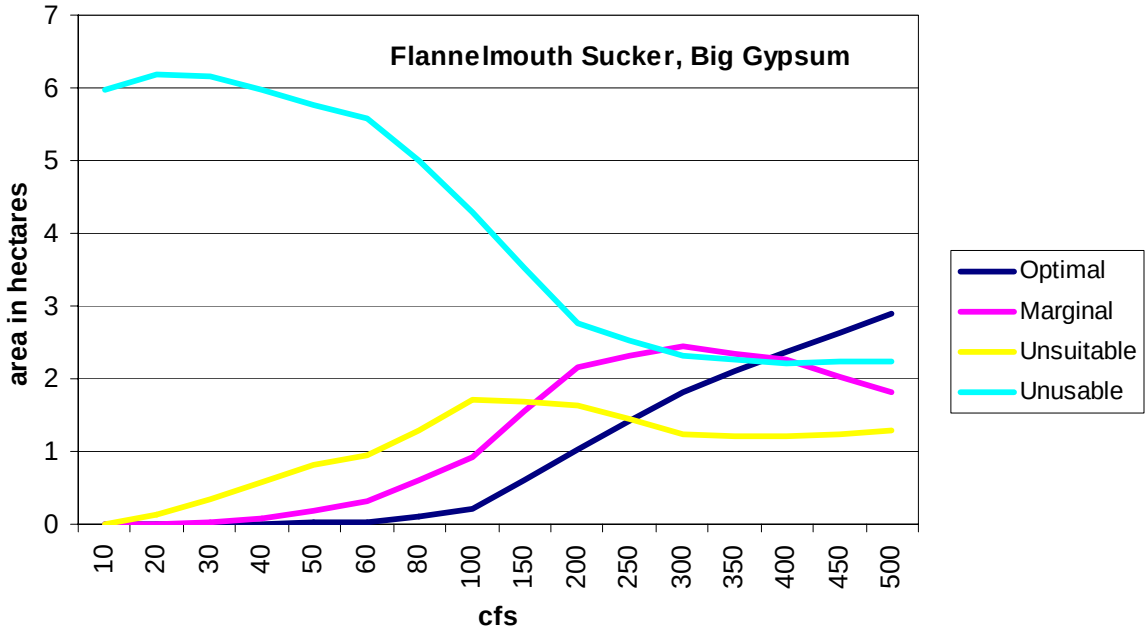


Figure 22. Flannelmouth sucker habitat availability at Big Gypsum, Dolores River.

Big Gypsum had a higher total biomass per hectare for all sites at a given flow due to its smaller channel. The slope of the flannelmouth biomass increased slowest from 10 to 60 cfs and the increase was fastest from 60 cfs to 150 cfs. At 150 cfs, the adult flannelmouth biomass was 150 kg/ha (Figure 23). Below 80 cfs the Big Gypsum site had less than 5 kg/ha. Big Gypsum had a higher projected flannelmouth biomass than the Colorado River. At 400 cfs, the projected biomass at Big Gypsum was 250 kg/ha, compared to 225 kg/ha and 200 kg/ha at flows of 1800 cfs at Corn Lake and 2000 cfs at Clifton respectively. Typically base flows are less than 60 cfs on the Dolores River. At 60 cfs, flannelmouth biomass was about 31 kg/ha and about 23 kg/ha at 50 cfs.

Corn Lake had the highest projected biomass for flows between 250 cfs and 500 cfs (Figure 23). At base flows of near 1000 cfs, biomass at Corn Lake was projected to be near 210 kg/ha. There was an inflection of the biomass curve at Corn Lake at 500 cfs. Above 500 cfs the biomass curve increased at a lower rate.

The **Clifton** site had the lowest adult flannelmouth biomass curve for flows over 300 cfs (Figure 23). Flows over 1000 cfs did not increase habitat potential for adult flannelmouths. The adult flannelmouth biomass curve for the entire 15-Mile Reach was likely intermediate to that found for Corn Lake and Clifton. Corn Lake was found to have a below-average mean width and Clifton had an above-average mean width. We defined Mean width as a geomorphic feature influencing velocities. Velocity strongly influenced habitat suitability. Corn Lake represented the upper limit and Clifton the lower limit regarding to flannelmouth habitat potential in the 15-Mile Reach.

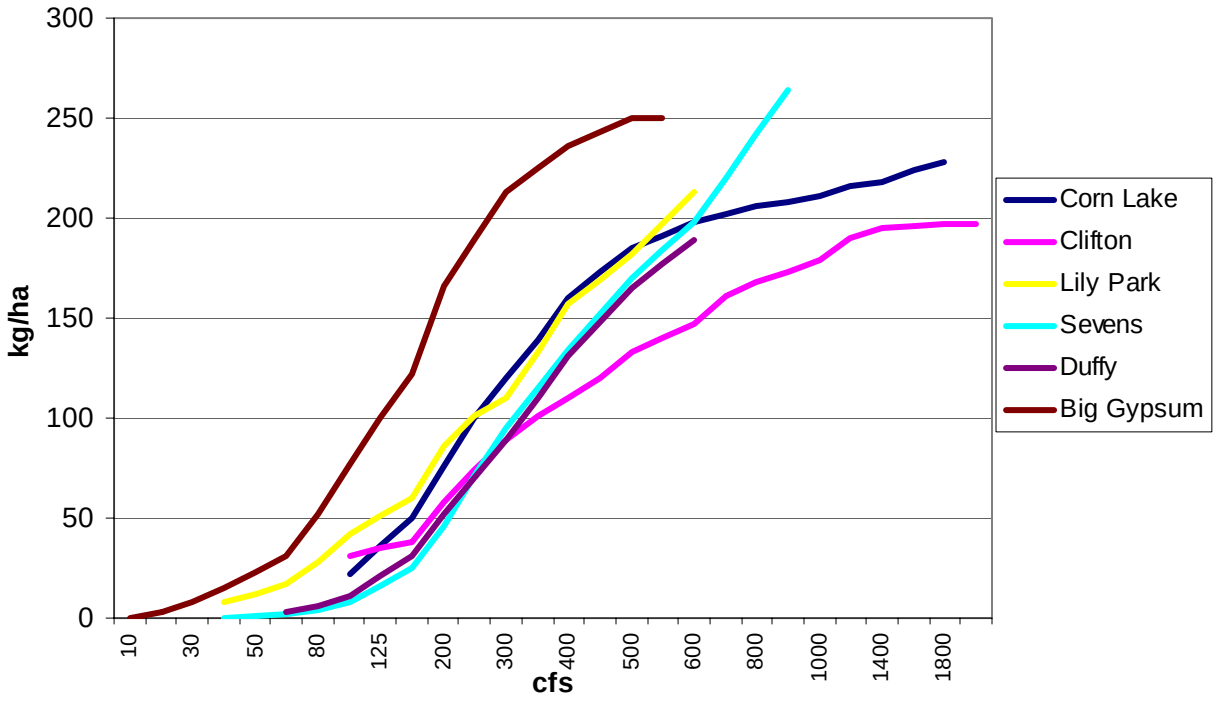


Figure 23. Project flannelmouth biomass as a function of flow for all study sites.

The **Lily Park** site had the highest potential for flannelmouth habitat at flows less than 200 cfs (Figure 23). The geomorphic characteristics that stood out at Lily Park were the narrower channel, higher bed slope and larger sediment size. The narrower channel and higher bed slope resulted in higher depths and velocities at lower flows. Corn Lake had a very similar projected biomass compared to Lily Park at flows from 150 to 500 cfs, indicating similar geomorphic characteristics between the sites. These data also suggested that given similar flow scenarios, the flannelmouth populations would be similar for these sites.

Sevens and **Duffy** have nearly identical flannelmouth curves for projected biomass (Figure 23). The geomorphology of these sites was similar with a lower bed slope and a wider wetted width in the lower flow range (>600 cfs). At about 600 cfs, biomass potential, based on the availability of the four functional meso-habitat types was nearly identical at the Sevens, Duffy, Lily Park and Corn Lake sites. At flows over 600, optimal velocities were being exceeded at Corn Lake and the curves flattened out. But at Sevens and Duffy, it appeared that flows of 400 cfs to 600 cfs were required to achieve the velocities that produced optimal habitat.

The projected biomass for the 60-day low flow was regressed against the measured biomass for all stations for which data was available except for Duffy. Duffy was excluded because pure flannelmouths are very rare at this site, a condition due to hybridization and predation, not due to habitat availability.

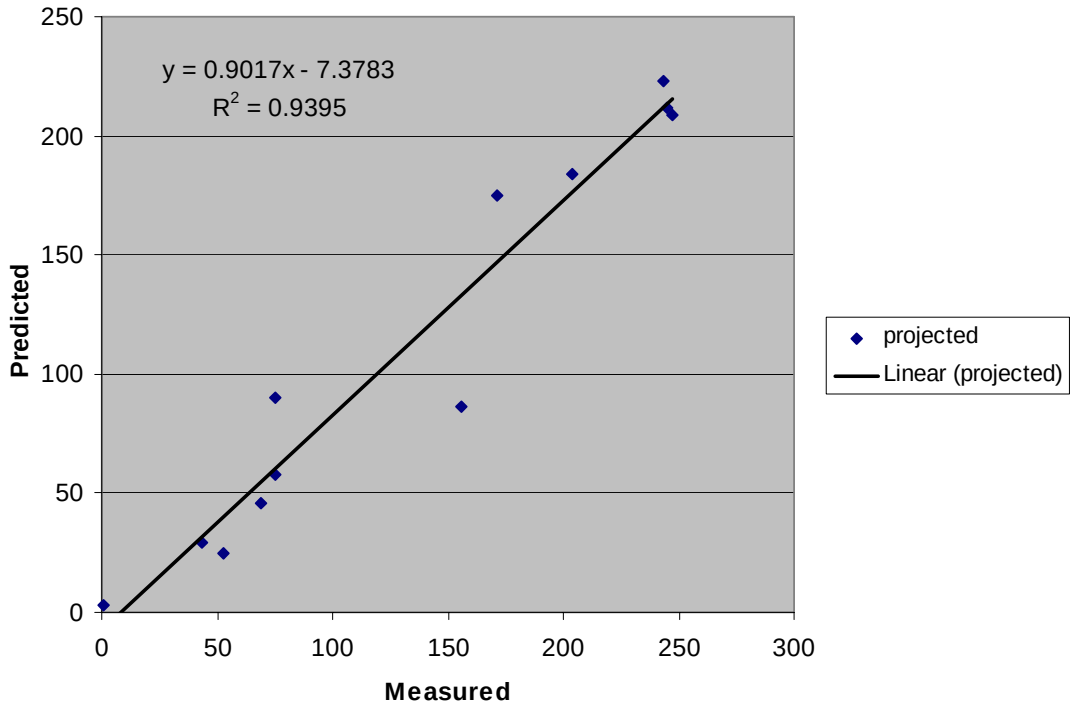


Figure 24. Projected versus observed flannelmouth sucker biomass for five study sites

DISCUSSION

Habitat Modeling, Flow Needs for Native Sucker

This study established baseline fishery data at six study sites and used this data to develop habitat suitability criteria and model validation. Another value of the fishery data was that it established consistency in the fish community through time. Consistency in community structure within each site strongly suggested a dynamic relationship among the sites' habitats. Consistency in fishery characteristics also promoted confidence that habitat modeled in one year not only represented both the geomorphic and fishery aspects for that time period, but that it also represented conditions through time.

The 2-D flow modeling quantified habitat conditions at each study site so that habitat availability could be directly correlated to fish biomass. The main variable of habitat availability was flow. Differences in habitat appeared to explain several differences in fish community composition and biomass among sites and between rivers. A significant correlation was found for the six study sites between habitat availability and abundance of the native blueheads and flannelmouths. The two sites in the 15-Mile Reach had the highest base flows, the highest optimal habitat availability and the highest density and biomass of total fish and native fish. Lower base flows and lower native sucker habitat and biomass were found at Sevens, Duffy and Big Gypsum.

Both blueheads and flannelmouths were found to have strong preferences for habitats with minimum velocities of above 0.5 m/s. In the Colorado River, habitats with currents over 0.5 m/s were abundant in the flow range of 800 to 1000 cfs. In the Yampa River base flows were typically less than 250 cfs and lower velocity runs were the dominant habitat between flows of 150 to 250 cfs.

Because a significant relationship was found between available habitat and bluehead and flannelmouth biomass, species abundance was used as a relative indicator of the habitat abundance. In the 15-Mile Reach, blueheads and flannelmouths had similar species composition and similar amounts of habitat availability. In the Yampa River flannelmouth biomass and habitat was much higher than it was for blueheads.

Bluehead population estimates made in 2000 and 2001 in the 15-Mile Reach were near 1200 fish per km and 100 kg/ha. Anderson (1997) reported fishery population data for three sites upstream of the 15 Mile-Reach. Species composition (30 to 37%), length-distribution and density estimates (90 to 97 kg/ha) made for blueheads near Una and Parachute were very similar to that in the 15-Mile Reach. Generally, flows during the irrigation season (April to November) were considerably higher upstream of the Roller Dam due to the amount of water that was being diverted (1200 to 1600 cfs). Bluehead sucker standing stocks were similar above and below the Roller Dam. That indicated similar habitat quality despite less flow in the 15-Mile Reach. The 2-D habitat analysis found only minor increases in bluehead habitat availability when flows increased above 1400 cfs.

Osmundson (1999) reported catch rates of blueheads (fish per minute of electro-fishing) in the Colorado River from samples made in 1994 and 1995. The catch rate in the 15-Mile Reach, Strata 9 (2.2 fish/min) was higher than upstream of the Roller Dam at Strata 10 near Una Bridge (0.8 fish/min) and at Strata 11 at Parachute (1.5/min). Osmundsons' fishery data indicated blueheads were more numerous in the 15-Mile Reach. This suggested bluehead habitat availability was also greater, even with reduced flows compared to above the Roller Dam.

The flannelmouth estimates made in 2000 and 2001 in the 15-Mile Reach were approximately 1600 fish per km and 220 kg/ha. These estimates were very similar to Anderson's (1997) reported density estimate of about 1750 flannelmouth / km at Parachute in 1994 and 1995. The flannelmouth biomass of 185 kg/ha (Anderson 1997) was lower than found in this study because it was calculated using mean channel width and not wetted width. Species composition of flannelmouths in the 15-Mile Reach was also similar to Parachute (34 to 40%) (Anderson 1997). The 2-D modeling found increasing flannelmouth habitat with increasing flows up to about 1200 cfs. Therefore, much higher flows at Parachute apparently have not resulted in a much larger population size of the flannelmouth.

Fish sampling data in the Colorado River from 1994 and 1995 by Osmundson (1999) found flannelmouth catch rates were highest in the 15-Mile Reach. Flannelmouth catch rates in Strata 9 or the 15-Mile Reach were about 1.6 fish/min compared to about 0.5 fish/min at Strata 10 (Una Reach) and about 1.2 fish/min at Strata 11 (Parachute) (Osmundson 1999). Osmundson's fishery data was fairly consistent with Anderson's (1997) and corroborated the 2-D modeling data that found that maximum flannelmouth habitat was provided by flows of 800 to 1200 cfs.

The 2-D habitat modeling showed that the 15-Mile Reach appeared to be near the carrying capacity of habitat for adult blueheads and flannelmouths in the flow range experienced during the study period (800 to 1000 cfs). The fishery data showed an abundance of juvenile blueheads and flannelmouths indicating habitat for smaller fish (<15 cm) was also available. Both the habitat modeling and the fishery data indicated that habitat for these native fish was not limiting or problematic.

Pitlick and Cress (2000) found that the Colorado River near Una and Parachute had a slope and bankfull width very similar to the 15-Mile Reach. Given similar channel morphology (width and slope) at particular sites, modeled habitat availability was also similar. Therefore the meso-habitat curves and flow recommendations determined for blueheads and flannelmouths in the 15-Mile Reach most likely were transferable to above the Roller Dam, since channel characteristics were similar.

Discharge (Q) equalled width x mean depth x mean velocity, so the same flow in a narrower channel meant either depths or velocities were increased. This was obvious at the Big Gypsum site, which had the narrowest stream width and was able to provide higher optimal bluehead habitat at lower flows. For the large rivers, Corn Lake had the

narrowest width for flows less than 600 cfs and had the highest percent of optimal bluehead habitat in the lower end of the modeled flows.

Other geomorphic features such as bed slope directly influenced mean depths and velocities. Sevens and Duffy had the lowest bed slopes of the study sites and the highest percentage of Unusable native sucker habitat at flows less than 400 cfs. Lily Park had the highest bed slope and maintained habitats with swifter currents at lower flows than did Sevens and Duffy. Higher bed slope and a narrower width likely explained the higher fish productivity at Lily Park compared to Sevens and Duffy.

The 2-D habitat model showed that Sevens and Duffy required a flow of 400 cfs to yield an equal amount of bluehead habitat as Corn Lake at a flow of 250 cfs. This was partially due to Sevens and Duffy being wider than the Colorado River sites. The Colorado River was a larger river than the Yampa in terms of drainage area and mean annual flow. The drainage area at the Cameo gage (Colorado River) was 8050 square miles. Mean annual flow was 3897 cfs and median peak flow was 17900 cfs (68 years). For the Yampa River Maybell gage (86 years), the drainage area was 3837 square miles, the mean annual flow was 1568 cfs and the median peak was 9880 cfs (86 years).

Piktlick (1999) reported the Colorado River channel had narrowed slightly and was more or less in equilibrium with the present flow and sediment transport regimes. Pitlick (1999) also found that, in general, base flows in the Colorado River were somewhat higher than natural base flows. The Yampa River likely had the reserve conditions. The channel upstream of Cross Mountain appeared to be unstable as indicated by a poor riparian zone along most of the river. Also current base flows were greatly reduced, primarily for irrigation use, compared to pre-development flows (CWCB report, htpp://cdss.state.co.us)

The 2-D habitat model appeared to be in sync with fishery data collected under a variety of flow conditions. The Yampa River represented fishery data from a community exposed to lower flow conditions than in the 15-Mile Reach. The Lily Park site had similar channel widths and slopes as the 15-Mile Reach, so differences in habitat availability were mainly due to the flow differences. Also, the first two years of fishery data at Sevens and Duffy were collected when summer flows were near 250 cfs (1998 and 1999), but flows were noticeably less during the second two years (2000 and 2001).

Sevens and Duffy had about 20% of the bluehead habitat at a flow of 250 cfs. Sevens had about 21% of the biomass of the 15-Mile Reach (900 cfs). Lily Park (250 cfs) had about 28% of the projected habitat availability and had 39% of bluehead biomass as the 15-Mile Reach (900 cfs). The 2-D model for Duffy (250 cfs) indicateed that bluehead habitat availability was much higher than reflected by the existing biomass, which was likely depressed by predation and hybridization (Anderson 2002). The 2-D modeling results indicated that bluehead sucker biomass in the 15-Mile Reach would decrease to about 20 to 40% of the current conditions if 250 cfs were to become the long-term mean flow.

At Lily Park, the flannelmouth density estimate was very similar to the 15-Mile Reach (near 1670/km), but Lily Park's flannelmouth biomass was 64% of that at Corn Lake. It appeared that the higher gradient at Lily Park was beneficial for maintaining flannelmouth numbers at the lower flows. Biomass was less at Lily Park because large flannelmouths were less frequently captured at Lily Park. At Lily Park, 42% of flannelmouths were larger than 40 cm and 3% were over 45 cm, but at Corn Lake 73% were larger than 40 cm and 30% were over 45 cm. Apparently, the shallower and slower habitats at Lily Park were not suitable for supporting the larger-sized adult flannelmouths.

The difference in size structure was even more pronounced at the Dolores River site, where the largest flannelmouth collected was 31 cm. This differential in size was also observed for both blueheads and roundtail chubs with there being high numbers of larger-sized fish at Corn Lake, fewer larger fish in the Yampa and even fewer in the Dolores River. Differences in fish size were observed at Sevens between the higher and lower flow periods for blueheads. During the relatively high flow year of 1999, 83% of blueheads were over 30 cm and 29% were over 35 cm. This was 45% over 30 cm and 9% over 35 cm during the low-flow year of 2001. Mean lengths of blueheads were high at Duffy because fish under 35 cm were likely removed by predation during the study period (Anderson 2002).

The lack of larger-sized (>35 cm) fish in a population was probably due to lack of adult fish habitat, which was likely an attribute of poor flow conditions. The fish community of the Dolores River in 2001 consisted mostly of blueheads and flannelmouths sucker less than 20 cm. The lack of adult-sized fish clearly indicated a lack of adult fish habitat for these species.

Habitat Composition and Diversity

Regressions between habitat and fish productively were significant among the six study sites. In general it appeared that sites with high amounts of riffle habitat had higher total fish biomass and higher bluehead biomass. Riffles were the primary meso-habitat for most aquatic macroinvertebrates. The availability of riffle habitat was a good indicator of general productivity of a river.

Sites with higher amounts of deep-run and deep-pool habitats had higher amounts of catfish, carp and white suckers. Not all species, however, displayed a direct relationship between biomass and a meso-habitat type (roundtail chub). Also, with only six study sites in the project, sample size was rather small for an in-depth analysis. Other factors such as variability in predation and hybridization rates between sites could not be included in a regression analysis. But even given these factors the analysis indicated habitat was a major influence on native fish biomass and composition.

The Shannon-Weaver diversity index provided a means of comparing habitat complexity at each study site, with higher habitat diversity suggesting improved conditions for maintaining fish community diversity. Habitat diversity (Shannon-Weaver) peaked at 1000 cfs at Clifton and at 1200 cfs at Corn Lake. Maximum meso-habitat diversity occurred in the same flow range that produced maximum habitat for adult native suckers. Flows of 1000 to 1200 cfs were also the near the flows when fish were sampled, and numerous age-0 and age-1 native suckers, roundtail chub and speckled dace were collected. These collections of young fish also indicated 1000 to 1200 cfs resulted in suitable habitat all life stages.

Since flows were not modeled above 600 cfs for the Yampa River the flow associated with peak habitat diversity was not identified. However, at 600 cfs Lily Park had the greatest habitat complexity (2.22) followed by Sevens (1.92) and Duffy which had the least complex habitat (1.73). This order of habitat complexity matched the order of fishery diversity found on the Yampa River. The consistency in species composition and size structure observed at Sevens and Duffy from 1998 to 2000 was not maintained in 2001 when flows and habitat complexity were less.

Field Observations, Flow Needs of Native Fish

There were some field observations made at Lily Park during electro-fishing that confirmed some of the 2D habitat modeling results for the Yampa River. In 2000 there was a large difference in flows between field trips (Anderson 2001). During trips when flow was less than 120 cfs, flannelmouths were collected from backwater habitats that were not occupied at flows above 120 cfs (Anderson 2002). These observations showed that flannelmouths were compelled to occupy non-preferred habitats when flow was less than 120 cfs. The electro-fishing raft had to be dragged in Lily Park at flows less than 120 cfs and during these occasions it was observed that fish were confined to the deepest remaining water pockets. The concentration of large numbers of fish in shallow and confined habitats made them highly vulnerable to capture by us, avian and terrestrial predators.

Anderson (2002) reported a dramatic decline in two native fish species in the Yampa River fish community in 2001. The speckled dace and the mottled sculpin were both common in 1998 and 1999 at Duffy and Sevens. Both are small-bodied fish that occupy shallow habitats. Small-bodied fish should be less susceptible to population crashes during low flow events, and these fish likely could have maintained viable populations if low flows were the only factor. The Dolores River population was comprised mostly of native species, but the vast majority were small, less than 20 cm length. The Dolores River did not have the same burden of nonnative predators as the Yampa River.

The disappearance of dace and sculpin in the year 2001 was concurrent with an increase in the number of smallmouth bass. Anderson (2002) considered the shifts in these species to be connected. As flows fell below a certain threshold (as experienced in both 2000 and 2001), velocities were reduced in virtually all riffles making them suitable

habitat for YOY smallmouth bass. YOY bass were not observed in riffles during the field surveys in 1998 and 1999. This shift in species composition occurred during years when stream flow was less than 120 cfs for most of the summer. When riffle habitats were unsuitable to maintain small-bodied fish like speckled dace, they become unusable for large-bodied fish bodied like blueheads.

Speckled dace on the Colorado River were found to comprise 72% of the catch from shallow riffles (Miller et al. 2003). The next most common fish in riffles were sand shiners at 9%, juvenile flannelmouths 6% and juvenile blueheads were 3 percent (Miller et al. 2003). Miller et al. (2003) made density and biomass estimates for small-bodied fish in the 15-Mile Reach using depletion sampling. Their estimate for speckled dace was 2.36 dace per meter square of riffle. This value multiplied by the area of riffle meso-habitat from the 2-D modeling at 1000 cfs for Corn Lake and Clifton resulted in a projected speckled dace density over 15000 dace/km in the 15-Mile Reach. If 2.36 dace/km is somewhat valid for the Yampa River riffles, based on riffle habitat area at 200 cfs, the projected speckled dace numbers 4500/km at Duffy, 1200/km at Sevens, and 4000/km at Lily Park. The speckled dace population dropped at 100 cfs to 856/km, 218/km and 1300/km for Duffy, Sevens and Lily Park respectively. Speckled dace numbers for 60 cfs were projected only for 196/km, 23/km, and 196/km at Duffy, Sevens and Lily Park respectively.

The roundtail chub was another large-bodied native fish that we attempted to model by determining its meso-habitat suitability. Significant correlations were not found between roundtail chub biomass and a meso-habitat type that could be defined by depths and velocities. Roundtail chub was a predator that occupied deep pools during the day and moved through several habitats to forage in the evening (Byers 2001). The roundtail chub, therefore, was a multi-habitat species that was found in the habitat it occupied at the time of the fish sampling. Stewart (2000) proposed an approach to characterize an analysis of adult chub habitat using habitat complexity indices such as richness and evenness. The approach was still under investigation at the time of this report, and will be examined further in the next project cycle.

The fish community of the Dolores River appeared to be highly stressed. Species composition of native fish was high, but most fish were small. Roundtail chub was the most common species and biomass was very low. These attributes appeared to be habitat and flow related. The lack of runoff flows in 2000 and 2001 may have negatively impacted productivity. Riffles and runs had large silt deposits and both forage and habitat potential seemed unnaturally low. If the Colorado River data can be used as an example of a high-quality habitat and fishery, the Dolores River data can be useful as an example of very poor quality habitat conditions. The lack of non-native piscivores, like smallmouth bass, apparently allowed young and small fish survival, but clearly there was a lack of habitat for larger individuals. Even the channel catfish was affected.

Since the construction of McPhee Reservoir, the spring runoff flows have been greatly modified. Mean monthly flows from 1985 to 2001, from the Bedrock gage, for May and June were about half of flows during the period prior to 1985. The loss of spring

runoff flows, as in the Dolores River below McPhee Reservoir, appeared to be causing channel downsizing and heavy siltation deposits. A more natural native fish community would be possible in the Dolores River if a natural shape was restored to the hydrograph.

Non-Native Fish Versus Flows

The 2D habitat modeling data suggested a relationship between habitat availability, and composition and of abundance of nonnative fish. On the 15-Mile Reach common carp were the most prevalent nonnative species and channel catfish and white suckers were fairly uncommon at about 5 to 6% of the total fish over 15 cm. Common carp and white sucker were collected, primarily in backwater and deep shoreline habitats, suggesting that faster mid-channel habitats were not suitable for these species.

On the Yampa River, white sucker and roundtail chub were very rare at Lily Park. This may have resulted from a lack of reproductive and nursery habitats in this high gradient site. White suckers were very common in the Yampa River upstream of Maybell. Elmblad (2003) reported that ISMP sampling found 50% of the catch at Maybell were white suckers. This species was 62% of the catch in the Juniper area. At Duffy about 70% of the fish collected were white suckers prior to 2001. The slow flowing (pool) habitats of Duffy appeared to be ideal for all life stages of this species. In contrast, the Dolores River is an example of a river with primarily slow flowing habitats, but has no white suckers. Without white suckers in the Yampa River, native sucker species could likely maintain a much stronger presence.

White suckers and its hybrids with flannelmouths and blueheads were examined on the Yampa River in the mid 1970's. About half of the white suckers examined in the field were identified as hybrids with native sucker species (Prewitt (1977). White x flannelmouth and white x bluehead hybrids were more successful than pure native suckers in the river upstream of Maybell. This may have been a function of habitat or possibly the white sucker hybridization imparted better predation defenses, as it co-evolved with the nonnative piscivores present in the Yampa River.

Results of the four years of sampling on the Yampa and 3 years on the 15-Mile Reach strongly indicated that the magnitude of base flows was critical for maintaining a strong native fish community. It was established that native fish prefer higher velocity habitats and that nonnative fish exhibit a preference for lower velocity habitats. Backwater and shallow pool habitats had higher composition during low flow. Sunfish and white sucker populations were increased during lower base flow years. The negative impacts of smallmouth bass were less in 1998 and 1999, the years that had higher base flows. Smallmouth bass had a much higher presence at Duffy and Lily Park in 2001 than at Sevens. The lower numbers of bass at Sevens suggested that habitat was less suitable for smallmouth bass at that site.

Flows during the irrigation season may be more important for minimizing non-native nuisance species than flows during the runoff. Large numbers of smallmouth bass YOY were observed in 1998 and 1999 when runoff flows were near 10,000 cfs. It appeared that normal high runoff flows did not negatively impact this species. It will take more years sampling to provide empirical data that will help determine the relative importance of base flows versus peak flows.

Anderson (2002) speculated that Cross Mountain Canyon was a barrier to fish passage at the flows observed in the summer of 2000. Fish passage in Cross Mountain Canyon could be problematic for migrating species, e.g., channel catfish and Colorado pikeminnow at flows of less than 100 cfs.

Hawkins et al. (1997) found a low occurrence of nonnative fish in the Little Snake River during a period when flows were near zero, but did not provide data about species composition during normal flow years. Hawkins et al. (1997) suggested that native species may be more tolerant of drought flows and therefore had an inherent advantage under such condition over non-native species. The fishery data from the Little Snake and Dolores Rivers appeared to be similar. There was a high native fish composition during very low flows. The Dolores River fish community appeared to be highly stressed and unnatural. In the Yampa River, native fish versus nonnative composition varied among sites. This indicated habitat availability was also important for non-native species as well as natives.

On the Colorado River, the Clifton site had more total area than Corn Lake, but it was entirely in pool and backwater habitat. The higher availability of pool and backwater habitat was primarily utilized by nonnative species (largemouth bass, green sunfish, carp) and somewhat by juvenile native fish (i.e. roundtail chub), but not by adult native fish. Reduced flows in the 15-Mile Reach increased unusable habitat for native fish and suitable habitat for nonnative species.

Flows for Endangered Fish

Flow recommendations by the Recovery Program were much different for the Yampa and Colorado Rivers. The Recovery Program recommended a mean monthly flow of 1243 cfs during the irrigation season for an average year for the 15-Mile Reach to maintain habitat for adult Colorado pikeminnow (Osmundson 1996). The flow recommendation for the Yampa River was to maintain 93 cfs at the historic frequency observed at the Maybell gage (Modde et al 1999), i.e., the frequency of flows less than 93 cfs were not to increase compared to gage records. The contrast in flow recommendations was quite dramatic given that life history and habitat needs of endangered fish should be similar regardless of the specific river.

The fishery data and the 2-D modeling results did not indicate habitat problems for non-endangered native species in the 15-Mile Reach. The 2-D modeling found that similar flows provided similar habitat availability for adult native suckers in the Colorado and Yampa Rivers. We interpret these results to indicate that habitat availability for adult

endangered species was not likely problematic in the 15-Mile Reach. The availability of prey fish (10 - 30 cm) appeared high in the 15-Mile Reach suggesting that forage availability was not lacking for adult Colorado pikeminnow (Osmundson 1999). In spite of seemingly good habitat and forage, the numbers of endangered fish collected in this study and by recent recovery program efforts have been very low in the 15-Mile Reach.

Catch rate and population estimate data suggested that Colorado pikeminnow had similar population sizes in the Colorado and Yampa Rivers during the period of 1987 to 2000 (McAda 2002 and Osumndson 2002). The fact that Colorado pikeminnow densities were similar for the Colorado and Yampa River further suggested that neither habitat nor forage availability has limited pikeminnow abundance in the 15-Mile Reach. The bottleneck for Colorado pikeminnow and razorback sucker in the Colorado River was most likely related to reproduction and recruitment (Osmundson and Kaeding 1991). Colorado pikeminnow reproduction occurred during the descending limb of the hydrograph and lack of recruitment was linked with predation of larvae (Bestgen 1997). Data from this study indicated that YOY smallmouth bass appeared to be an efficient predator of fish larvae in the Yampa River. If YOY smallmouth bass become prevalent in Dinosaur Canyon, this could have a major impact on survival of Colorado pikeminnow larvae.

FLOW RECOMMENDATIONS

The intent of this project was to develop flow recommendations that would be adequate to provide suitable flows for maintaining existing populations of native fish. The first three years of the project were spent documenting the status of existing native fish populations in the 15-Mile Reach of the Colorado River, the Yampa River and the Dolores River. The fish population data was necessary to create the habitat suitability criteria and also to provide baseline population data given existing habitat conditions.

The habitat analysis found several similarities in channel morphology, suitability curves and flow/habitat relationships between the Yampa and Colorado Rivers. The data also strongly suggested the Yampa and Colorado Rivers would have similar native sucker populations given similar instream flow scenarios. Flow recommendations for these two rivers, however, were not similar because of large differences in historical flows and water availability.

Colorado River

The base flows in the 15-Mile Reach in 2000 (900) and 2001 (1000) were found to be near optimal in providing suitable for habitat for native suckers and in maintaining habitat diversity. Neither the fish sampling data nor the habitat modeling results gave indications that flows above 1200 cfs would improve habitat conditions or biomass of native sucker species. Base flows observed in the Colorado River in 2000 and 2001 appeared suitable to maintain the existing native fish population for the long term.

The 2-D habitat model showed that bluehead habitat and projected biomass falls rapidly when flows drop below 600 cfs, and at 200 cfs or less habitat availability and predicted biomass is very low compared to current estimates. Base flows of 600 to 800 cfs appear sufficient to maintain the bluehead sucker population size found during the study period.

Pitlick (1999) reported that base flows in the Colorado River were slightly higher than native flow. For the historic record, flows less than 800 cfs have been uncommon in the 15-Mile Reach (Osmundson and Keading 1991), establishing a history of near optimal habitat conditions. We recommend that optimal habitat be sustained. The 2-D habitat modeling data indicated that a mean monthly flow of 650 cfs during the late irrigation season (July 1 to October 31) would likely maintain native sucker species at or very near the existing population size. A mean monthly flow of 650 cfs would be achieved if flows exceed 400 cfs for 100% of the month, exceed 525 cfs for 25% of the month and exceed 650 cfs for 50% of the month. To simplify the recommendation to a single flow, 600 cfs should be considered the instream flow recommendation for the Colorado River in the 15-Mile Reach.

Yampa River

The Tennant Method (Instream Flow Council 2002) calculates a minimum flow of 465 cfs as a recommendation for the Yampa Rivers' mean annual flow of 1552 cfs. Base flows over 300 cfs have been uncommon in the Yampa River during the irrigation season even though 300 cfs seems fairly low for a river the size of the Yampa. The median minimum flow for the Maybell gage was only 121 cfs. Both fish observations and habitat modeling identified that flows less than 120 cfs do not provide enough habitat to adequately support native fish.

The goal for flow management on the Yampa River is to provide enough flow to avoid degraded habitat (unsuitable depths and velocities in riffles and runs). The fish sampling data found conclusively that summer flows during 2000 and 2001 had negative impacts on the native fish populations of the Yampa River. The recovery time frame of native fish (speckled dace, mottled sculpin and bluehead sucker) is unknown at this time since flows in 2002 were even lower. Base flows of 1998 and 1999 were found to sustain native fish. It is recommended that the flow conditions of these years be used to model for instream flow scenarios in the future.

Compared to the Colorado River the Yampa River upstream of Cross Mountain Canyon appears overly-wide and the channel is unstable. Improved riparian management and activities that promote bank stabilization and a more natural-sized channel would have long term benefits for native fish in the Yampa River. Also, base flows on the Yampa River are much reduced compared to native flow.

The 2-D meso-habitat model found that flows below 200 cfs appear to be highly problematic for blueheads on the Yampa River. It appears that base flows need to be over 400 cfs to have a significant improvement in bluehead habitat at all three sites. In regard to blueheads, it appeared flows less than 200 cfs should be avoided.

A minimum flow of 200 cfs is necessary to maintain native fish at the levels observed in 1998 and1999. A monthly average of 200 cfs would likely avoid severely degraded conditions. To achieve this standard it is recommended that flows exceed 120 cfs for 100% of the month, exceed 150 cfs for 25% of the month and exceed 200 cfs for 50% of the month. If a single flow is desirable then the instream flow recommendation is 175 cfs.

Dolores River

The Dolores River was found to have a high species composition of native fish, but very poor size structure and biomass. In fact, the fishery of the Dolores River in Big Gypsum was so poor it has become an example of a fish community representative of extremely altered flows and habitat. The Dolores River has the potential to be an important river for native fish management given adequate instream flows. Habitat modeling found that flows of 200 cfs would maintain riffle habitats. Base flows of this magnitude would likely result in a fish density and biomass similar to estimates in the 15-Mile Reach. However, it does not appear likely that flows of 200 cfs are available.

Perhaps an even larger problem than base flows is the change in runoff flows. There has also been a lack of peak or flushing flows in the Dolores River during the study period. The lack of flushing flows appears to have severely reduced productivity of this river. The 2-D modeling suggests an instream flow of at least 80 cfs. The field data suggests a runoff flow of near 1200 cfs, but more modeling is needed for this river.

SUMMARY

Four years of fish population characteristics were summarized at Sevens and Duffy on the Yampa River. Density, biomass and size structure in the first two years 1998 and 1999 were higher than in 2000 and 2001. We examined the fish data at Lily Park in 2000 and 2001. We attributed the observed changes in the fishery at Sevens and Duffy to poorer flow and habitat conditions in 2000 and 2001. Low flows appeared to be responsible for negative impacts to blueheads, speckled dace, mottled sculpin, flannelmouths, white suckers and channel catfish. Smallmouth bass and sand shiners appeared to respond positively during the lower flow years on the Yampa.

Three years (1999, 2000 and 2001) of fish population characteristics were summarized at Corn Lake in the 15-Mile Reach and two years (2000 and 2001) of fish data were collected at the Clifton site. Density, biomass and size structure of the native fish community appeared to be at carrying capacity and representative of an ideal population.

Two years (2000 and 2001) of fish population characteristics were summarized at the Big Gypsum site on the Dolores River. Although native fish species composition was high in both years, fish density, biomass and size structure were considered to be fair in 2000 and very poor in 2001. The Dolores River fishery appeared to have a highly stressed and unnatural fish community and served as an example of a population in a highly degraded habitat.

We observed two-dimensional habitat modeling at all sites with fishery data. We developed meso-habitat suitability curves based on fish distribution within each site. Meso-habitat suitability were validated and used to project habitat availability for a range of simulated flows. Geomorphic characteristics were similar for the Yampa River and Colorado in the range of flows modeled. Habitat for flannelmouth and bluehead suckers were maximized or optimal at flows near 1000 to 1200 cfs for the Colorado. The 1000 to 2000 cfs flows were likely the optimal flows in the Yampa River, but the flows were not modeled over 600 cfs. Flows less than 400 cfs provided significantly reduced habitat for flannelmouth and bluehead suckers. Nearly 100% of available habitat was in the unusable category for flannelmouth and bluehead suckers at flows of 100 cfs and less.

We made instream flow recommendations based on the 2-D meso-habitat modeling and observations made during the fish sampling. To maintain the existing population in the 15-Mile Reach instream flows should exceed 600 cfs. A instream flow target for the Yampa River is 200 cfs and flows less than 120 cfs need to be avoided to prevent loss of riffle-habitats. Instream flows of 60 to 80 cfs may be sufficient to maintain a native fish community in the Dolores River, as long as runoff flows are provided in the spring. The lack of spring flows in the Dolores River appears to have severely reduced the fishery potential there.

CONCLUSIONS

- 2-D habitat modeling found that flows of the same magnitude provide about the same amount of habitat availability for both the Colorado and Yampa Rivers.

- 2-D habitat modeling found the Yampa River had a larger stream width at flows less than 600 cfs even though the Colorado River had the larger drainage area and mean annual flow.

- Flows (900 to 1000 cfs), habitat availability and the non-endangered native fish community in the 15-Mile Reach documented during the study period were all found to be representative of near ideal conditions.

- Flows above 1200 cfs on the Colorado River do not enhance habitat availability for adult native suckers.

- Flows below 400 cfs will likely result in significant reductions in density and biomass of flannelmouths and blueheads in the 15-Mile Reach.

- The present flow management strategy for the 15-Mile Reach is to maintain historic flows and optional habitat conditions. Flows of 600 to 800 cfs will provide suitable habitat to maintain the existing native fish population in the 15-Mile Reach.

- Flows, habitat availability and the non-endangered native fish communities in the Yampa River documented during the study period were poor compared to their potential and to the 15-Mile Reach.

- Flows less than 120 cfs do not provide suitable habitat for adult native suckers and should be avoided.

- Flows of 300 to 400 cfs are required to provide suitable habitat for a healthy native fish population at the Yampa River.

- The flow management strategy for the Yampa River is to avoid severe habitat degradation. An instream flow of 200 cfs should be considered the minimum flow for the Yampa River.

- The Dolores River was sampled under similar base flow for two years, but the fish population was much degraded in the second year. Lack of peak flows appears to have caused the negative impact on the native fish population of this river.

- For the Dolores River an instream flow of 80 cfs and a minimum runoff flow of 1200 cfs are recommended. Further study is required on the Dolores River.

RECOMMENDATIONS FOR FUTURE FLOW RESEARCH

1. Reform model flows for the Yampa River 2D sites up to 2000 cfs as was done for the 15-Mile Reach. This is needed to complete modeling habitat suitability and habitat diversity.

2. Continue working with Dr. Richard of Mesa State College to determine channel geomorphology. Conduct a channel geomorphic study for the Yampa River to determine bankfull flows and channel stability. Also, summarized flow records are needed to determine the scale in reduction of base flows on the Yampa River.

3. Survey the floodplain of the Dolores River study site and determine bankfull flows at the Big Gypsum site. Determine the rate of channel narrowing through contract work with Dr. Richard of Mesa State.

4. Continue to sample the fish sites on the Yampa and 15-Mile Reach for at least two years (2003 and 2004). The drought of record statewide occurred in 2002. The hydrograph for the Yampa River was severely reduced in 2002 from flows during the sampling period. Median peak flow on the Yampa River was 9880 cfs and median minimum flow was 129 cfs (84 years) at the Maybell gage. In 2002, the peak flow was 3420 cfs and the minimum flow was only 2 cfs. The flows in the 15-Mile Reach in 2002 were also lower. The peak flow was only 2780 cfs and the minimum flow was 58 cfs compared to the median peak of 13500 cfs and the median minimum flow of 558 for the Palisade gage (11 years). Fish population data collected in 2003 could provide data on impacts from the 2002 flows. A result of this continued sampling would be validation of projections about impacts of habitat loss on fish density and biomass.

5. Complete and report on habitat availability for roundtail chub analysis.

6. Perform polygon analysis for the other fish native and nonnative in the 15-Mile Reach and the Yampa River. Include the new two additional years of fishery data for developing meso- habitat suitability. These species include roundtail chub, speckled dace, common carp, white sucker, channel catfish, smallmouth bass, largemouth bass and green sunfish.

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REFERENCES

Anderson, R. M. 2002. Riverine fish-flow investigations. Colorado Division of Wildlife. Federal Aid Project F-289-R5. Job Prog. Report. Fort Collins, CO 92pp.

Anderson, R. M. and G. Stewart. 2001. Riverine fish-flow investigations. Colorado Division of Wildlife. Federal Aid Project F-289-R4. Job Prog. Report. Fort Collins, CO 83pp.

Anderson, R. M. and G. Stewart. 2000. Riverine fish-flow investigations. Colorado Division of Wildlife. Federal Aid Project F-289-R3. Job Prog. Report. Fort Collins, CO 96pp.

Anderson, R. M. and G. Stewart. 1999. Riverine fish-flow investigations. Colorado Division of Wildlife. Federal Aid Project F-289. Job Prog. Report. Fort Collins, CO 44pp.

Anderson, R. M. 1998. Riverine fish-flow investigations. Colorado Division of Wildlife. Federal Aid Project F-288. Job Progress Report. Fort Collins, CO 44pp.

Anderson, R. M. 1997. An evaluation of fish community structure and habitat potential for Colorado squawfish and razorback sucker in the unoccupied reach (Palisade to Rifle) of the Colorado River, 1993-1995. Final Report. Project No. 18. Colorado Division of Wildlife. Federal Aid Project F-288. Job Progress Report. Fort Collins, CO 44pp.

Andrews, E.D., 1980. Effective and bankfull discharges of streams in the Yampa river basin, Colorado and Wyoming. Journal of Hydrology 46, pp. 311-30.

Bestgen, K. R. 1997. Interacting effects of physical and biological factors on recruitment of age-0 Colorado pikeminnow. Unpublished Ph.D. Dissertations, Colorado State University, Fort Collins, CO. 203 pp.

Bovee, K. 1996. Perspectives on two-dimensional river habitat models: the PHABSIM experience. *Proceedings - 2nd International Symposium on Habitat Hydraulics*. B150-B152.

Bovee, K. D. 1982. A guide to stream habitat analysis using the instream flow incremental methodology. Instream flow information paper 12. FWS/OBS-82/86. United States Department of the Interior, Coop Instream Flow Service Group, Fort Collins Colorado.

Bundy, J. M. and K.R. Bestgen. 2001. Evaluation of the interagency standardized monitoring program sampling technique in backwater of the Colorado River in the Grand Valley, Colorado. Larval Fish Lab Contribution 119, CSU, Fort Collins, CO.

Bureau of Reclamation, 1999, draft. Late summer and fall operations report of the HUP managing entities and water managers. BOR, Grand Junction CO, 13 pp.

Byers, D. W., C. Sodergren, J. M. Bundy, and K. R. Bestgen 2001. Habitat use and movement of bluehead sucker, flannelmouth sucker and roundtail chub in the Colorado River. Larval Fish Laboratory, CSU. Fort Collins Co 32 pp.

Brunner, G. W. 1998. HEC-RAS River analysis system, user manual version 2.2. U.S. Army Corps of Engineers, Hydrologic Engineering Center. Davis CA pp 230.

Carlson, C.A., C.G. Prewitt, D. E. Snyder, E. J. Wick, E. L. Ames, and W.D. Fronk. 1979. Fishes and macroinvertebrates of the White and Yampa Rivers, Colorado. Colorado Bureau of Land Management Biological Series 1.

DeVries, R and S. G. Maurer. 1997. Dolores River Guide. Southwest Natural and Cultural Heritage Asso. Albuquerque, NM.

Elmbald 2003 (in review). The interagency standardized monitoring program in Colorado result from 1986 to 2000. Final Report, Colorado Division of Willdlife, Grand Junction, CO.

Espegren, G. D. 1998. Evaluation of the standards and methods used for quantifying instream flows in Colorado. Colo. Water Con. Board. Denver, CO. 18 pp.

Everhart, W. H. and W. D. Youngs. 1981. Principles of fishery science. Cornell University press.

Hawkins, J.A., E. J. Wick and D. E. Jennings. 1997. Icthyofauna of the Little Snake River, Colorado, 1994. Report to: U.S. National Park Service, Denver CO, and Colorado River Endangered Fish Recovery Prog. , Denver CO. 44pp.

Instream Flow Council. 2002. Instream Flows for Riverine Resource Stewardship. Publisher at www.instreamflowcouncil.org. USA.

King, I. 1997. The users guide to RMA2 WES Version 4.3. The U.S. Army Corps of Engineers – Waterways experiment laboratory. pp 240.

Kondolf, G. M., E. W. Larsen and J. G. Williams. 2000. Measuring and modeling the hydraulic environment for assessing instream flows. North American Journal of Fisheries Management 20:1016-1028.

Leclerc, M., Boudreault, A., Bechara, J.A., and Corfa, G. 1995. "Two-dimensional hydrodynamic modeling: a neglected tool in the instream flow incremental methodology", *Trans. Am. Fisheries Soc.*, **124**(5), 645-662.

McLean, S.R., S.R. Wolfe, and J.M. Nelson. (1999). Predicting boundry shear stress and sediment transport over bed forms. Journal of Hydraulic Engineering. July 1999:725-736.

McAda, C.W. 2002. Subadult and adult pikeminnow monitoring; summary of results, 1986 – 2000. Recovery Program Project Number 22, Final Report. U.S.F.W.S., Grand Junction, Co. 60pp.

McAda, C.W, W.R. Elmblad, K.S. Day, M. A. Trammel and T. E. Chart. 1997. Interagency Standardized Monitoring Program; Summary of Results, 1996. Annual report. Recovery Program for the Endangered Fishes of the Upper Colorado River Basin, U.S. Fish and Wildlife Service , Denver, Co.

Miller, W.H., D.L. Archer, H.M. Tyus and R. M. McNatt. 1982. Yampa River fishes study. Final Report for Memorandum of Understanding 14-16-0006-81-931(IA), U.S. National Park Service. U.S. Fish and Wildlife Service, Salt Lake City, UT.

Modde, T., W. J. Miller, R M. Anderson, and D. Irving. 1995. Determination of habitat availability and habitat use, and flow needs of endangered fishes in the Yampa River between August and September. Colorado River Recovery Program Report for Project #CAP-9. Denver Colorado. 128 pp.

Modde, T. and G. Smith. 1999. Flow recommendations for endangereed fishes in the Yampa River. Final Rport submitted to the Recovery Implementation Program for the Recovery of Endangered Fishes in the Upper Colorado River Basin. U.S. Fish and Wildlife Service, Denver, CO. 44 pp.

Nehring, R. B. 1979. Evaluation of instream flow methods and determination of water quantity needs for stream in the state of Colorado. Colo. Div. Wild. Job Compl. Report. U. S. Fish and Wildl. Service Contract No. 14-16-0006-78-909. 144pp.

Nelson, J.M. (1996). Predictive techniques for river channel evolution and maintenance. Air and Soil Pollution. 90:321-333.

Nelson, J.M., R.L. Shreve, R. McLean, and T.G. Drake. (1995). Role of near-bed turbulence structure in bed load transport and bed form mechanics. Water Resources Research. 31(8):2071-2086.

Osmundson, D., and L. R. Kaeding. 1991. Recommendations for flows in the 15-Mile Reach during October-June for maintenance and enhancement of endangered fish population in the upper Colorado. Final Report. U. S. Fish and Wildlife Service Grand Junction, CO. 82 pp.

Osmundson, D., B., P. Nelson, K, Fenton, and D. W. Ryden. 1995. Relationships between flow and rare fish habitat in the '15-mile reach' of the upper Colorado River. U. S. Fish and Wildlife Service Final Report. Grand Junction, CO.

Osmundson, D., 1999. Longitudinal variation in fish community structure and water temperature in the Upper Colorado River: Implications for Colorado Pikeminnow habitat suitability. Report A, Project No. 48. U. S. Fish and Wildlife Service Final Report. Grand Junction, CO.

Osmundson, D., 2000. Importance of the 15-Mile Reach to Colorado River populations of endangered Colorado pikeminnow and razorback sucker. Final Report. U. S. Fish and Wildlife Service Position Paper. Grand Junction, CO.

Osmundson, D., 2001. Flow regimes for restoration and maintenance of sufficient habitat to recover endangered razorback sucker and Colorado pikeminnow in the Upper Colorado River. Project No. 47. U. S. Fish and Wildlife Service. Grand Junction, CO.

Osmundson, D., 2002. Population dynamics of Colorado pikeminnow in the Upper Colorado River. Project no. 22-A, U. S. Fish and Wildlife Service Final Report. Grand Junction, CO.

Parasiewicz, P. 2001. MesoHABSIM: A concept for application of instream flow models in river restoration planning. Fisheries. Vol. 26. 9:6-13.

Pitlick, J., M. M. Van Steeter, B. Barkett, R. Cress and M. A. Franseen. 1999. Geomorphology and Hydrology of the Colorado and Gunnison Rivers and implications for habitats used by endangered fishes. Final Report, U.S. Fish and Wildlife Service, Grand Junction.

Pitlick, J., and R. Cress. 2000. Longitudinal trends in channel characteristics of the Colorado River and implications for food-web dynamics. Final Report. University of Colorado, Boulder.

Prewitt, C. G. 1977. Catostomid fishes of the White and Yampa Rivers Colorado. M. S. Thesis, Colorado State Univ., Fort Collins, CO. 122 pp.

Rose, K. L., and D. R. Hahn. 1989. A summary of historic habitat modeling on the Yampa River using the physical habitat simulation system. U.S. Fish and Wildlife Service, Grand Junction, Colo. 18 pp.

Stewart, G. 2000. Two-dimensional hydraulic modeling for making instream-flow recommendations. M.S. Thesis. Colorado State University. Fort Collins CO.

Sublette, J. E., M. D. Hatch and M. Sublette. 1990. The Fishes of New Mexico. University of Nextci Press, Albuquerque NM.

Thompson, D.M., J.M. Nelson, and E.E. Wohl. (1998). Interactions between pool geometry and hydraulics. Water Resources Research. 34(12):3673-3681.

Topping, D.J., D.M. Rubin, J.M. Nelson, P.J. Kinzel III, I.C. Corson. (2000). Colorado River sediment transport. 2. Systematic bed-elevation and grain-size effects of sand supply limitation. Water Resources Research. 36(2):543-570.

Valdez, R. A., W. J. Masslich and A.Wasowicz. 1992. Dolores River native fish habitat suitability study (UDWR Contract No. 90-2559). BIO/WEST Inc. Logan Utah. 118 pp.

Valdez, R. A., L. Jonas, and J. Munk. 1999. Nonnative fish control in backwater habitats in the Colorado River. Interim progress report, Project 87b. Colorado Division of Wildlife, Fort Collins. 11p.

Wick, E. J., T.A. Lytle, and C.M. Haynes. 1981. Colorado squawfish and humpback chub population and habitat monitoring, 1979-1980. Progress Report SE-3-3. Endangered Wildlife Investigations. Colorado Division of Wildlife, Denver, Colorado.

Wick, E. J., J. A. Hawkins and C. A. Carlson. 1986. Colorado squawfish population and habitat monitoring. 1985. Final Report, SE 3-8. Endangered Wildlife Investigations, Colorado Division of Wildlife, Denver, Colorado.

Williams, J. E., Johnson, J. E., Hendrickson, D. A., Contreras-Balderas, S., Williams, J. D., Navarro-Mendoz, M., McAllister, D. E., & Deacon., J. E. 1989. Fishes of North America endangered, threatened, or of special concern: 1989, Fisheries (Bethesda) 14(6): 2-20.

Woodling, J. 1985. Colorado's little fish: A guide to the minnows and other lesser know fishes in the state of Colorado. Colorado Division of Wildlife, Denver, CO.

Wydowski and Hamil 1991. Evolution of a cooperative recovery program for endangered fishes in the upper Colorado River basin. Pages 123-135 in W.L. Minckley and J.E. Deacon, editors Battle against extinction: native fish management in the American West. University of Arizona Press, Tucson.

APPENDIX

Tables and Figures

A-Table 1. Density and biomass estimates for all species in **fish per kilometer** and in **kilograms per kilometer** for each study site.

	no./km	No./km	no./km	no./km	kg/km	kg/km	kg/km	kg/km
YAMPA RIVER	SEVENS	SEVENS	SEVENS	SEVENS	SEVENS	SEVENS	SEVENS	SEVENS
Species	1998	1999	2000	2001	1998	1999	2000	2001
Total Fish	1147	1115	778	653	1136.7	1004.5	633.1	491.9
Flannelmouth Sucker	395	376	296	263	413.4	411.6	361.4	227.7
Bluehead Sucker	274	238	309	120	110.5	93.5	26.0	30.1
Roundtail Chub	73	41	54	29	43.8	26.6	13.6	14.9
White S. + Crosses	200	190	106	138	157.6	159.3	63.5	55.9
Channel Catfish	111	109	22	46	161.5	122.7	41.3	58.1
Carp	77	69	45	33	215.3	168.6	118.5	95.2
Smallmouth Bass	20	29	6	37	10.0	10.0	4.3	5.2
Northern Pike	62	22	3	3	24.5	12.3	4.4	4.9
	no./km	no./km	no./km	no./km	kg/km	kg/km	kg/km	kg/km
LONG REACH	DUFFY	DUFFY	DUFFY	DUFFY	DUFFY	DUFFY	DUFFY	DUFFY
Species	1998	1999	2000	2001	1998	1999	2000	2001
Total Fish	387	403	316	430	509.6	453.8	340.5	291.9
Flannelmouth Sucker	25	15	11	5	34.2	19.3	15.6	6.1
Bluehead Sucker	24	23	16	19	14.0	9.5	10.1	12.1
Roundtail Chub	12	25	5	10	12.0	26.6	5.1	9.6
Colo. Pikeminnow	8	5	4	3	18.8	9.4	6.1	4.7
White S. + Crosses	241	242	203	185	265.8	266.6	231.5	176.0
Channel Catfish	19	29	15	23	34.5	39.1	23.7	27.5
Carp	22	8	4	2	101.6	39.7	21.8	10.6
Smallmouth Bass	40	58	58	215	17.2	26.8	22.4	43.7
Northern Pike	17	16	3	6	11.3	16.8	4.2	1.5
	no./km	no./km	no./km	no./km	kg/km	kg/km	kg/km	kg/km
MAPPED REACH	DUFFY	DUFFY	DUFFY	DUFFY	DUFFY	DUFFY	DUFFY	DUFFY
Species	1998	1999	2000	2001	1998	1999	2000	2001
Total Fish	435	343	467	716				
Flannelmouth Sucker	13	5	9	9				
Bluehead Sucker	21	10	12	3		2.6	4.1	2.1
Roundtail Chub	16	7	7	3		3.1	1.2	0.5
Colo. Pikeminnow	11	5	6	3				
White S. + Crosses	272	230	289	248				
Channel Catfish	6	20	66	25				
Carp	6	1	0	1				
Smallmouth Bass	119	51	112	399				
Northern Pike	33	13	3	15				
	no./km	no./km	no./km	no./km	kg/km	kg/km	kg/km	kg/km
YAMPA RIVER			Lily Park	Lily Park			Lily Park	Lily Park
Species			2000	2001			2000	2001
Total Fish			6279	3168			2368.6	1760.3
Flannelmouth Sucker			2238	1667			1315.7	801.3
Bluehead Sucker			552	346			194.5	114.0
Roundtail Chub			2	2			3.0	0.1
Colo. Pikeminnow			5	2			0.0	0.0
White S. + Crosses			14	2			1.1	0.6

Channel Catfish			3668	1395			555.4	526.3
Carp			186	171			193.4	203.8
Smallmouth Bass			121	501			69.9	87.0
Northern Pike			19	14			35.5	27.2
	no./km	no./km	no./km	no./km	kg/km	kg/km	kg/km	kg/km
COLORADO RIVER		CORN L.	CORN L.	CORN L.		CORN L.	CORN L.	CORN L.
Species		1999	2000	2001		1999	2000	2001
Total Fish		3962	3417	4007		2760.8	2854.1	2605.3
Flannelmouth Sucker		1550	998.75	1661.75		1261.2	1268.9	1280.6
Bluehead Sucker		1573	1182.25	1272		806.4	504.4	596.1
Roundtail Chub		192	357	170.5		57.2	68.0	41.2
Colo. Pikeminnow		5	0	0		9.3	18.8	5.7
White S. + Crosses		139	124	552		56.2	43.2	120.3
Channel Catfish		195	301.25	440.5		180.9	228.4	354.2
Carp		309	525.25	198.5		389.6	722.4	207.0
	no./km	no./km	no./km	no./km	kg/km	kg/km	kg/km	kg/km
COLORADO RIVER		CLIFTON	CLIFTON	CLIFTON		CLIFTON	CLIFTON	CLIFTON
Species			2000	2001		1999	2000	2001
Total Density estimate			3766	4547			3207	3341
Flannelmouth Sucker			1822	1563			1280	1075
Bluehead Sucker			1138	1164			452	496
Roundtail Chub			437	357			100	94
Colo. Pikeminnow			2	2				
White S. + Crosses			333	199			116	64
Channel Catfish			641	530			708	447
Carp			570	845			552	1165
	no./km	no./km	no./km	no./km	kg/km	kg/km	kg/km	kg/km
DOLORES RIVER			BIG GYP	BIG GYP			BIG GYP	BIG GYP
Species			2000	2001			2000	2001
Total Density estimate			196.6	231.7			259.0	48.7
Flannelmouth Sucker			35.8	105.9			88.7	1.5
Bluehead Sucker			3.0	12.7			7.0	0.3
Roundtail Chub			81.0	65.1			14.9	4.5
Channel Catfish			68.6	62.2			100.0	22.6
Carp			24.4	6.0			48.3	19.8
Green Sunfish			5.2	1.5				
Black Bullhead			13.7	3.7				

A-Table 2. Density and biomass estimates for all species in **fish per hectare** and **kilograms per hectare** for each study site.

	no/ha	no/ha	no/ha	no/ha	kg/ha	kg/ha	kg/ha	kg/ha
YAMPA RIVER	SEVENS	SEVENS	SEVENS	SEVENS	SEVENS	SEVENS	SEVENS	SEVENS
Species	1998	1999	2000	2001	1998	1999	2000	2001
Total Fish	185.2	180.0	125.6	105.4	183.5	162.1	102.2	79.4
Flannelmouth Sucker	63.8	60.7	47.8	42.5	66.7	66.4	58.3	36.7
Bluehead Sucker	44.3	38.4	49.8	19.4	17.8	15.1	4.2	4.9
Roundtail Chub	11.8	6.6	8.6	4.7	7.1	4.3	2.2	2.4
White S. + Crosses	32.3	30.7	17.1	22.3	25.4	25.7	10.2	9.0
Channel Catfish	17.9	17.5	3.6	7.4	26.1	19.8	6.7	9.4
Carp	12.5	11.1	7.2	5.3	34.8	27.2	19.1	15.4
Smallmouth Bass	3.2	4.7	1.0	5.9	1.6	1.6	0.7	0.8
Northern Pike	10.0	3.5	0.5	0.4				
	no/ha	no/ha	no/ha	no/ha	kg/ha	kg/ha	kg/ha	kg/ha
LONG REACH	DUFFY	DUFFY	DUFFY	DUFFY	DUFFY	DUFFY	DUFFY	DUFFY
Species	1998	1999	2000	2001	1998	1999	2000	2001
Total Fish	55.3	57.7	45.3	61.4	72.9	64.9	48.7	41.7
Flannelmouth Sucker	3.6	2.1	1.6	0.7	4.9	2.8	2.2	0.9
Bluehead Sucker	3.5	3.3	2.3	2.7	2.0	1.4	1.4	1.7
Roundtail Chub	1.7	3.6	0.7	1.4	1.7	3.8	0.7	1.4
Colo. Pikeminnow	1.2	0.7	0.5	0.4	2.7	1.3	0.9	0.7
White S. + Crosses	34.5	34.7	29.1	26.4	38.0	38.1	33.1	25.2
Channel Catfish	2.6	4.1	2.1	3.3	4.9	5.6	3.4	3.9
Carp	3.1	1.2	0.5	0.3	14.5	5.7	3.1	1.5
Smallmouth Bass	5.7	8.3	8.3	30.7	2.5	3.8	3.2	6.3
Northern Pike	2.4	2.3	0.5	0.8	1.6	2.4	0.6	0.2
	no/ha	no/ha	no/ha	no/ha	kg/ha	kg/ha	kg/ha	kg/ha
MAPPED REACH	DUFFY	DUFFY	DUFFY	DUFFY				
Species	1998	1999	2000	2001				
Total Fish	85.9	67.8	92.3	141.4				
Flannelmouth Sucker	2.6	1.1	1.8	1.7				
Bluehead Sucker	4.1	1.9	2.3	0.7				
Roundtail Chub	3.1	1.3	1.4	0.7				
Colo. Pikeminnow	2.2	0.9	1.2	0.7				
White S. + Crosses	53.7	45.4	57.0	49.1				
Channel Catfish	1.2	4.0	13.1	5.0				
Carp	1.2	0.2	0.0	0.2				
Smallmouth Bass	23.5	10.0	22.1	78.9				
Northern Pike	6.4	2.7	0.5	2.9				
	no/ha	no/ha	no/ha	no/ha	kg/ha	kg/ha	kg/ha	kg/ha
YAMPA RIVER			Lily Park	Lily Park			Lily Park	Lily Park
Species			2000	2001			2000	2001
Total Fish			1047.6	528.5			395.2	293.7
Flannelmouth Sucker			373.3	278.1			219.5	133.7
Bluehead Sucker			92.1	57.7			32.5	19.0
Roundtail Chub			0.3	0.3			0.5	0.0
Colo. Pikeminnow			0.9	0.3			0.0	0.0

White S. + Crosses			2.3	0.3			0.2	0.1
Channel Catfish			611.9	232.7			92.7	87.8
Carp			31.0	28.5			32.3	34.0
Smallmouth Bass			20.2	83.5			11.7	14.5
Northern Pike			3.2	2.3			5.9	4.5
	no/ha	no/ha	no/ha	no/ha	kg/ha	kg/ha	kg/ha	kg/ha
COLORADO RIVER		CORN L.	CORN L.	CORN L.		CORN L.	CORN L.	CORN L.
Species		1999.0	2000.0	2001.0		1999	2000	2001
Total Fish		765.1	659.9	773.8		533.2	551.2	503.1
Flannelmouth Sucker		299.4	192.9	320.9		243.6	245.1	247.3
Bluehead Sucker		303.8	228.3	245.7		155.7	97.4	115.1
Roundtail Chub		37.0	68.9	32.9		11.1	13.1	8.0
Colo. Pikeminnow		1.0	0.0	0.0		1.8	3.6	1.1
White S. + Crosses		26.7	23.9	106.6		10.9	8.3	23.2
Channel Catfish		37.7	58.2	85.1		34.9	44.1	68.4
Carp		59.6	101.4	38.3		75.2	139.5	40.0
			no/ha	no/ha			kg/ha	kg/ha
COLORADO RIVER								
Species			2000	2001			2000	2001
Total Density estimate			600	724			511	532
Flannelmouth Sucker			290	249			204	171
Bluehead Sucker			181	185			72	79
Roundtail Chub			70	57			16	15
Colo. Pikeminnow			0	0				
White S. + Crosses			53	32			18	10
Channel Catfish			102	84			113	71
Carp			91	135			88	185
			no/ha	no/ha			kg/ha	kg/ha
DOLORES RIVER			BIG GYP	BIG GYP			BIG GYP	BIG GYP
Species			2000	2001			2000	2001
Total Density estimate			116.3	137.1			153.2	28.8
Flannelmouth Sucker			21.2	62.6			52.5	0.9
Bluehead Sucker			1.8	7.5			4.2	0.2
Roundtail Chub			47.9	38.5			8.8	2.6
Channel Catfish			40.6	36.8			59.1	13.4
Carp			14.4	3.5			28.6	11.7
Green Sunfish			3.1	0.9				
Black Bullhead			8.1	2.2				

A-Table 3. Corn Lake polygon area, polygon mean depth, polygon mean velocity and polygon density and biomass for bluehead and flannelmouth sucker.

		Bluehead		Flannelmouth			
Polygon	AREA	Density	Biomass	Density	Biomass	Depth	Velocity
Lable	hectare	fish/ha	kg/ha	fish/ha	kg/ha	Meters	m/s
CORN LAKE - 800							
lu-800	2.01	113	72	290	299	1.02	0.41
2r-800	0.87	211	114	23	24	0.56	0.85
3u-800	3.21	102	34	158	80	1.24	0.34
4r-800	1.95	370	187	357	303	0.61	0.66
5b-800	0.05	0	0	0	0	0.57	0.15
6r/u-800	2.26	362	158	315	278	0.61	0.83
7b-800	0.27	0	0	0	0	0.60	0.01
9r/u-800	1.24	193	89	383	61	0.90	0.61
10r/u-800	1.91	546	329	545	491	0.67	0.74
12r/u-800	0.86	458	206	782	552	0.80	0.74
13b-800	0.07	0	0	0	0	0.69	0.05
14r/u-800	2.17	316	74	453	369	0.79	0.71
15b-800	0.14	80	26	121	21	0.53	0.03
16u-800	1.56	230	119	329	218	0.38	0.64
CORN LAKE – 1000							
lu-1000	2.02	156	64	414	224	1.09	0.48
2r-1000	0.89	635	258	109	148	0.63	0.94
3u-1000	3.21	148	54	158	98	1.31	0.40
4r-1000	2.01	286	132	406	298	0.67	0.73
5b-1000	0.05	4	1	0	0	0.64	0.14
6r/u-1000	2.32	369	184	423	344	0.67	0.91
7b-1000	0.29	8	27	18	2	0.65	0.01
9r/u-1000	1.26	329	54	266	318	0.96	0.69
10r/u-1000	1.99	363	158	439	345	0.72	0.81
12r/u-1000	0.90	211	89	755	623	0.85	0.84
13b-1000	0.08	0	0	0	0	0.90	0.08
14r/u-1000	2.27	221	101	306	241	0.81	0.79
15b-1000	0.15	0	0	45	8	0.54	0.03
16u-1000	1.65	233	101	226	187	0.41	0.70
CORN LAKE - 1800							
1u-1800	2.15	314	151	403	305	1.25	0.69
2r-1800	1.01	449	231	107	188	0.76	1.17
3u-1800	3.29	57	28	223	147	1.49	0.61
4r-1800	2.41	375	175	293	218	0.78	0.89
5-1800	0.07	0	0	16	13	0.73	0.15
6r/u-1800	2.64	508	265	229	185	0.81	1.14
7b-1800	0.34	0	0	111	6	0.84	0.02
9r/u-1800	1.30	257	158	352	365	1.07	0.91
10r/u-1800	2.29	324	203	282	268	0.84	1.02
12r/u-1800	1.45	800	345	300	185	0.95	1.08
13b-1800	0.11	64	12	75	88	0.91	0.16
14r/u-1800	2.65	178	89	406	315	0.91	1.00
15b-1800	0.76	100	52	40	7	0.49	1.14
16u-1800	1.89	83	64	147	176	0.52	0.88

A-Table 4. Clifton polygon area, polygon mean depth, polygon mean velocity and polygon density and biomass for bluehead and flannelmouth sucker.

		Bluehead		Flannelmouth		Mean	Mean
Polygon	AREA	Density	Biomass	Density	Biomass	Depth	Velocity
Lable	hectare	fish/ha	kg/ha	fish/ha	kg/ha	meters	m/s
CLIFTON 800							
3u-800	1.00	133	77	413	502	0.77	0.39
4u-800	0.18	840	200	nd	nd	0.54	0.73
5sc-800	0.15	55	22	127	64	0.14	0.19
6sc-800	0.24	49	20	51	26	0.12	0.27
8r-800	1.10	479	136	343	155	0.51	0.78
12u-800	1.67	154	74	358	251	0.50	0.51
15f-800	1.48	106	30	120	51	0.42	0.79
18u-800	1.27	317	154	516	378	0.76	0.39
21r-800	1.22	105	40	33	22	0.43	0.81
24u-800	1.35	234	106	267	193	0.93	0.37
27f-800	1.71	275	120	273	206	0.75	0.82
30u-800	3.70	47	18	123	86	1.14	0.24
33u-800	1.24	375	149	585	333	0.51	0.63
37u-800	0.77	512	270	535	415	0.42	0.55
38u-800	0.88	185	77	271	163	0.43	0.72
42u-800	2.12	249	122	520	287	0.65	0.56
45u-800	2.07	359	169	337	249	0.73	0.46
CLIFTON 1000							
3u-1000	1.02	60	34	404	370	0.84	0.44
5sl-1000	0.17	117	47	188	94	0.22	0.30
6sc-1000	0.32	199	80	188	94	0.18	0.38
8r-1000	1.15	629	201	359	221	0.57	0.80
12u-1000	1.82	213	94	463	261	0.59	0.52
15f-1000	1.66	335	149	96	52	0.48	0.74
18u-1000	1.30	169	82	886	544	0.85	0.41
21r-1000	1.30	387	218	65	59	0.50	0.80
24u-1000	1.43	73	49	248	343	0.97	0.41
27f-1000	1.73	347	155	203	189	0.81	0.87
30u-1000	3.71	25	8	47	26	1.20	0.28
33u-1000	1.43	86	27	802	551	0.52	0.59
37u-1000	0.87	90	42	328	345	0.50	0.53
38u-1000	0.98	246	104	86	185	0.50	0.72
42u-1000	2.24	246	67	295	151	0.74	0.58
45u-1000	2.15	273	86	140	84	0.81	0.49
49b-1000	0.13	0	0	0	0	0.89	0.05
50b-1000	0.68	0	0	0	0	1.32	0.03

A-Table 5. Lily Park polygon area, polygon mean depth, polygon mean velocity and polygon density and biomass for bluehead and flannelmouth sucker.

		Bluehead		Flannelmouth		Mean	Mean
Polygon	Area	Density	Biomass	Density	Biomass	Depth	Velocity
Lable	hectare	fish/ha	kg/ha	fish/ha	kg/ha	meters	(m/s
LILY PARK - 150 CFS							
1-150	0.35	161	66	493	401	0.24	0.26
2-150	1.50	173	66	278	159	0.20	0.24
4-150	1.36	65	25	473	262	0.28	0.28
5-150	0.95	87	34	443	254	0.23	0.37
6-150	2.44	17	6	116	67	0.55	0.19
7-150	0.42	0	0	0	0	0.23	0.43
8-150	0.58	81	28	751	376	0.61	0.23
9-150	1.61	29	10	235	110	0.65	0.17
10-150	0.48	86	23	709	330	0.38	0.46
11-150	0.34	70	20	711	272	0.34	0.26
12-150	0.05	0	0	0	0	0.47	0.12
13-150	0.32	443	148	888	392	0.33	0.32
14-150	0.38	15	4	1022	538	0.72	0.26
15-150	1.02	0	0	0	0	1.17	0.17
16-150	0.28	360	116	764	394	0.44	0.31
17-150	0.66	18	5	112	51	1.08	0.14
18-150	1.14	21	7	84	44	0.93	0.17
19-150	0.56	11	4	95	50	0.70	0.31
LILY PARK - 300 CFS							
1-300	0.38	264	95	218	201	0.37	0.34
2-300	1.67	95	38	239	152	0.31	0.38
4-300	1.47	201	78	329	203	0.32	0.37
5-300	1.12	124	48	228	144	0.24	0.43
6-300	2.51	46	19	396	247	0.57	0.25
7-300	0.45	0	0	0	0	0.17	0.49
8-300	0.62	154	60	721	489	0.50	0.28
9-300	1.63	35	12	154	80	0.55	0.19
10-300	0.54	311	102	835	486	0.36	0.64
11-300	0.36	148	45	485	294	0.50	0.41
12-300	0.06	0	0	0	0	0.57	0.14
13-300	0.41	220	88	498	307	0.43	0.56
14-300	0.43	112	44	685	462	0.77	0.38
15-300	1.18	20	9	441	305	1.15	0.22
16-300	0.32	195	76	920	550	0.50	0.50
17-300	0.75	83	30	495	348	1.09	0.22
18-300	1.24	19	6	418	270	0.97	0.28
19-300	0.65	81	32	821	488	0.74	0.27

A-Table 6. Sevens polygon area, polygon mean depth, polygon mean velocity and polygon density and biomass for bluehead and flannelmouth sucker.

		Bluehead		Flannelmouth		Mean	Mean
polygon	Area	Density	Biomass	Density	Biomass	Depth	Velocity
lable	hectare	fish/ha	kg/ha	fish/ha	kg/ha	meters	m/s
SEVESN 80							
1-80	0.50	155	31	199	173	0.32	0.14
2-80	0.52	286	94	38	83	0.21	0.21
3b-80	0.54	48	13	238	182	0.60	0.07
3a-80	1.38	9	2	39	23	0.53	0.07
4-80	0.96	18	7	23	25	0.41	0.10
5a-80	0.42	41	12	268	283	0.62	0.07
5b-80	0.68	0	0	4	4	0.41	0.09
6-80	0.44	39	14	138	137	0.54	0.08
7-80	1.20	22	7	30	33	0.28	0.14
9-80	1.07	0	0	16	14	0.62	0.05
10-80	1.64	32	6	71	61	0.42	0.12
11-80	0.18	0	0	0	0	0.24	0.02
12-80	0.46	0	0	0	0	0.48	0.09
13-80	0.02	0	0	0	0	0.26	0.00
13-80	1.15	0	0	29	46	0.42	0.09
14-80	1.53	0	0	69	50	0.76	0.04
SEVENS 200							
1-200	0.54	170	109	188	169	0.40	0.25
2-200	0.57	183	40	47	11	0.28	0.34
3b-200	0.59	191	72	471	318	0.66	0.15
3a-200	1.49	11	16	80	104	0.60	0.15
4-200	1.02	16	4	53	75	0.48	0.20
5a-200	0.43	255	53	202	97	0.70	0.16
5b-200	0.70	8	2	46	12	0.50	0.18
6-200	0.51	98	35	164	181	0.66	0.17
7-200	1.30	73	13	36	18	0.36	0.25
8-200	0.86	0	0	0	0	0.24	0.23
9-200	1.16	41	27	132	183	0.73	0.10
10-200	1.79	40	16	86	93	0.53	0.20
11-200	0.22	0	0	13	0	0.34	0.00
12-200	0.46	23	7	47	21	0.64	0.15
13a-200	0.02	0	0	0	0	0.26	0.00
13-200	1.21	17	7	51	44	0.56	0.17
14-200	1.57	22	0	78	45	0.89	0.10

A-Table 7. Duffy polygon area, polygon mean depth, polygon mean velocity and polygon density and biomass for bluehead and flannelmouth sucker.

		Bluehead		Flannelmouth		Mean	Mean
polygon	Area	Density	Biomass	Density	Biomass	Depth	Velocity
lable	hectare	fish/ha	kg/ha	fish/ha	kg/ha	meters	m/s
DUFFY 80							
1	1.4	0		0		**0.37**	0.11
2	0.4	0		4		**0.23**	0.36
3	2.7	0		2		**0.84**	0.05
4	1.0	0		0		**0.40**	0.08
5	0.3	0		7		**0.41**	0.18
6	0.5	0		5		**0.30**	0.21
7	1.0	6		4		**0.46**	0.14
8	1.0	0		4		**0.26**	0.25
9	1.1	6		6		**0.28**	0.15
DUFFY 200							
1	1.6	0		0		**0.49**	0.18
2	0.6	0		0		**0.32**	0.53
3	2.9	4		0		**0.86**	0.12
4	1.1	0		0		**0.44**	0.17
5	0.4	59		0		**0.43**	0.34
6	0.5	0		0		**0.37**	0.33
7	1.2	26		1		**0.51**	0.28
8	1.2	40		1		**0.35**	0.35
9	1.3	16		1		**0.39**	0.22

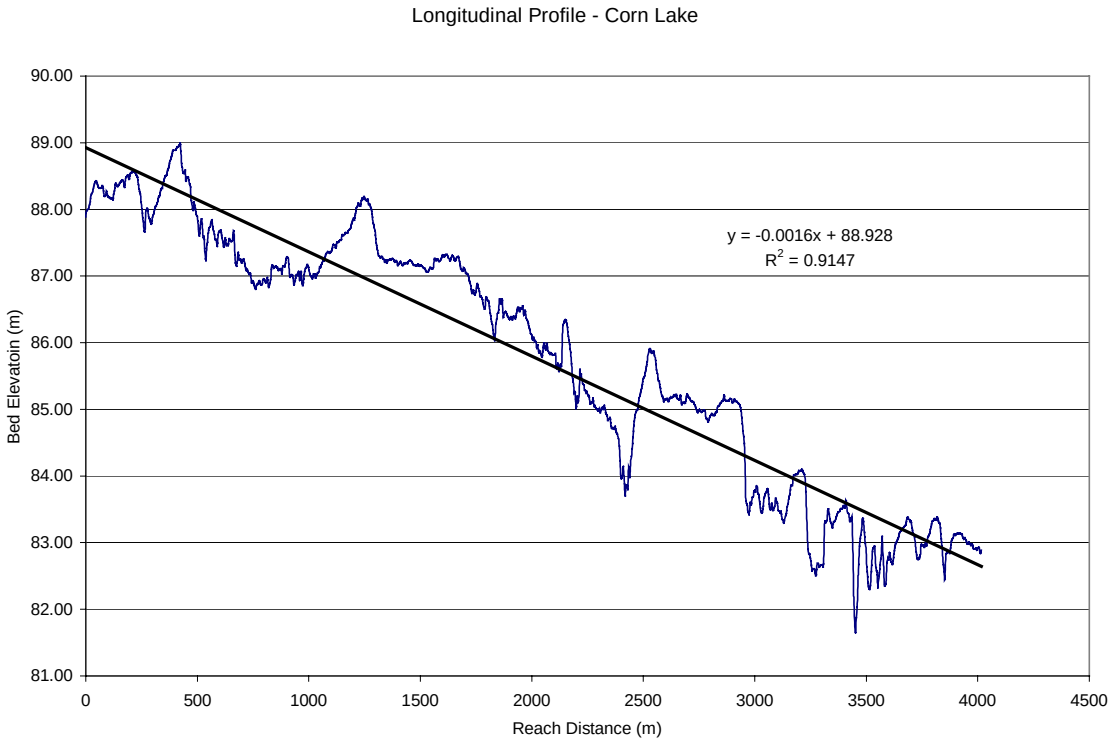


Figure A1. Longitudinal profile for Corn Lake site, Colorado River.

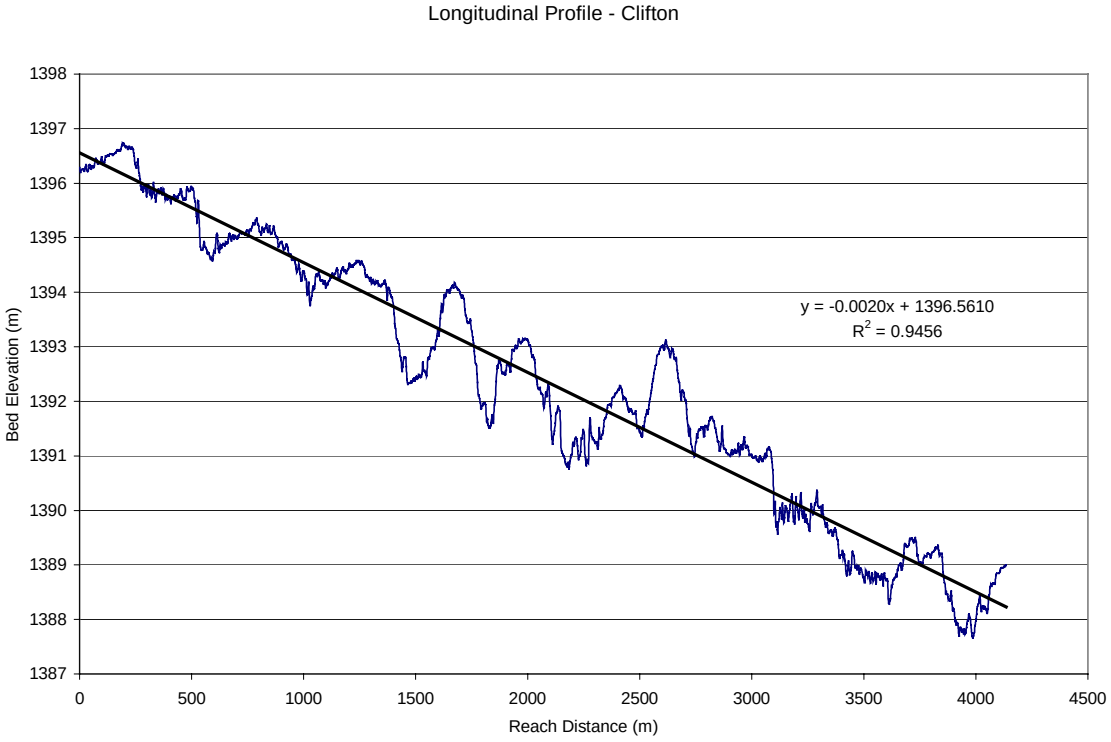


Figure A2. Longitudinal profile for Clifton site, Colorado River.

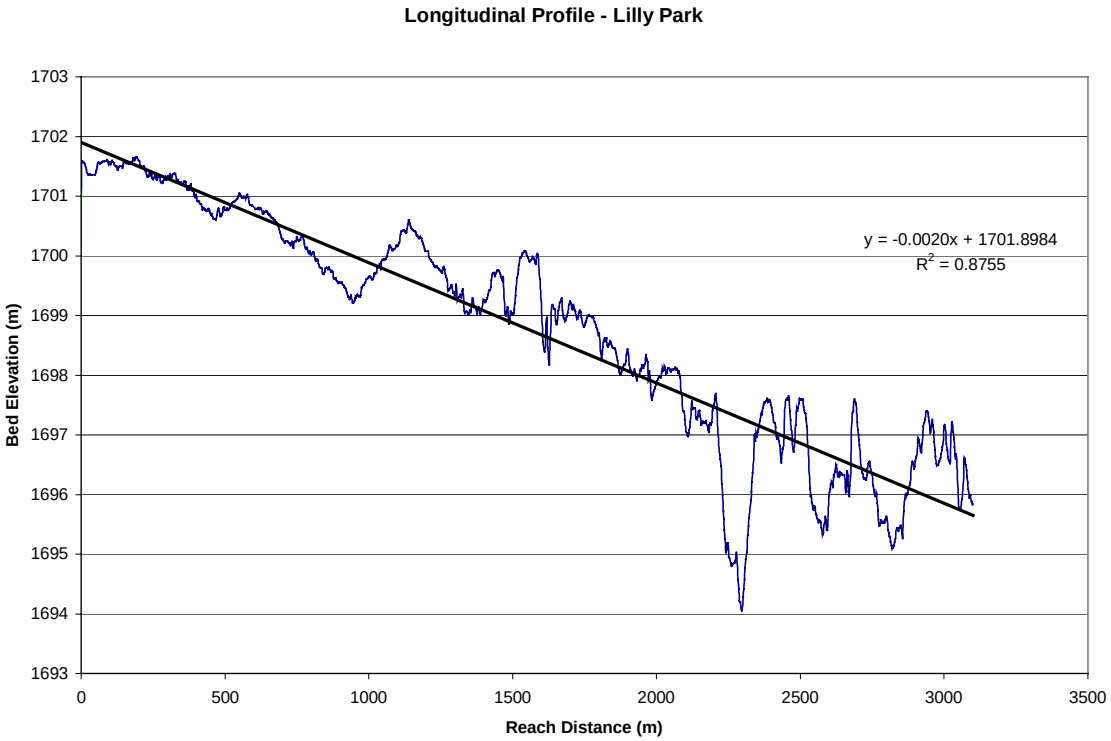


Figure A3. Longitudinal profile for Lily Park site, Yampa River.

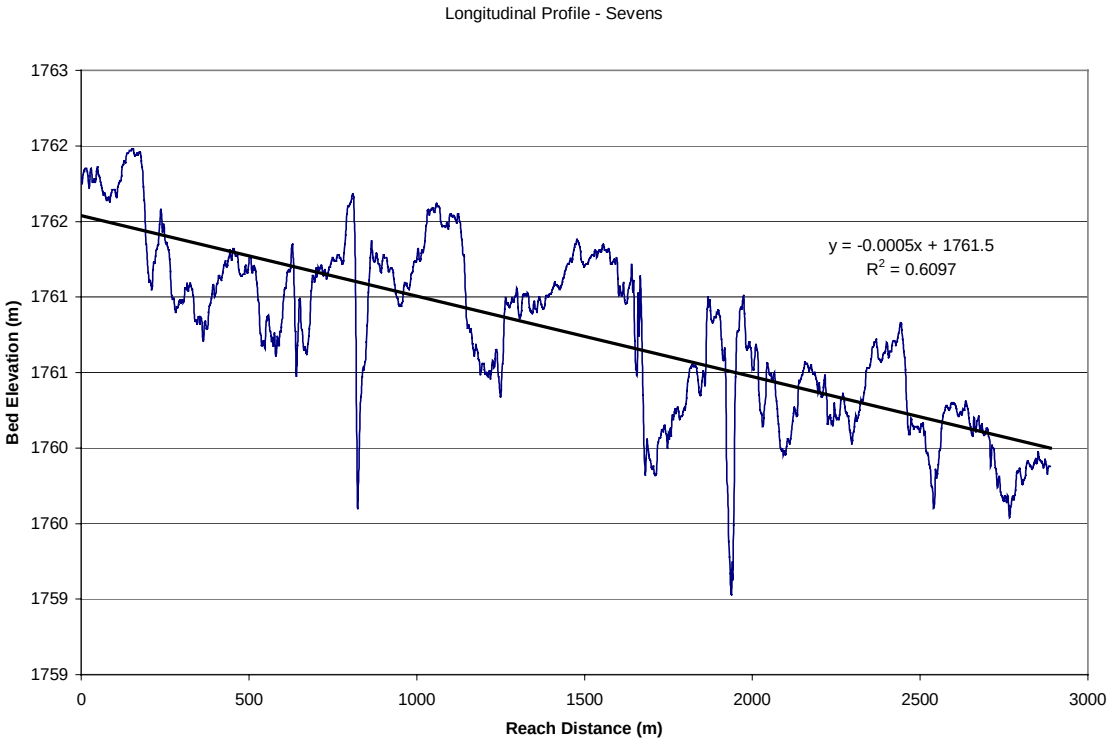


Figure A4. Longitudinal profile for Sevens site, Yampa River.

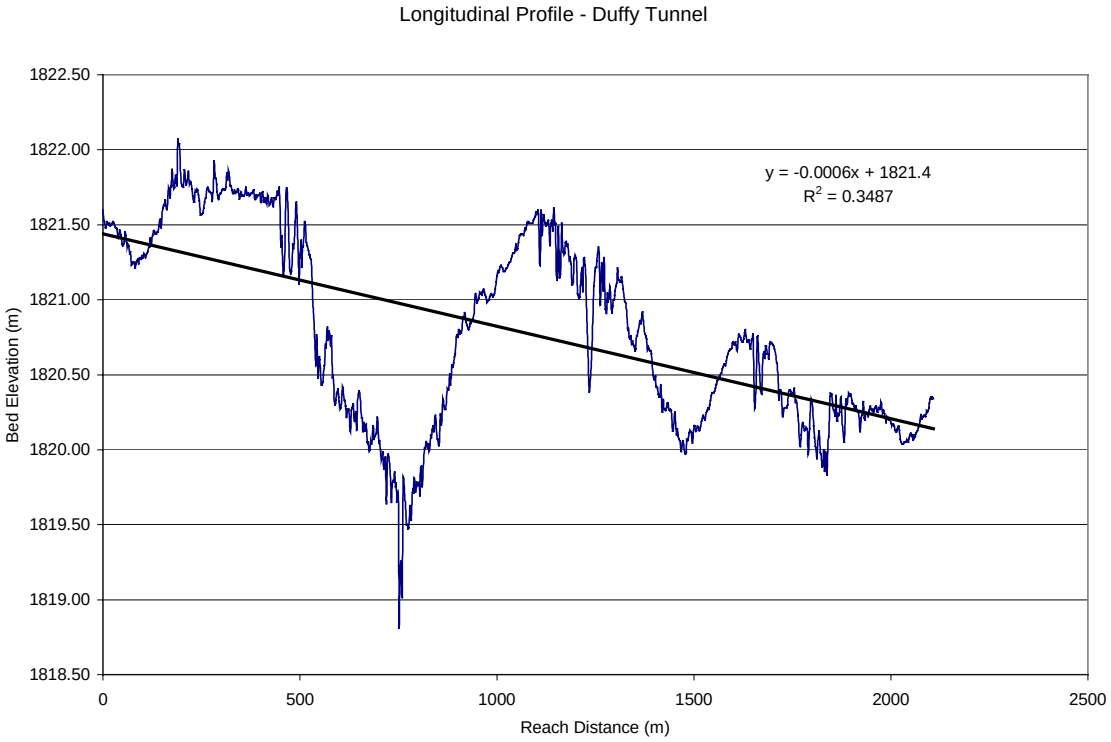


Figure A5. Longitudinal profile for Duffy site, Yampa River.

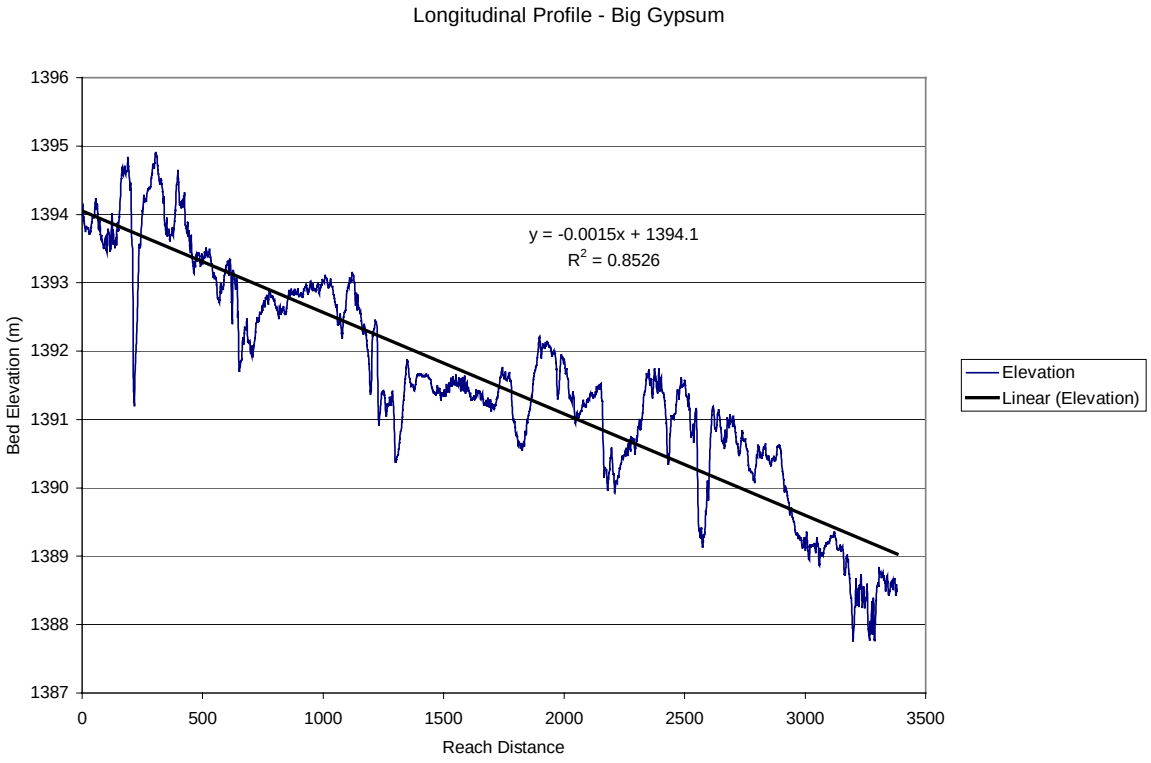


Figure A6. Longitudinal profile for Big Gypsum site, Dolores River.

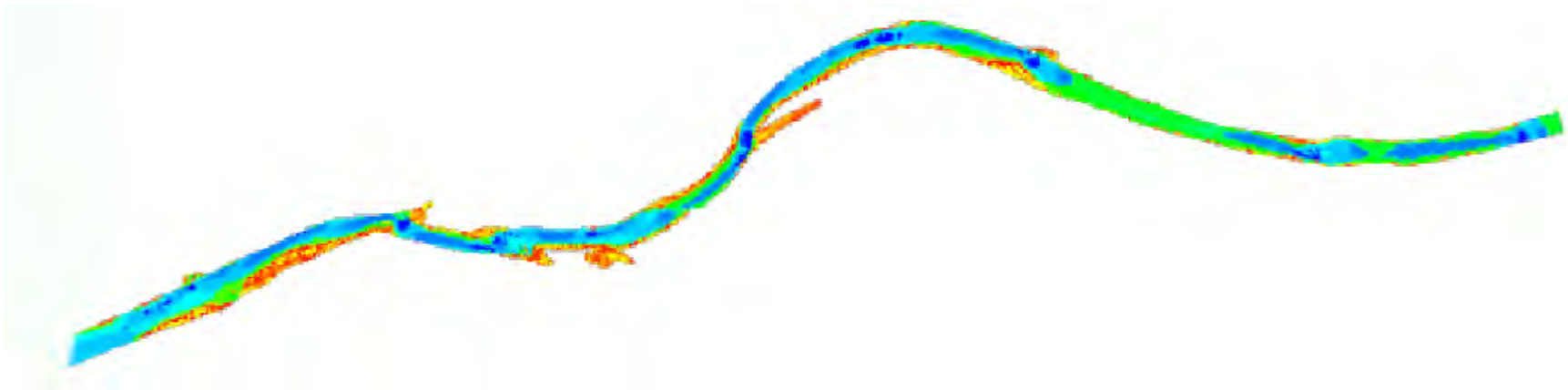


Figure A7. Corn Lake study site with meso-habitat distribution at 1000 cfs, Colorado River.

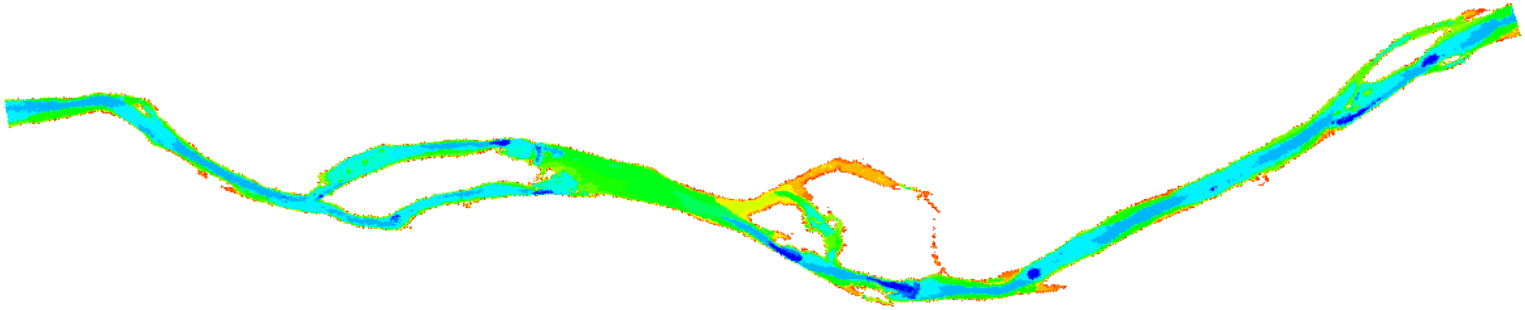


Figure A8. Clifton study site with meso-habitat distribution at 1000 cfs, Colorado River.

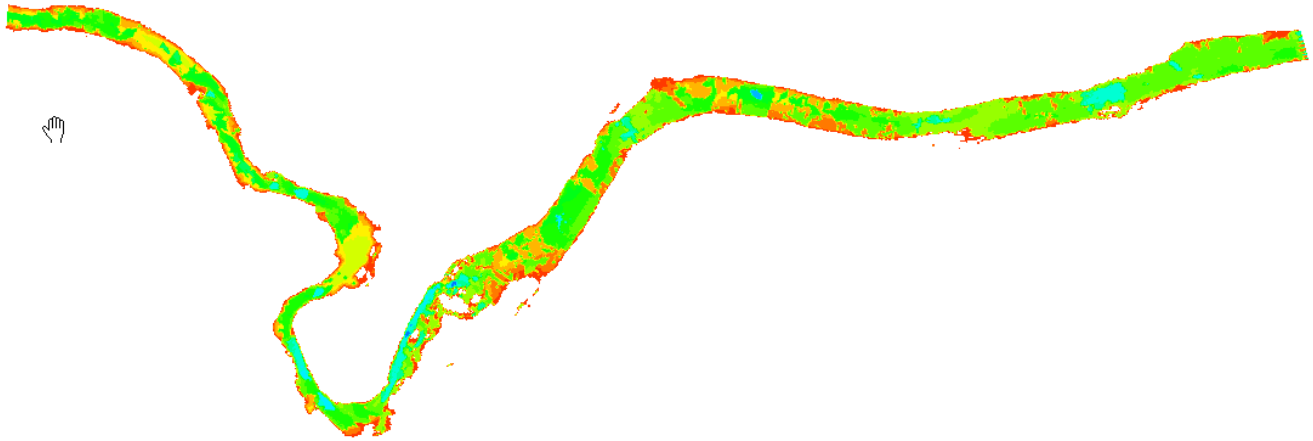


Figure A9. Lily Park study site with meso-habitat distribution at 200 cfs, Yampa River.

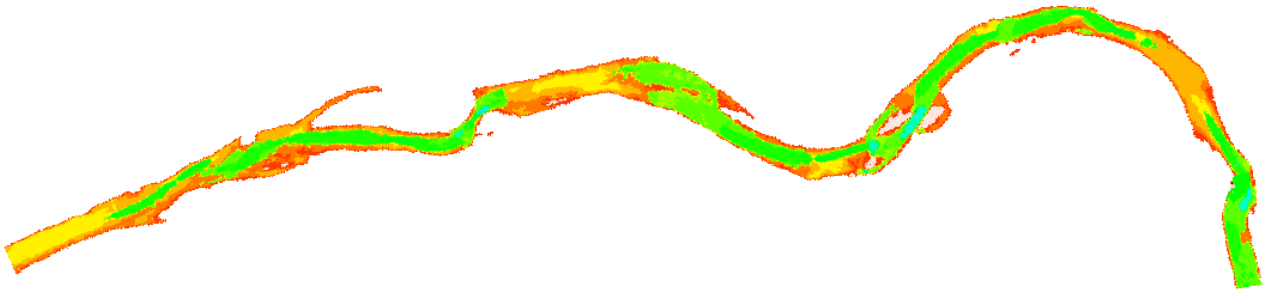
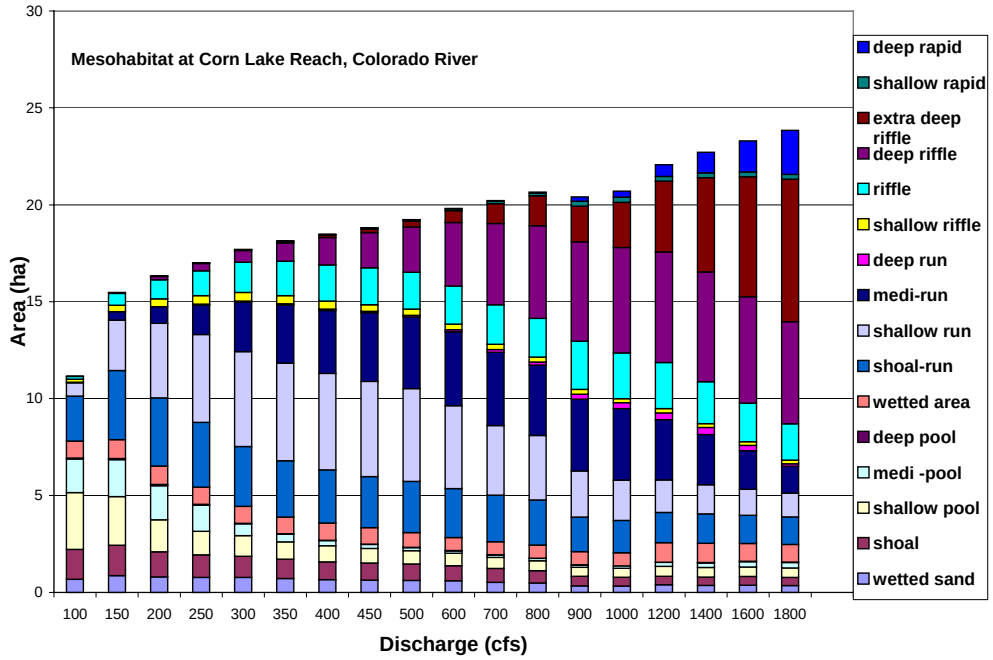
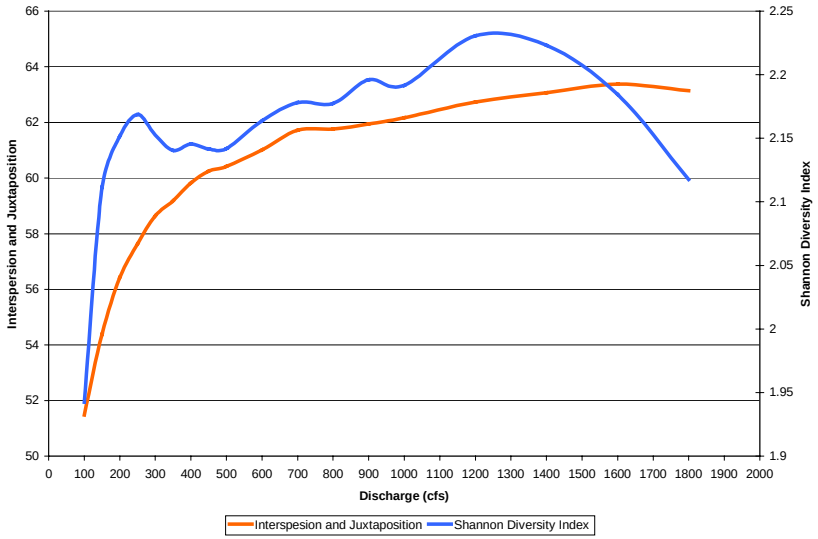
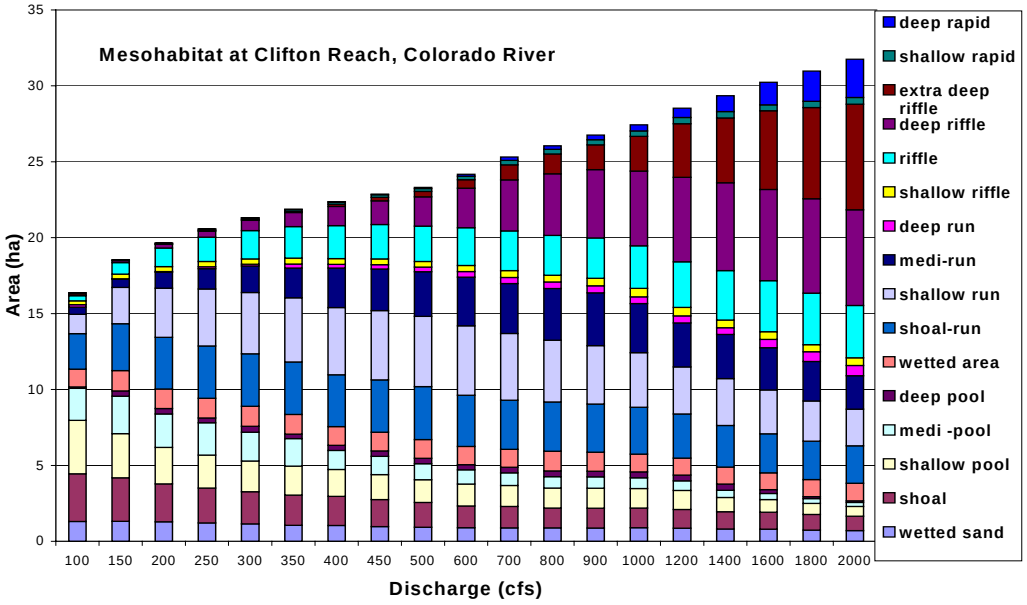
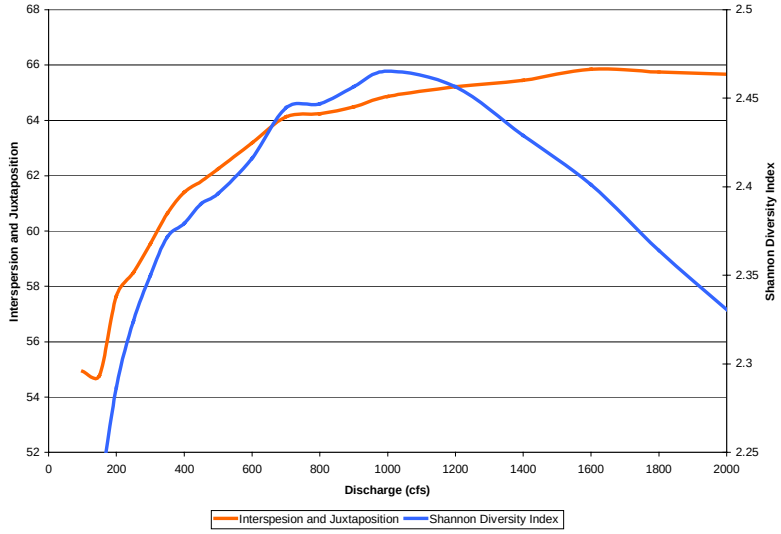


Figure A10. Sevens study site with meso-habitat distribution at 200 cfs, Yampa River.

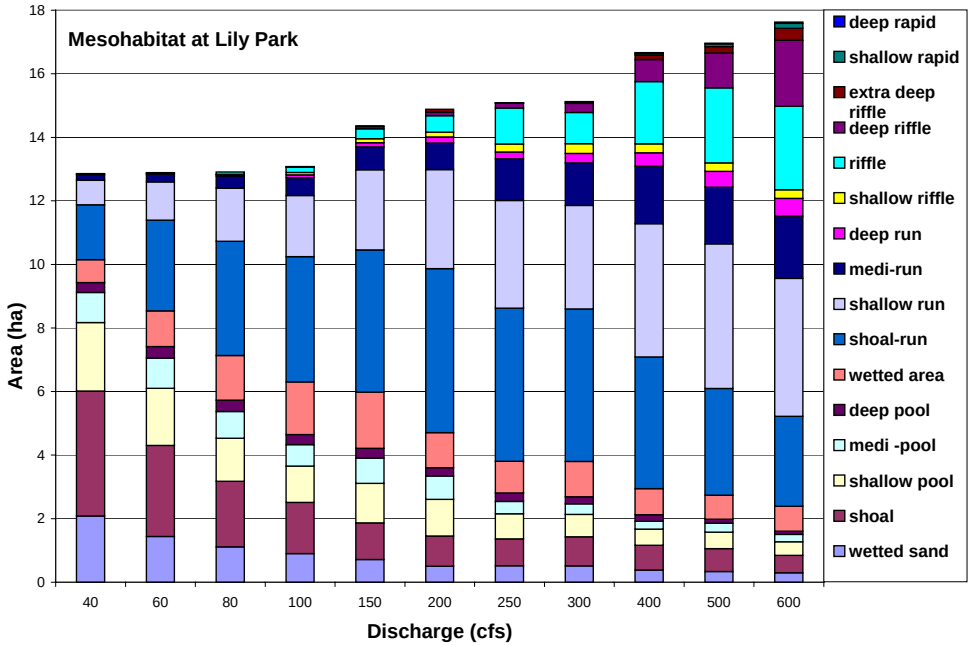


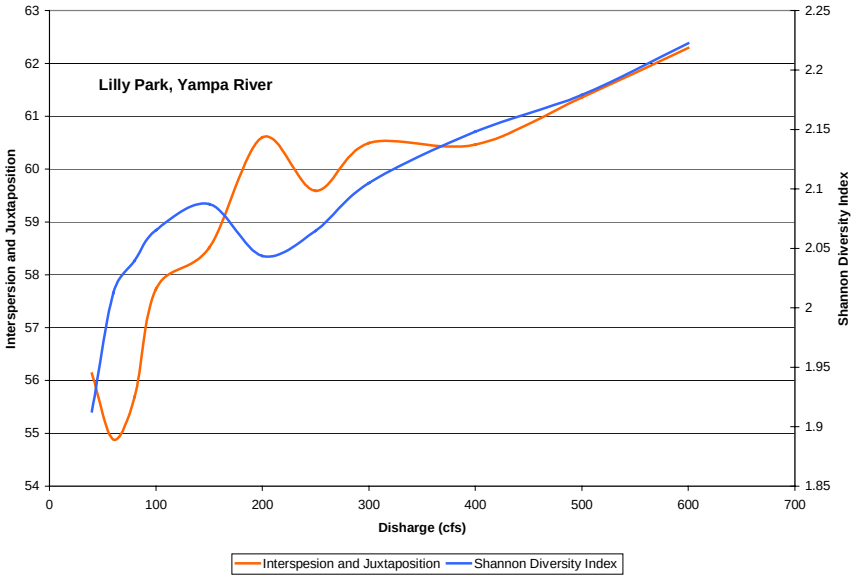


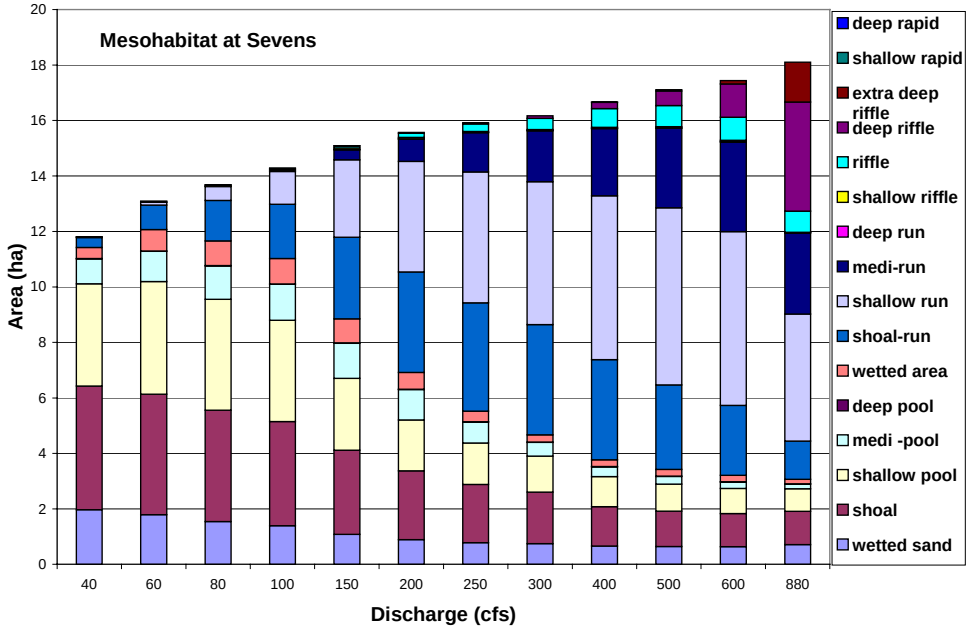


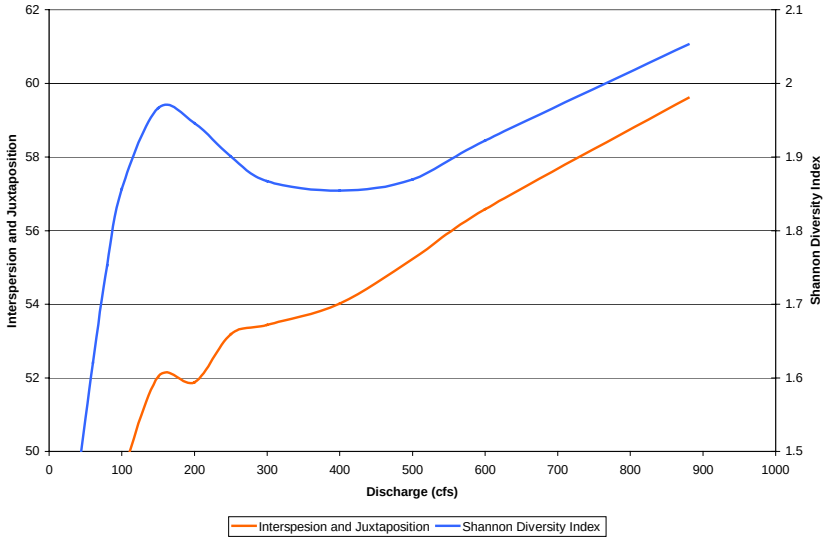


Figures A11 a, b, c, d. Meso-habitat and Shannon Diversity and Interspersion for modeled flows at Corn Lake (above) and Clifton, Colorado River.

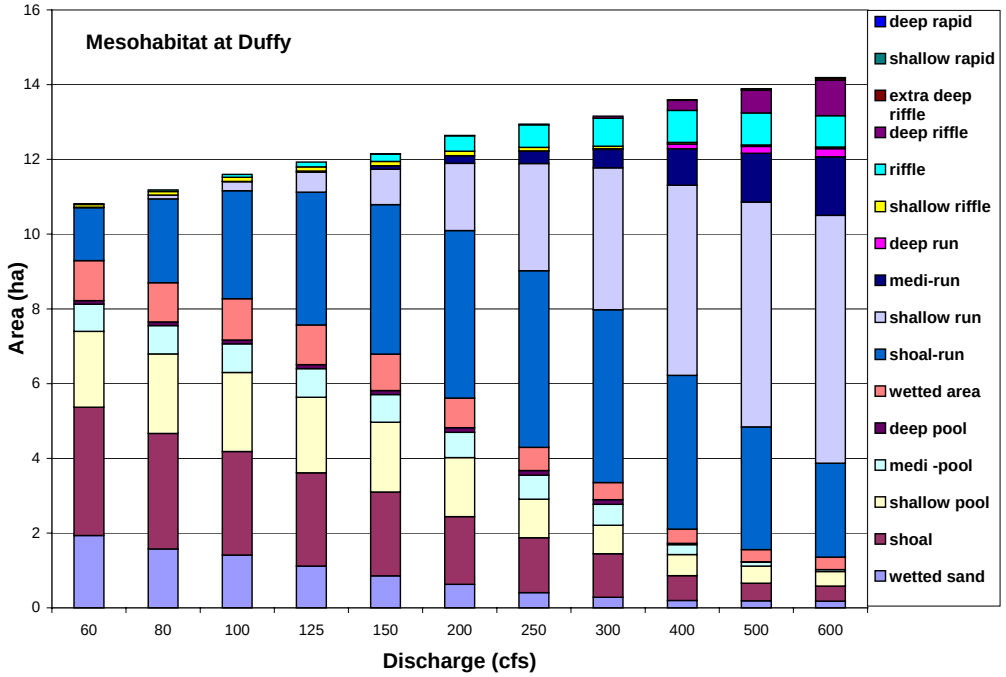


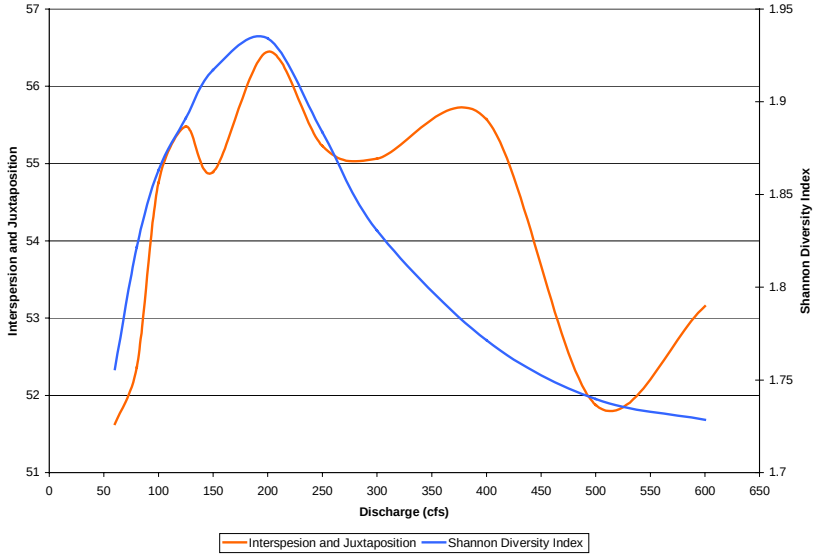


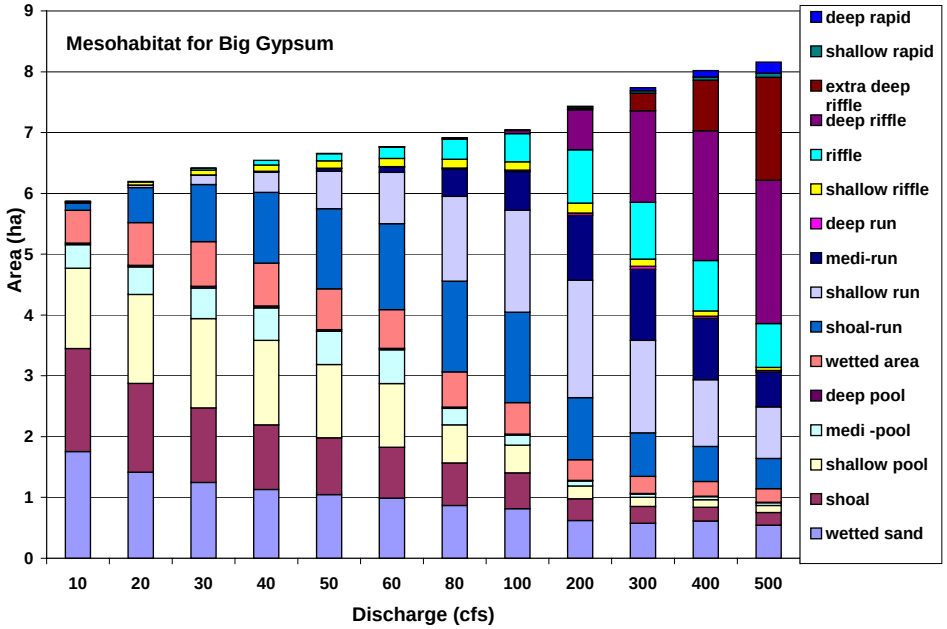


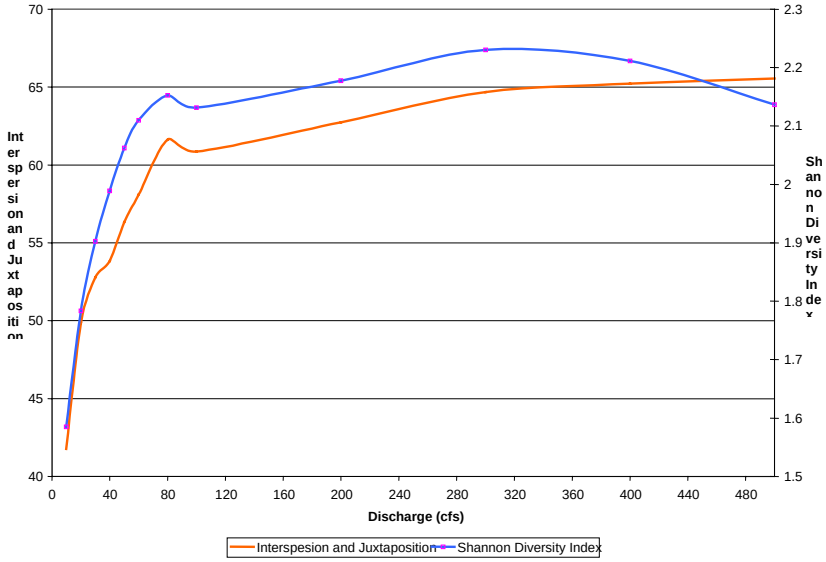


Figures A12 a, b, c, d. Meso-habitat and Shannon Diversity and Interspersion for modeled flows at Lily Park (above) and Sevens, Yampa River.









Figures A13 a, b, c, d. Meso-habitat and Shannon Diversity and Interspersion for modeled flows at Duffy(above), Yampa River and Big Gypsum, Dolores River.

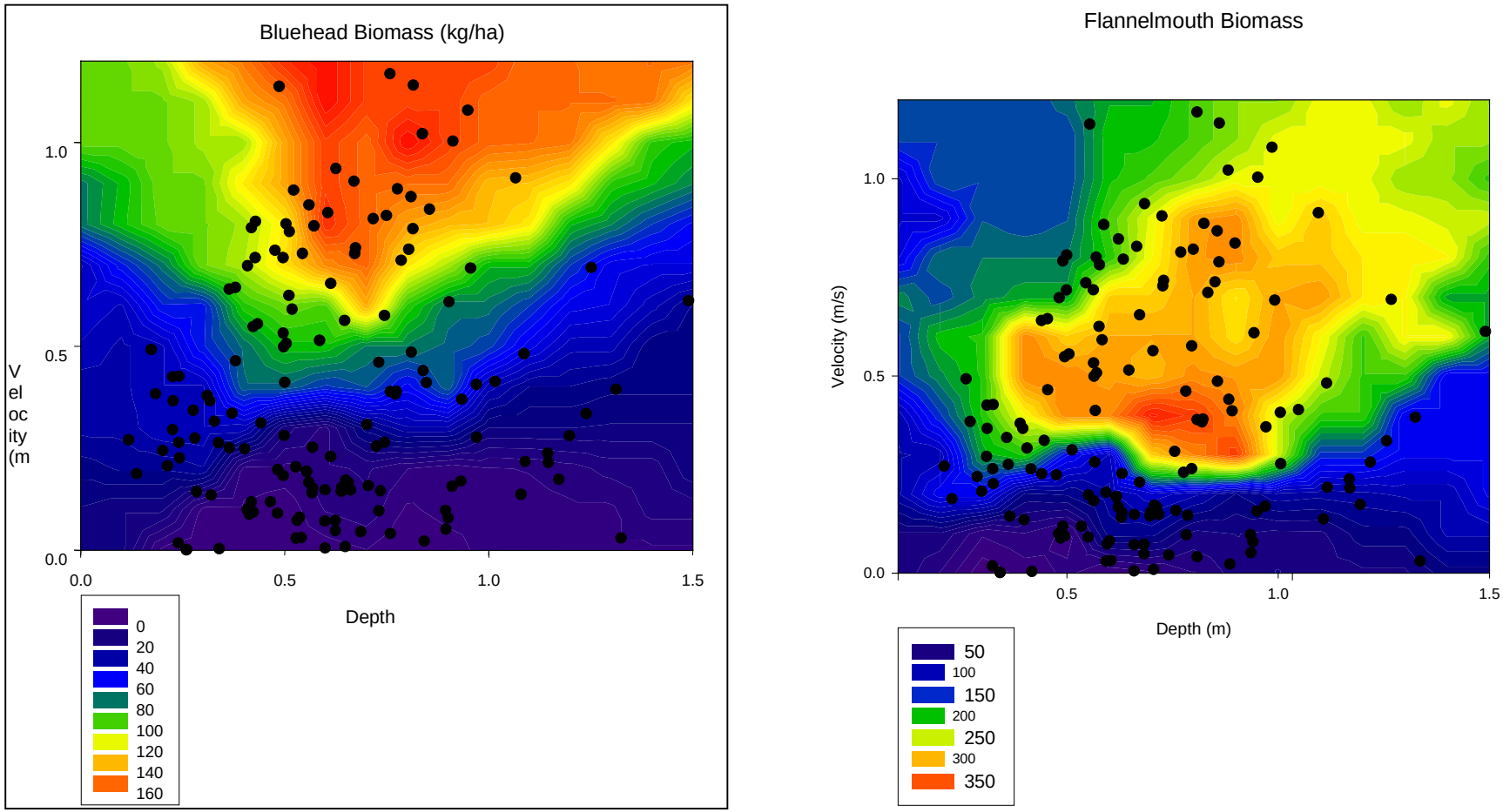


Figure A14. Sigma plot for Bluehehad (left) and Flannelmouth (right) sucker, showing biomass at polygon mean depth (x axis) and velocity (y axis).

Exhibit 15

4/17/2015

Basin Implementation Plan

Southwest Basin Roundtable

Ann Oliver and Carrie Lile
HARRIS WATER ENGINEERING, INC.

EXECUTIVE SUMMARY

The Southwest Basin Roundtable (Roundtable) is unique for the complexity of hydrography, political entities, water compacts and treaties, and distinct communities that it encompasses. The Roundtable provides a forum for water discussions pertaining to nine distinct sub-basins, including the San Juan, the Piedra, the Pine, the Animas (including the Florida River), the La Plata, the Mancos, McElmo Creek, the Dolores rivers and the San Miguel River, eight of which flow out of Colorado.

Many communities, agricultural producers, and natural systems depend on the water produced by these sub-basins. The Southwest Basin is home to the Southern Ute Indian Tribe and the Ute Mountain Ute Indian Tribe, the only two Indian Reservations in Colorado. Neighboring these tribal lands are 10 counties including Archuleta, La Plata, San Juan, Montezuma, Dolores, San Miguel and portions of Mineral, Hinsdale, Montrose, and Mesa. These tribal areas and counties represent distinct communities and landscapes, with their own specific and unique social, economic and environmental values, challenges and opportunities.

The Southwest Basin is a region of diverse natural systems, agricultural heritage, outstanding beauty, and extensive recreational opportunities. The area supports many water-dependent species of wildlife, including warm and cold water fish species addressed by three different multi-state conservation agreements, and four terrestrial species that are currently listed under the Endangered Species Act. Many towns within the area rely heavily on tourism and the recreational industry as a primary economic driver. Agriculture and the open spaces it maintains contribute to the culture, economy and quality of life of the Southwest Basin. Municipal and industrial activities round out the economic and social values and help support the diverse and vibrant communities of the region.

The Roundtable has developed this Basin Implementation Plan (BIP) based on the best available information and current conditions. The Roundtable plans to employ and maintain the BIP as a living document to be reviewed and updated periodically as conditions evolve and new information becomes available. The Roundtable takes a balanced and cooperative approach to include and address all water supply needs. While acknowledging that they sometimes represent competing demands and conflicting interests, the Roundtable treats agricultural, municipal, industrial, environmental and recreational needs equally, and is open to new projects and processes that can help address the Southwest Basin's goals.

Through its consensus-based discussions, the Roundtable has developed agreement around several salient aspects of both Southwest Basin-wide and state-wide water supply. Highlights of these agreements include conditions under which the Roundtable can consider a new trans-mountain diversion project, goals for statewide municipal water conservation measures, and the Basin's outstanding data needs.

The Roundtable is concerned about any new trans-mountain diversion (TMD). A new TMD would increase the risk of a Colorado River Compact call, as well as the risk of contingency measures to address serious conditions such as the inability to generate power from Lake Powell or levels of Lake Mead dropping below Las Vegas's municipal water supply intake. An increase in such risks jeopardizes the Southwest Basin's ability to develop water supplies to meet needs in the Southwest Basin and puts additional pressure on the Basin's agriculture to meet downstream water needs for compact compliance and/or obligations. Therefore, the Roundtable agrees on eight factors to be addressed prior to considering a new TMD.

The Roundtable supports the idea that on a statewide basis we all need to be more efficient with our water use and achieve high conservation. Recognizing that municipal demand is one of the driving forces behind agricultural dry-up and that outdoor urban irrigation is one of the highest consumptive uses of municipal water. The Roundtable agrees that before it will consider a new TMD, outdoor irrigation by water providers using agricultural buy–up and dry-up and/or pursuing a TMD should meet the higher goal of 70/30 ratio of inside to outside use of municipal water by the year 2030.

In development of Colorado's Water Plan and the Southwest BIP, the Roundtable has discussed water supply "gaps" that exist for various uses throughout the State. In evaluating those needs for southwestern Colorado, it is important that future uses and needs for the Western Slope be recognized and preserved. The Roundtable also acknowledges that uses in other parts of the state, especially demands on the Front Range, may develop sooner than those in southwestern Colorado, and that, prior to consideration of any TMD, an allocation for future uses shall be recognized for development in the San Juan and Dolores River basins.

In Colorado, the authority to establish water policies of the state, determine the beneficial uses of the water resources, and administer water rights pursuant to the Doctrine of Prior Appropriation fall under the jurisdiction of state government. It is recognized that there is a significant amount of land administered by the federal government in Colorado, which creates the potential for conflicts between state and federal laws and policies. Congress and Federal agencies have a long standing deference to state water allocation systems, and Colorado continues to promote state-federal cooperation to avoid contentious water rights issues. Federal policies and actions could affect existing and future water supplies and planning efforts in southwestern Colorado.

Therefore, the Roundtable supports Colorado's system of water rights administration and allocation and the full recognition of tribal rights under the Colorado Ute Indian Water Rights Settlement. The Roundtable also encourages and supports creative solutions sought through collaborative efforts, negotiated settlements, and strengthening the use of State-Federal MOUs, to limit conflicts between state, tribal and federal polices, laws and land management plans. Maintaining opportunities that allow for management solutions that provide for multiple beneficial

uses and are protective of environmental and recreational values are critical for the planning and strategic development of the water resources in the State of Colorado.

With respect to the Southwest Basin's Environmental and Recreational values and water needs, the Roundtable recognizes that there are significant gaps in the data and understanding regarding the flows and other conditions necessary to sustain these values. The Roundtable also recognizes that the tools currently available to help maintain those conditions are limited. The Roundtable has identified two methods that it hopes can help address and bridge this need for additional information and tools. These are:

1. Evaluation of environmental and or recreation gaps is planned to be conducted for improvement of non-consumptive resources and/or in collaborative efforts with development of consumptive IPPs. The evaluations may be conducted by a subgroup of the Roundtable or by individuals, groups, or organizations with input from the Roundtable. The evaluation may utilize methodologies such as the southwest attribute map, flow evaluation tool, R2 Cross, and any other tools that may be available.

2. Where environmental and/or recreational gaps are identified, a collaborative effort will be initiated to develop innovative tools to protect water identified as necessary to address these gaps.

The Roundtable has adopted 21 goals and 30 measureable outcomes to meet identified gaps and water supply needs. Since SWSI 2010, the Roundtable success rate for completing IPPs is 44%. A total of 55 projects were completed since the drafting of the SWSI 2010 list. Through the BIP outreach process over 80 new projects were added to the list. The list totals about 160 IPPs for all sub-basins. Of these 160, about 50% of the IPPs are for needs such as agricultural, municipal and industrial while the remaining 50% of the IPPs are for environmental and recreational needs.

At the end of 2014, the Roundtable had granted $1,906,626 from the Southwest Basin account and $5,162,859 from the statewide account; for a total of $7,069,485 granted to projects and processes aimed at meeting water needs within the Southwest Basin (See Appendix A – Final WRSA Annual Report).

TABLE OF CONTENTS

Executive Summary 1

Appendices 5

Figures 6

Tables 7

Abbreviations 8

Section 1: Basin Goals & Measurable Outcomes 9

Section 2: Evaluate Needs 19

2.1 Environmental & Recreational Needs 19

2.2 Agricultural, Municipal and Industrial Needs 27

Section 3: Constraints & Opportunities 38

3.1 Analysis of Constraints & Opportunities Based on Existing Data 38

3.2 Water Management & Water Administration 48

3.3 Sensitive Species 54

3.4 Historical Streamflow 56

3.5 Predicted Future Hydrology 68

Section 4: Projects & Methods 73

4.1 Education, Participation & Outreach 75

4.2 Watershed Health & Water Quality 84

4.3 Conservation Projects & Processes 92

4.4 New Multi-Purpose, Cooperative, & Regional Projects & Processes 92

4.5 M&I Projects & Processes 94

4.6 Agricultural Projects & Processes 95

4.7 Environmental Projects & Processes 96

4.8 Recreational Projects & Processes 98

Section 5. Strategies & Tools 99

5.1 Strategies 99

5.2 Strategies for Relating to a New Transmountain Diversion 100

5.3 Tools for Implementation of IPPs 103

Section 6. How the BIP meets the Roundtable's Goals & Measureable Outcomes 107

References 118

APPENDICES

Appendix A – Draft Identified Projects and Processes Lists and supporting documents

- Draft IPP list as of March 2015
- Completed IPP list as of July 2014

Appendix B – Public Outreach Efforts and supporting documents

- Public Outreach Meetings BIP PowerPoint Presentation
- Public Outreach Meetings CWP PowerPoint Presentation
- Pagosa Springs Public Meeting Notes
- Bayfield Public Meeting Notes
- Mancos Public Meeting Notes
- Placerville Public Meeting Notes
- Sub-basin Map for Outreach and associated Sample of Basin IPPs Bullet List
- Summation of Public Comments

Appendix C – Education Action Plan

- Education Action Plan for 2015

Appendix D – Supporting Documents

- Colorado Water Plan – SWCD Statement of Importance January 2014
- Water Rights Analysis
- Final WSRA Annual Report October 2014

FIGURES

Figure 1. Southwest Basin Nonconsumptive Needs Assessment Environmental & Recreational Subcategory Count per Stream Segment (CWCB 2011, Figure 2-4, pg 2-6) 22

Figure 2. Map of reaches with Environmental Values with no identified flow protections 24

Figure 3. Map of reaches with Recreational Values with no identified flow protections 25

Figure 4. Water Critical Basins and structures placing calls between November 1, 2000 and October 31, 2013 (Source: Division of Water Resources) 50

Figure 5. Key Stream Flow Gages in Southwest Basin 57

Figure 6. San Juan River at Navajo 58

Figure 7. Piedra River at Arboles 59

Figure 8. Pine River at Boca 60

Figure 9. Animas River at the State Line 61

Figure 10. La Plata River at the State Line 62

Figure 11. Mancos River at Towaoc 63

Figure 12. Dolores River near Dolores 64

Figure 13. Dolores River near Bedrock 65

Figure 14. San Miguel River near Placerville 66

Figure 15. San Miguel River near Uravan 67

Figure 16. Comparison of historic and prehistoric flow reconstruction to average future flow projections for the Animas River at Durango, from the Colorado Drought Mitigation and Response Plan (CWCB 2013) 71

Figure 17. Comparison of historic and prehistoric flow reconstruction to average future flow projections for the Dolores River, from the Colorado Drought Mitigation and Response Plan (CWCB 2013) 72

Figure 18. IPPs sorted by sub-basins and type of needs 74

Figure 19. Colorado Wildland Fire Susceptibility Index (Colorado State Forest Service 2008) . 85

Figure 20. Colorado Water Quality Control Division water quality listings and designations for waterbodies in the Southwest Basin 87

Figure 21. Map of all 2015 Environmental, Recreational or Multipurpose IPPs; identified flow protections; and recreational attributes without identified flow protections 113

Figure 22. Map of all 2015 Environmental, Recreational or Multipurpose IPPs; identified flow protections; and environmental attributes without identified flow protections 114

TABLES

Table 1. Goals and Measureable Outcomes for the Southwest Basin Implementation Plan 12

Table 2. Southwest Basin Environmental and Recreational Attributes and Categories identified in SWSI 2010 (CWCB 2011) 21

Table 3. Current and Estimated Future Irrigated Acres by Sub-Basin, from SWSI 2010 (CWCB 2011) 28

Table 4. Estimated Current & Future Agricultural Demands in the Southwest Basin, by Sub-basin 30

Table 5. Annual Shortage in Water Supply needed to meet crops IWR 31

Table 6. Population Projections (source: CWCB 2011) 33

Table 7. 2050 Municipal Water Demand Estimates 34

Table 8. 2050 M&I Demand Projections for Counties in the Southwest Basin (CWCB 2011) ... 36

Table 9. Summary of Opportunities and Constraints Associated with Southwest Basin Measureable Outcomes 39

Table 10. Hydrologic Classification Criteria 56

Table 11. Southwest Basin Roundtable 2015 EAP and Budget 82

Table 12. Southwest Basin Roundtable 2016 to 2020 EAP and Budget 83

Table 13. IPPs Completed To Date 107

Table 14. How the Southwest Basin Implementation Plan IPPs address Theme A, B, C, F, and G Goals and Measureable Outcomes 108

ABBREVIATIONS

AF – Acre-feet

BIP – Basin Implementation Plan

BOR – Bureau of Reclamation

CDPHE – Colorado Department of Public Health and Environment

CDSS – Colorado Decision Support Systems

CFWE – Colorado Foundation for Water Education

CPW – Colorado Parks and Wildlife

CWCB – Colorado Water Conservation Board

CWP – Colorado Water Plan

CU – Consumptive Use

EAP – Education Action Plan

ESA – Endangered Species Act

gpcd – gallons per capita day

IBCC – Interbasin Compact Committee

IPP – Identified Projects and Processes

ISF – Instream Flow

IWR – Irrigation Water Requirement

Roundtable – Southwest Basin Roundtable

SJRIP – San Juan River Basin Recovery Implementation Program

SWCD – Southwestern Water Conservation District

SWSI 2010 - SWSI 2010 Southwest Basin Report Basinwide Consumptive and Nonconsumptive Water Supply Needs Assessments

TMD – Trans-mountain Diversions

Upper Program – Upper Colorado River Endangered Fisheries Recovery Program

USFWS – Untied States Fish and Wildlife Services

USFS – Untied States Forest Service

WIP – Water Information Program

WQCD – Water Quality Control Division

WSL-CU – Water Supply Limited Consumptive Use

SECTION 1: BASIN GOALS & MEASURABLE OUTCOMES

The Southwest Basin Roundtable is unique for the complexity of hydrography, political entities, water compacts and treaties, and distinct communities that it encompasses. Although the name suggests only one basin, the Roundtable actually provides a forum for water discussions pertaining to nine distinct sub-basins, including the San Juan, the Piedra, the Pine, the Animas (including the Florida River), the La Plata, the Mancos, McElmo Creek, the Dolores and the San Miguel rivers, eight of which flow out of Colorado. Together these nine sub-basins make up the interdependent landscape of Southwest Colorado.

Many communities, both natural and human, depend on the water produced by these sub-basins. The Southwest Basin is home to the Southern Ute Indian Tribe and the Ute Mountain Ute Indian Tribe, the only two Indian Reservations in Colorado. Neighboring these tribal lands are 10 counties including Archuleta, La Plata, San Juan, Montezuma, Dolores, San Miguel and portions of Mineral, Hinsdale, Montrose and Mesa. Each of these tribal areas and counties represent distinct communities and landscapes, with their own specific and unique social, economic and environmental values, challenges and opportunities.



Vallecito Reservoir (Pine River basin)

Multiple layers of legal agreements govern water use in the Southwest Basin's area, adding additional complexity, opportunity and challenge. All of the nine sub-basins are tributary to the Colorado River and therefore fall under the Colorado River Compact and the Upper Colorado River Basin Compact: seven are part of the San Juan River sub-basin and two, the Dolores and San Miguel rivers, are part of the Colorado River sub-basin. All of the water to which the State of New Mexico is entitled under the Upper Colorado River Compact has its origins in those basins that are part of the San Juan River sub-basin (e.g. the San Juan, Piedra, Pine, Animas, La Plata, Mancos and McElmo rivers).

A treaty and settlement with both Ute Indian tribes pertain to waters within specific sub-basins. The La Plata River Compact apportions La Plata River water between Colorado and New Mexico with a daily delivery requirement to New Mexico. The San Juan/Chama Project delivers water trans-mountain from the San Juan River sub-basin in Colorado to the Rio Grande River in New Mexico to provide a portion of New Mexico's Colorado River entitlement (annual average of 85,000 to 100,000 AF). These New Mexico obligations are met by the waters of the Southwest Basin, and affect the water available to meet the needs of the area's communities. The Animas La Plata Compact provides for diversion and storage of flows for use in both Colorado and New Mexico.

The area supports many water-dependent species of wildlife, including warm and cold water fish species addressed by three different multi-state conservation agreements, and four terrestrial species that are currently listed under the Federal Endangered Species Act.

Finally, the Southwest Basin is a region of diverse natural systems, agricultural heritage, outstanding beauty, and extensive recreational opportunities. Many communities within the area rely heavily on tourism and the recreational industry as a primary economic driver. Agriculture and the open spaces it maintains contribute to the culture, economy and quality of life of the Southwest Basin. Municipal and industrial activities round out the economic and social values and help support the diverse and vibrant communities of the region.

These geographic, political, economic and legal complexities lead to unique challenges and opportunities. Appreciation of this context is basic to the development of the Roundtable's goals and to its BIP. Therefore, the Roundtable prefaces its BIP Goals with the following underlying principles. Many of these are also stated in the Southwestern Water Conservation District's Statement of Importance January 2014 (Appendix D), which was adopted by the Roundtable on January 8, 2014.

The Roundtable:

- *Intends to develop, use, and maintain the Basin Implementation Plan as a living document.*
- *Agrees that all water uses are important to the future of this region.*
- *Identifies specific and unique projects that are important to maintaining the quality of life in this region and should accommodate the development and maintenance of flows, including domestic supplies, environmental needs, agriculture, recreation, and commercial/industrial needs to provide for further economic development.*
- *Supports multi-purpose projects when possible and when they can be accomplished in a manner that is protective of the values present.*
- *Recognizes and upholds the unique settlement of tribal reserved water rights claims in the Colorado Ute Indian Water Rights Final Settlement Agreement of December 10, 1986, as authorized by Congress in the Colorado Ute Indian Water Rights Settlement Act of 1988, Pub. L. No. 100-585, and as amended by the Colorado Ute Settlement Act Amendments of 2000, Pub. L. No. 106-554 and Pub. L. No, 110-161 (2007); and the 1991 Consent Decrees.*
- *Recognizes and addresses the downstream challenges faced by water users in southwest Colorado due to continued development and pressures from users in the State of New Mexico; protect interests in southwest Colorado, while complying with existing Compact obligations. The entitlement to Colorado River flows for New Mexico will be based on deliveries from southwest Colorado.*
- *Intends to preserve the Southwest Basin's ability to develop Colorado River Compact entitlements and to meet our water supply gaps.*
- *Recognizes and addresses the challenges to all water uses that future drought and/or climate variability may bring.*

- *Recognizes that the flows necessary to support the full complement of values are not currently well understood.*
- *Limit Conflicts and Promote Collaboration within the Framework of State, Tribal and Federal Plans, Policies, Authorities and Rights.*

The Roundtable has established 21 goals (Table 1) to address the following seven themes (in no particular order):

A. Balance All Needs and Reduce Conflict
B. Maintain Agriculture Water Needs
C. Meet Municipal and Industrial Water Needs
D. Meet Recreational Water Needs
E. Meet Environmental Water Needs
F. Preserve Water Quality
G. Comply with CO River Compact and Manage Risk

In order to clarify the desired results of these goals and to help the Roundtable gauge progress toward meeting the goals over the planning horizon of this BIP (thru 2050), the Roundtable has agreed upon 31 Measureable Outcomes (Table 1). While recognizing the value of identifying measureable outcomes, the Roundtable is also cognizant of its limitations.

One limitation is that the development of ambitious but realistic measurable outcomes requires an understanding of the extent to which the Roundtable's stated goals are already being met. Measurable outcomes in this BIP were developed without a thorough understanding of the current status of those measures and of water supply needs, particularly for environmental and recreational values.

An additional limitation is that there are factors which may complicate the attainment of these outcomes. These factors include uncertainty around the ability of sponsors to implement Identified Projects and Processes (IPPs) due to issues with funding, permitting, partner support, etc.; lack of sufficient support/interest in implementing a Measureable Outcome, concern for unintended consequences, as well as difficulty in obtaining the necessary data to assess some of the identified outcomes.

Given these limitations and consistent with its principle that this BIP be a "living document," the Roundtable intends periodic reviews and updates of its Measurable Outcomes as more reliable information is developed and attainment is better understood.

TABLE 1. GOALS AND MEASUREABLE OUTCOMES FOR THE SOUTHWEST BASIN IMPLEMENTATION PLAN

A. BALANCE ALL NEEDS AND REDUCE CONFLICT

ID	Goals	Measurable Outcomes (by 2050)
A1	Pursue a high success rate for identified specific and unique IPPs to meet identified gaps and to address all water needs and values.	1. 100% of IPPs shall consider from the initial planning stage maintaining and enhancing environmental and recreational needs. 2. Complete 27 multipurpose IPPs to meet identified gaps. 3. Support and participate in 10 IPPs (such as processes) that promote dialogue, foster cooperation and resolve conflict. 4. At least 50% of identified watersheds have existing or planned IPPs that are protective of critical infrastructure and/or environmental and recreational areas. 5. All towns and major water supply systems with water supply infrastructure have watershed/wildfire assessments that identify strategies/treatments necessary to mitigate the impacts that occur to hydrology in a post-fire environment. 6. All major reservoirs have watershed/wildfire assessments that identify strategies/treatments necessary to mitigate the impacts that occur to hydrology in a post-fire environment.
A2	Support specific and unique new IPPs important to maintaining the quality of life in this region, and to address multiple purposes including municipal, industrial, environmental, recreational, agricultural, risk management, and compact compliance needs.	
A3	Implement multi-purpose IPPs (including the creative management of existing facilities and the development of new storage as needed).	
A4	Promote dialogue, foster cooperation and resolve conflict among water interests in every basin and between basins for the purpose of implementing solutions to Southwest Colorado's and Colorado's water supply challenges *(SWSI 2010)*.	
A5	Maintain watershed health by protecting and/or restoring watersheds that could affect critical infrastructure and/or environmental and recreational areas.	

*Note that several of these outcomes, indicated by an asterisk, pertain directly to supporting implementation of the projects and processes, either planned or in progress, that are currently on the Southwest Basin's IPP list. They will be periodically reviewed and updated in the future.

TABLE 1. CONTINUED…

B. MEET AGRICULTURAL NEEDS		
ID	Goals	Measurable Outcomes (by 2050)
B1	Minimize statewide and basin-wide acres transferred.	1. Implement projects (e.g. ATMs, efficiency, etc.) in order to help preserve agriculture and open space values, and to help address municipal, environmental, recreational, and industrial needs; while respecting private property rights. 2. Implement strategies that encourage continued agricultural use and discourage permanent dry-up of agricultural lands. 3. The water providers in the state that are using dry- up of agricultural land (defined as requiring a water court change case) and/or pursuing a new TMD (as defined by IBCC to be a new west slope to east slope diversion project) shall have a higher standard of conservation. The goal for these water providers is a ratio of 70% in-house use to 30% outdoor use (70/30 ratio). 4. Implement at least 10* agricultural water efficiency projects identified as IPPs (by sub-basin).
B2	Implement efficiency measures to maximize beneficial use and production.	
B3	Implement IPPs that work towards meeting agricultural water supply shortages.	

*Note that several of these outcomes, indicated by an asterisk, pertain directly to supporting implementation of the projects and processes, either planned or in progress, that are currently on the Southwest Basin's IPP list. They will be periodically reviewed and updated in the future.

TABLE 1. CONTINUED…

C. MEET MUNICIPAL AND INDUSTRIAL WATER NEEDS		
ID	Goals	Measurable Outcomes (by 2050)
C1	Pursue a high success rate for identified specific and unique IPPs to meet the municipal gap.	1. Complete 40* IPPs aimed at meeting municipal water needs. 2. Consistently meet 100% of residential, commercial and industrial water system demands identified in SWSI 2010 in each sub-basin, while also encouraging education and conservation to reduce demand. 3. Implement at least 1* IPP that protects or enhances the ability of public water supply systems to access and deliver safe drinking water that meets all health-based standards. 4. Change the ratio of in-house to outside treated water use for municipal and domestic water systems (referred to as water providers herein) from the current ratio of 50% in-house use and 50% outside use, to 60% in-house use and 40% outside use (60/40 ratio) for Southwest Colorado and the entire State by 2030. 5. Implement 3 informational events about water reuse efforts, tools and strategies. 6. The water providers in the state that are using dry-up of agricultural land (defined as requiring a water court change case) and/or pursuing a new TMD (as defined by IBCC to be a new west slope to east slope diversion project) shall have a higher standard of conservation. The goal for these water providers is a 70/30 ratio by 2030. This is a prerequisite for the Roundtable to consider support of a new TMD.
C2	Provide safe drinking water to Southwest Colorado's citizens and visitors.	
C3	Promote wise and efficient water use through implementation of municipal conservation strategies to reduce overall future water needs.	
C4	Support and implement water reuse strategies.	

*Note that several of these outcomes, indicated by an asterisk, pertain directly to supporting implementation of the projects and processes, either planned or in progress, that are currently on the Southwest Basin's IPP list. They will be periodically reviewed and updated in the future.

TABLE 1. CONTINUED…

D. MEET RECREATIONAL WATER NEEDS		
ID	Goals	Measurable Outcomes (by 2050)
D1	Maintain, protect and enhance recreational values and economic values to local and statewide economies derived from recreational water uses, such as fishing, boating, hunting, wildlife watching, camping, and hiking.	1. Implement 10* IPPs to benefit recreational values and the economic value they provide. 2. At least 80% of the areas with recreational opportunities have existing or planned IPPs that secure these opportunities and supporting flows/lake levels within the contemporary legal and water management context. Based on the map of recreational attributes generated for SWSI 2010 (Figure 1) 80% of each specific value equates to approximately 428 miles of whitewater boating, 185 miles of flat-water boating, 4 miles of Gold medal Trout Streams, 545 miles of other fishing streams and lakes, 3 miles of Audubon Important Bird Area, 143 miles of waterfowl hunting/viewing parcels, and 6 miles of Ducks Unlimited projects. 3. Address recreational data needs.

*Note that several of these outcomes, indicated by an asterisk, pertain directly to supporting implementation of the projects and processes, either planned or in progress, that are currently on the Southwest Basin's IPP list. They will be periodically reviewed and updated in the future.

TABLE 1. CONTINUED…

E. MEET ENVIRONMENTAL WATER NEEDS		
ID	Goals	Measurable Outcomes (by 2050)
E1	Encourage and support restoration, recovery, and sustainability of endangered, threatened, and imperiled aquatic and riparian dependent species and plant communities. *(See list of such species in the Southwest Basin)***	1. Implement 15* IPPs to directly restore, recover or sustain endangered, threatened, and sensitive aquatic and riparian dependent species and plant communities. 2. At least 95% of the areas with federally listed water dependent species have existing or planned IPPs that secure the species in these reaches as much as they can be secured within the existing legal and water management context. 3. At least 90% of areas with identified sensitive species (other than ESA species) have existing or planned IPPs that provide direct protection to these values. Based on the map of environmental attributes generated for SWSI 2010 (Figure 1) 90% for individual species equates to approximately 169 miles for Colorado River cutthroat trout, 483 miles for roundtail chub, 794 miles for bluehead sucker, 700 miles for flannelmouth sucker, 724 miles for river otter, 122 miles for northern leopard frog, 921 miles for active bald eagle nesting areas and 229 miles for rare plants. 4. Implement 26* IPPs to benefit the condition of fisheries and riparian/wetland habitat. 5. At least 80% of areas with environmental values have existing or planned IPPs that provide direct protection to these values.
E2	Protect, maintain, monitor and improve the condition and natural function of streams, lakes, wetlands, and riparian areas to promote self-sustaining fisheries, and to support native species and functional habitat in the long term, and adapt to changing conditions.	

*Note that several of these outcomes, indicated by an asterisk, pertain directly to supporting implementation of the projects and processes, either planned or in progress, that are currently on the Southwest Basin's IPP list. They will be periodically reviewed and updated in the future.

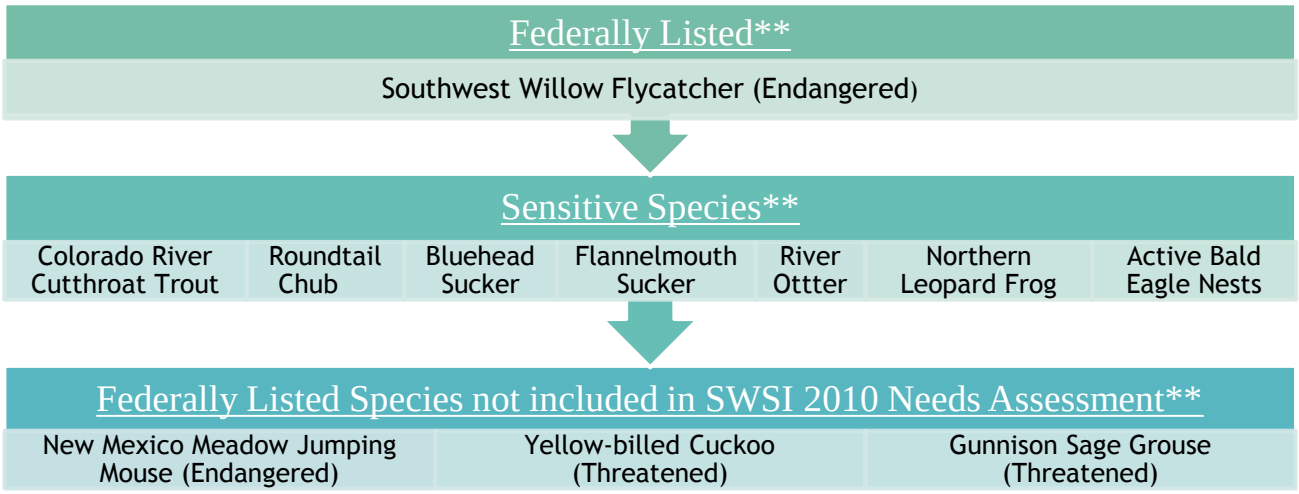


TABLE 1. CONTINUED…

F. PRESERVE WATER QUALITY		
ID	Goals	Measurable Outcomes (by 2050)
F1	Monitor, protect and improve water quality for all classified uses.	1. By 2016, replace the following statewide outcomes with outcomes based on the current status of these measures in the Roundtable area, followed by a periodic status review every five years. a. 60% of stream miles and 40% of reservoir acres attain water quality standards and support all designated uses. b. 15% of impaired stream miles and reservoir acres are restored to meet all applicable water quality standards. c. 50% of stream miles and 30% of reservoir acres are attaining water quality standards. d. 100% of existing direct use and conveyance use reservoirs attain the applicable standards that protect the water supply use classification. 2. Implement 6* IPPs to monitor, protect or improve water quality.

*Note that several of these outcomes, indicated by an asterisk, pertain directly to supporting implementation of the projects and processes, either planned or in progress, that are currently on the Southwest Basin's IPP list. They will be periodically reviewed and updated in the future.

TABLE 1. CONTINUED…

G. COMPLY WITH CO RIVER COMPACT AND MANAGE RISK		
ID	Goals	Measurable Outcomes (by 2050)
G1	Plan and preserve water supply options for all existing and new uses and values.	1. Water providers proposing a new TMD shall achieve a 60/40 ratio by 2020 and 70/30 ratio by 2030 as a prerequisite for the Roundtable to consider support of a new TMD. 2. A conceptual agreement is developed between roundtables regarding how to approach a potential future TMD from the West Slope to the East. 3. Protect 100% of pre-compact water rights in the Southwest Basin Area. 4. Implement 2* IPPs aimed at utilizing Tribal Water Rights Settlement water. 5. Implement 2* IPPs aimed at meeting La Plata River compact. 6. Participate in Compact Water Bank efforts.
G2	Recognize and address the challenges faced by water users in southwest Colorado due to continued development and pressures from users in the State of New Mexico; protect interests in southwest Colorado, while complying with existing Compact obligations. New Mexico's entitlement to Colorado River flows are based on deliveries from southwest Colorado (*SWCD Statement of Importance).*	
G3	Preserve Southwest Basin's ability to develop CO River compact entitlement to meet our water supply gaps. *(SWCD Statement of Importance).*	
G4	Recognize and uphold the unique settlement of tribal reserved water rights claims in the 1988 Tribal Water Rights Settlement and the 1991 Consent Decree. *(SWCD Statement of Importance).*	
G5	Support strategies to reduce demand in the Colorado River Basin to ensure levels in Lake Powell are adequate to produce power.	
G6	Support strategies to mitigate the impact of a Colorado River Compact curtailment should it occur.	

*Note that several of these outcomes, indicated by an asterisk, pertain directly to supporting implementation of the projects and processes, either planned or in progress, that are currently on the Southwest Basin's IPP list. They will be periodically reviewed and updated in the future.

SECTION 2: EVALUATE NEEDS

2.1 ENVIRONMENTAL & RECREATIONAL NEEDS

Identifying environmental and recreational water needs within the Southwest Basin poses a significant challenge. In SWSI 2010 the Roundtable was able to identify and map the location of environmental and recreational values defined by the Roundtable and by public input received at Roundtable hosted outreach meetings in Durango, Telluride, Cortez and Pagosa Springs. (Appendix C, SWSI 2010). However, the water, habitat or infrastructure needed to support the identified values has not been quantified or identified so the Southwest Basin's environmental and recreational supply needs cannot be fully defined.



Hesperus Mountain (Mancos River basin)

Given the constraints of time to develop this BIP, the Roundtable has chosen to address the issue by supporting an IPP that contemplates the development of this information:

> "Evaluation of environmental and or recreation gaps is planned to be conducted for improvement of non-consumptive resources and/or in collaborative efforts with development of consumptive IPPs. The evaluations may be conducted by a subgroup of the Roundtable or by individuals, groups, or organizations with input from the Roundtable. The evaluation may utilize methodologies such as the southwest attribute map, flow evaluation tool, R2 Cross, and any other tools that may be available."

Any changes resulting from the information gathered through the IPP will be considered in the future, consistent with the Roundtable's principle that the BIP is a "living document."

In developing this BIP, the Roundtable conducted numerous interviews to update the Basin's list of IPPs (Appendix A). Guided by the goals and measureable outcomes identified in Section 1, the Roundtable then used mapping to assess the stream miles of environmental and

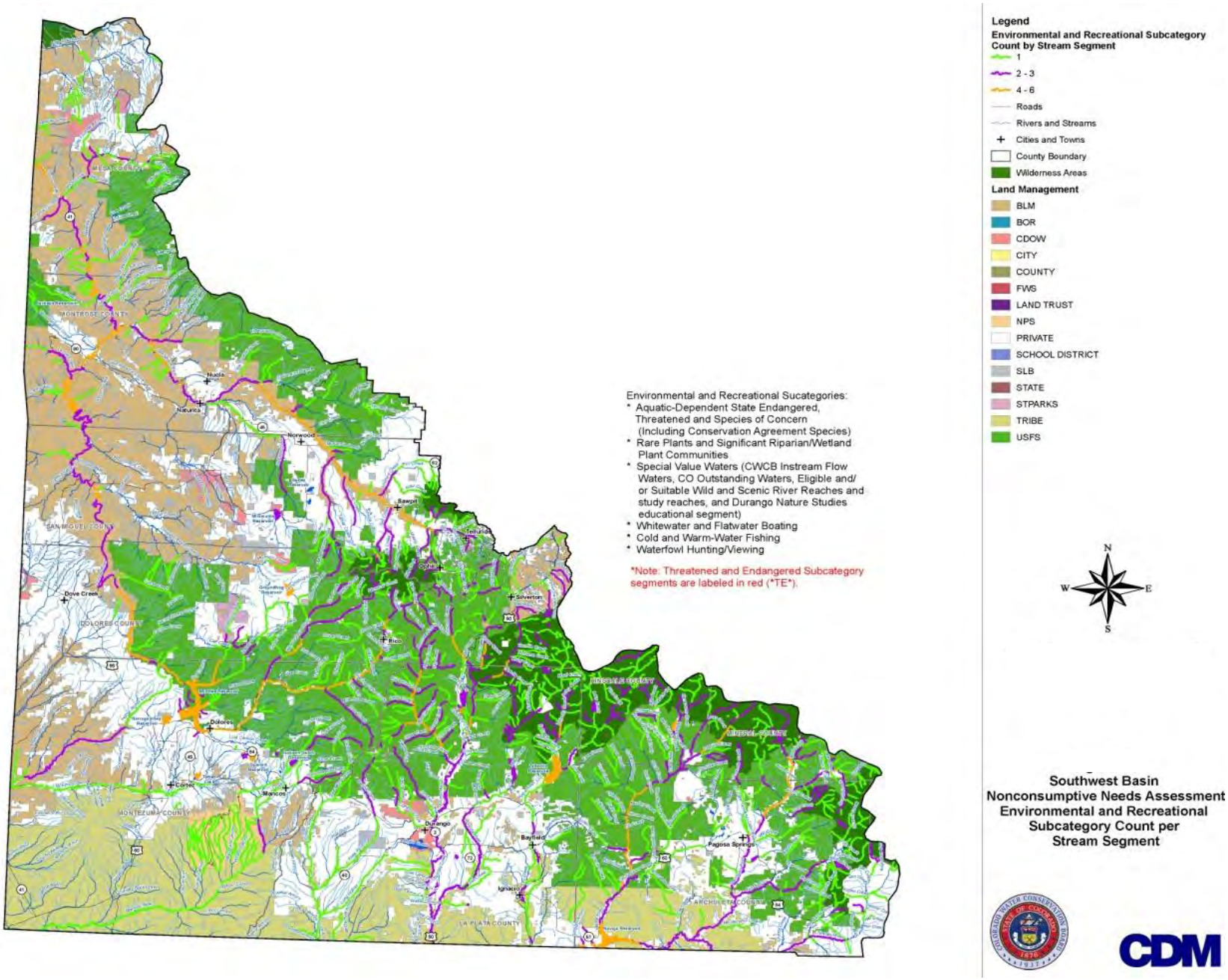
recreational values on reaches and water bodies in the Southwest Basin that are benefiting, to some unknown extent, from existing protections or IPPs, and the stream miles of these values that currently do not appear to be benefitting from protections or IPPs.

Appendix C of SWSI 2010 presented the results of the Roundtable's extensive inventory of its environmental and recreational attributes, or values. This inventory identified the following 22 environmental (15) and recreational (7) attributes or values, which were then grouped into six subcategories (Table 2) and mapped (Figure 1) (CWCB 2011).

TABLE 2. SOUTHWEST BASIN ENVIRONMENTAL AND RECREATIONAL ATTRIBUTES AND CATEGORIES IDENTIFIED IN SWSI 2010 (CWCB 2011)

SUB-CATEGORY	CATEGORY	ATTRIBUTE
Aquatic-Dependent State Endangered, Threatened and Species of Concern.	1	Colorado River Cutthroat Trout
	2	Roundtail Chub
	3	Bluehead Sucker
	4	Flannelmouth Sucker
	5	River Otter
	6	Northern Leopard Frog
	7	Active Bald Eagle Nests
	8	Southwestern Willow Flycatcher
Special Value Waters	9	Outstanding Waters
	10	Wild and Scenic Eligibility/Suitability
	11	CWCB ISF Water Rights
	12	CWCB Natural Lake Level Water Rights
	13	Durango Nature Studies
Rare Plants and Significant Riparian/Wetland Plant Communities	14	Rare Plants
	15	Significant Plant Communities
Whitewater and Flat-water Boating	16	Whitewater Boating
	17	Flat-water Boating
Cold and Warm water Fishing	18	Gold Medal Trout Streams
	19	Other Fishing Streams and Lakes
Waterfowl Hunting/Viewing	20	Audubon Important Bird Areas
	21	Waterfowl Hunting/Viewing Parcels
	22	Ducks Unlimited Projects

FIGURE 1. SOUTHWEST BASIN NONCONSUMPTIVE NEEDS ASSESSMENT ENVIRONMENTAL & RECREATIONAL SUBCATEGORY COUNT PER STREAM SEGMENT (CWCB 2011, FIGURE 2-4, PG 2-6)



Three species that are currently listed under the Federal Endangered Species Act, but that were not included in SWSI 2010 are the New Mexico Meadow Jumping Mouse (Endangered), the Yellow-billed Cuckoo (Threatened) and the Gunnison Sage Grouse (Threatened).

Complete or partial protections for environmental or recreational flows that exist in the Southwest Basin include the following:

- CWCB ISF reaches (decreed, pending, and recommended)
- Reaches found Suitable for Wild & Scenic designation
- Recreational in-channel diversion
- Wilderness Areas
- National Parks

In addition to these protections which are easily mapped to specific reaches or areas, water management, water administration (e.g. senior water rights), and compact administration in the Basin, as well as two Programmatic Biological Opinions issued under Section 7 of the Endangered Species Act function to maintain some level of flow in some rivers under certain circumstances. These protections are not specific to reaches or flows, and therefore do not lend themselves to mapping. They cover several rivers within and outside of the Basin and provide some level of long term maintenance of flows out of the state. However, the level of flow maintained in a given reach of river in a given year is dependent on conditions elsewhere in the Colorado River basin, and therefore difficult to know or plan on for the maintenance of a given environmental or recreational value. Programmatic Biological Opinions, water management, and water administration will be discussed in detail in Section 3.

Map layers reflecting the stream reaches where the bulleted protections exist were overlaid onto the map of Southwest Basin environmental and recreational attributes. The resulting maps (Figures 2 and 3) allow an assessment of the stream reaches where environmental and recreational values currently exist with some level of protection that may benefit the values at some unknown level, as well as the stream reaches where no such protections appear to exist.

FIGURE 2. MAP OF REACHES WITH ENVIRONMENTAL VALUES WITH NO IDENTIFIED FLOW PROTECTIONS

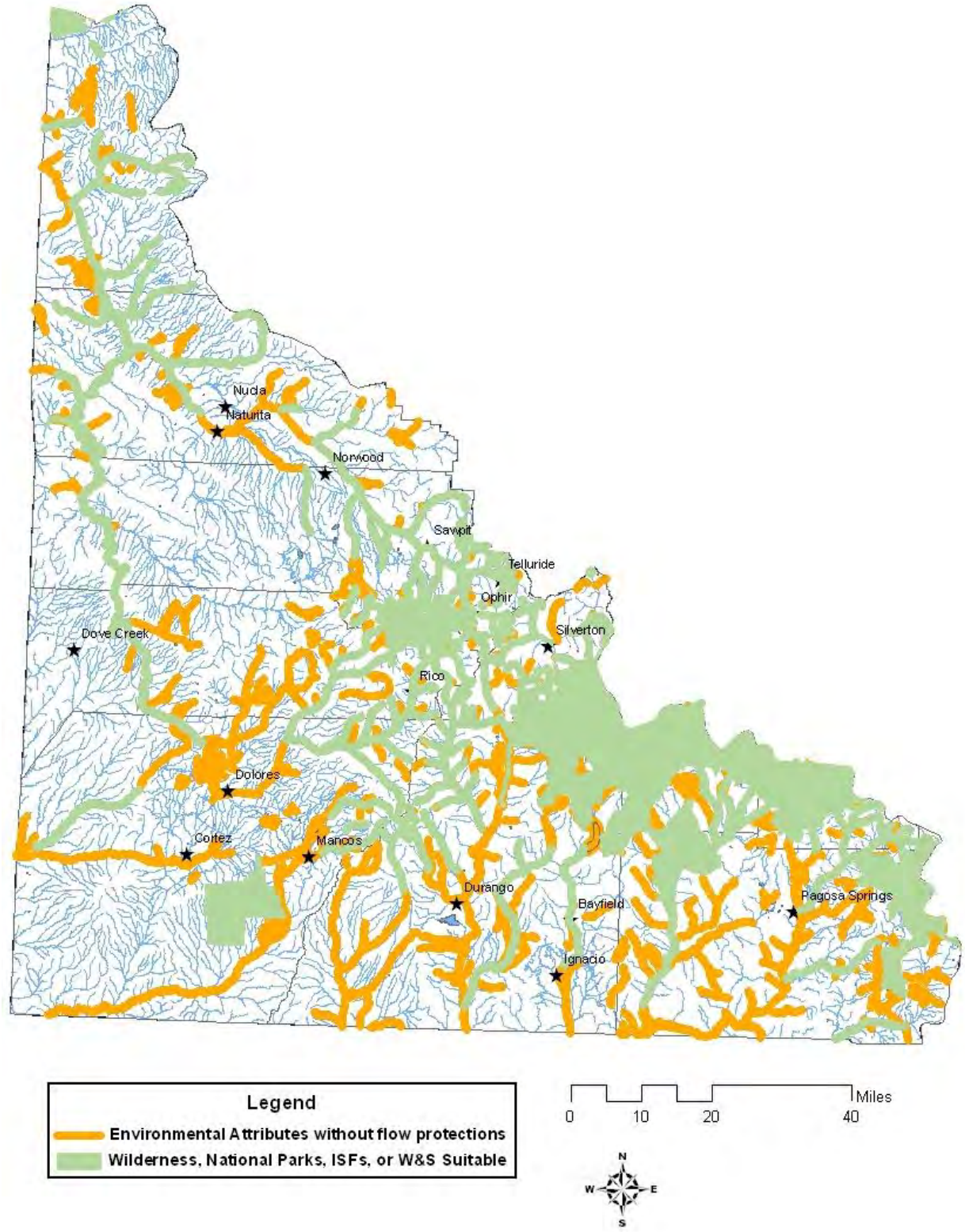
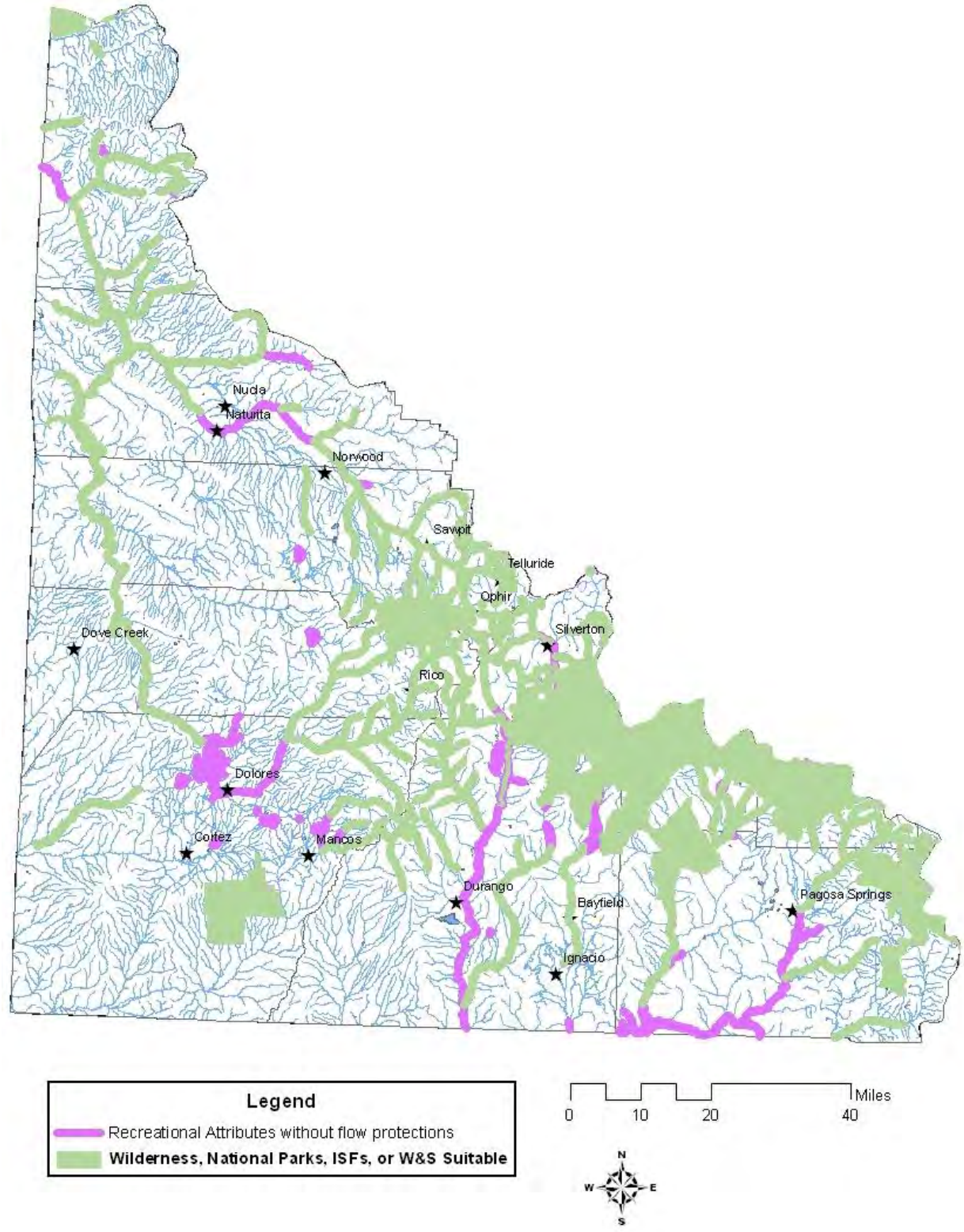


FIGURE 3. MAP OF REACHES WITH RECREATIONAL VALUES WITH NO IDENTIFIED FLOW PROTECTIONS



The Roundtable recognizes that there are significant gaps in the data and understanding regarding the flow regimes (stream flow frequency, magnitude, duration and timing) and other conditions necessary to sustain many of the environmental and recreational values identified in the Southwest Basin. The Roundtable also recognizes that the tools currently available to help maintain those conditions are limited. Therefore the Roundtable cautions against any assumption that the presence of an existing protection (e.g. ISF) is sufficient to maintain or sustain the attribute(s) identified in that reach. Assessment of the sufficiency of such measures depends on the particular attributes, the condition of the stream reach and the measures in place. The Roundtable has identified two IPPs that it hopes can help address and bridge these needs for more information and additional tools (Sections 4 and 5).

2.2 AGRICULTURAL, MUNICIPAL AND INDUSTRIAL NEEDS

2.2.1 AGRICULTURAL

SWSI 2010 provided information about the methodologies used to develop estimates of current irrigated acres, estimates of 2050 irrigated acres, and estimates of the average annual agricultural demand by basin for the year 2050.

Current irrigated acres were estimated using the CDSS program's spatial databases which include crop types, irrigation practices, and water source (e.g. locations of wells or diversion structures). The most recent year of data collected that is provided as a spatial database is 2005. According to SWSI 2010, the Southwest Basin has the third highest percentage of irrigated acres of Colorado's west slope basins (seventh overall in the state).

To develop estimates of 2050 irrigated acres the baseline of current irrigated acres was used. Multiple factors (a total of 8) were qualitatively addressed, while three factors (urbanization of existing irrigated lands, agricultural to municipal water transfers, and water management decisions) were quantified. For detailed explanation of the quantification of factors reference SWSI 2010 Section 4.3.1.2 Irrigation Acres Methodology. Table 3 provides a comparison of current irrigated acres to estimated future irrigated acres.



Lemon Reservoir (Animas River basin)

Lemon Reservoir is a main feature of the Florida Project on the Florida River northeast of Durango. The reservoir was completed in 1963, and the canal rehabilitation was completed in 1965. The reservoir can store about 40,000 AF, and provides supplemental irrigation for approximately 20,000 acres. Through recent agreements, efficiency improvements, and court changes, the storage can also provide domestic and augmentation requirements while continuing to meet the irrigation demand. The Florida Water Conservancy District manages the project, which is identified as a multipurpose IPP.

TABLE 3. CURRENT AND ESTIMATED FUTURE IRRIGATED ACRES BY SUB-BASIN (CWCB 2011)

	CURRENT IRRIGATED ACRES (ACRES)	ESTIMATED DECREASE IN IRRIGATED ACRES DUE TO URBANIZATION (ACRES)*		ESTIMATED DECREASE IN IRRIGATED ACRES DUE TO AGRICULTURAL TO MUNICIPAL TRANSFERS TO ADDRESS M&I GAP (ACRES)*		ESTIMATED 2050 IRRIGATED ACRES*		ESTIMATED DECREASE IN IRRIGATED ACRES BY 2050*	
		Low	High	Low	High	Low	High	Low	High
San Juan	15,840	626	799	200	413	15,014	14,628	826	1,213
Piedra	7,074	129	165	89	185	6,856	6,725	219	350
Pine	46,755	934	1,347	590	1,220	45,231	44,188	1,524	2,567
Animas	32,193	578	854	406	840	31,209	30,499	984	1,694
La Plata	21,305	382	565	269	556	20,654	20,184	651	1,121
Mancos	11,617	54	72	147	303	11,417	11,242	200	375
McElmo	11,394	43	57	131	270	11,220	11,067	173	327
Dolores	80,368	479	634	943	1,949	78,946	77,784	1,422	2,584
San Miguel	32,879	921	1,314	415	858	31,543	30,708	1,336	2,171
Total	**259,400**	**4,100**	**5,800**	**3,200**	**6,600**	**252,100**	**247,000**	**7,300**	**12,400**

*Estimates based on projected level of population growth.

The Southwest Basin has numerous reservoirs (e.g. Animas La Plata Project, Electra Lake, Lemon Reservoir, Vallecito Reservoir, Pagosa Area Water and Sanitation District reservoirs, Jackson Lake, McPhee Reservoir, Norwood Water Commission reservoirs, Gurley Reservoir, etc.) that provide or plan to provide municipal and industrial water. While some extent of urbanization is inevitable, the Southwest Basin does not assume that current irrigation water supply will be transferred to meet the municipal and industrial gap. A minor exception is augmentation planning. Augmentation plans are developed on a case by case basis where a water rights holder is drying-up (taking out of production) their own land in order to provide additional water supply for a different use (such as domestic water).

The estimated average annual agricultural demand is based on the estimated 2050 irrigated acres and the average amount of water consumptively used by crops on irrigated lands. The consumptive use (CU) for a crop is the amount of water provided to the crop during the growing season. The irrigation water requirement (IWR) is the amount of water the crop would use if it were available. To quantify a crop's CU, the IWR is compared to the average water supply, the minimum of these two values over a period of time (typically months) is the water supply limited consumptive use (WSL CU). The WSL CU is assumed to represent the water necessary to sustain existing levels of agricultural acreage.

In addition to agricultural consumptive demands, SWSI 2010 estimated non-irrigation agricultural consumptive demands, such as stock ponds. For detailed explanation of the agricultural demand methodology see Section 4.3.1.4 2050 Agricultural Demand Methodology in SWSI 2010.

Two types of agricultural need were identified during the outreach efforts for the BIP. One of these we will term as an "annual shortage". This shortage can be quantified by comparing the WSL-CU to the IWR for a specific basin to indicate how often throughout the season a crops potential water use (IWR) is met. As an example, Table 4 provides estimates of current and 2050 annual agricultural demands. The Annual Shortage is calculated by subtracting the WSL-CU from the IWR.

TABLE 4. ESTIMATED CURRENT & FUTURE AGRICULTURAL DEMANDS IN THE SOUTHWEST SUB-BASINS

	IRRIGATED ACRES		IRRIGATION WATER REQUIREMENT (AF/YR)		WATER SUPPLY LIMITED-CU (AF/YR)		ANNUAL SHORTAGE (AF/YR)		NON-IRRIGATION DEMAND* (AF/YR)	
	SWSI 2010	2050 Estimate	SWSI 2010	2050 Estimate	SWSI 2010	2050 Estimate	SWSI 2010	2050 Estimate	SWSI 2010	2050 Estimate
San Juan	15,840	14,821	34,693	32,460	22,597	21,139	12,096	11,321	2,941	2,752
Piedra	7,074	6,790	14,839	14,243	8,595	8,250	6,244	5,993	946	908
Pine	46,755	44,710	103,096	98,586	90,515	86,555	12,581	12,031	9,311	8,904
Animas	32,193	30,854	74,431	71,336	53,817	51,579	20,614	19,757	5,843	5,600
La Plata	21,305	20,419	44,493	42,643	14,286	13,692	30,207	28,951	1,757	1,684
Mancos	11,617	11,329	31,560	30,779	16,060	15,663	15,499	15,116	2,716	2,649
McElmo	72,463	11,144	157,219	26,732	110,571	23,016	46,648	3,717	6,547	6,403
Dolores	19,298	78,365	48,728	174,195	28,050	112,190	20,678	62,005	11,925	11,623
San Miguel	32,879	31,125	71,167	67,371	37,396	35,402	33,770	31,969	3,937	3,727
Total	**259,400**	**249,557**	**580,200**	**558,345**	**381,900**	**367,486**	**198,300**	**190,859**	**45,900**	**44,250**

* includes stock ponds, ditch losses, etc.

Table 5 shows the shortage in water supply on an annual basis that is needed to meet the IWR for the existing irrigated acreage identified in SWSI 2010. Percentages shown represent the SWSI 2010 Annual Shortage value as a percent of the SWSI 2010 IWR provided in Table 4. It can be seen from Table 5 that the La Plata River basin shows the largest discrepancy between the amounts of water that the existing irrigated crops could use if it were available and the amount of water they are supplied with annually.

TABLE 5. ANNUAL SHORTAGE IN WATER SUPPLY NEEDED TO MEET CROPS IWR

SUB-BASIN	SHORTAGE
San Juan	35%
Piedra	42%
Pine	12%
Animas	28%
La Plata	68%
Mancos	49%
McElmo	30%
Dolores	42%
San Miguel	47%

The La Plata River basin has about 21,305 acres of existing irrigated lands (CWCB 2011). The average annual water supply is 23,153 AF. Based on this acreage and average annual water supply, about 0.71 AF per acre is supplied to the crops, assuming a high efficiency of delivery (e.g. conveyance losses of 10% and on-farm losses of 25%), as used by Bureau of Reclamation (BOR). The IWR is 2.09 AF per acre, so this annual water supply on average is meeting the IWR about 32% of the time for a single irrigation season.

The La Plata River is also unique in that it is administrated according to the La River Compact, as well as Colorado water law. See Section 3.2 for details of the compact. The compact requires half of the measured flow, not to exceed 100 cubic feet per second, at the Hesperus gaging station be delivered to the state line.

The second type of agricultural need identified in the Southwest Basin is the amount of irrigable land that is either not currently irrigated or not currently under production. We term this an “irrigation gap”. As part of the Animas La-Plata Project the BOR conducted land classifications of the Animas and La Plata river drainage areas and found many acres that are dry-land farmed that are potentially irrigable (DPR Appendix B, 1979). Of the present dry-land farming acreage, approximately 30,000 acres could be irrigated, in addition, 13,000 acres are presently not in crop production that could be irrigated as well. Assuming an IWR of 1.9 AF per acre (conveyance losses of 10% and on-farm losses of 25%, as assumed by BOR) the water supply needed to irrigate these new lands would be about 110,295 AF. This is well out of range for the average annual water supply in the La Plata Basin to provide for these new lands in addition to the existing lands’ needs. However, extensive studies identify trans-basin water as a source of potential water supply. The



McPhee Reservoir (Dolores River basin)

trans-basin water would be used to meet the demands of the existing lands in addition to the development of these new lands. Examples of trans-basin agricultural water development exist in the Southwest Basin today.

In some regions the needs of one basin have been met through a trans-basin diversion. An example is the McElmo River basin which receives irrigation water diverted out of the Dolores River through the Dolores Project. The Dolores Project irrigates about 28,500 acres of land from Yellow Jacket to Dove Creek, to the north, and about 7,600 acres around the toe of Ute Mountain (operated by Ute Mountain Ute Farm and Ranch). The Dolores Project also provides supplemental irrigation water to 26,300 acres in the Montezuma Valley Irrigation Company's service area that are classified as irrigable by the BOR. The Ute Mountain Ute Farm and Ranch has identified additional needs for irrigation water (see Appendix A) in the amount of 4,000 AF. This is a known, quantifiable irrigation gap. Please see Section 5 for proposed strategies and tools that could potentially meet a portion or all of this need.

2.2.2 MUNICIPAL

SWSI 2010 provided information about the methodologies used to develop population projections and future municipal demands by 2050. For a detailed explanation of municipal demands, reference Section 4.2 M&I and SSI Consumptive Needs in SWSI 2010 (CWCB 2011). Population projections were estimated using standard methods and forecasting processes utilized by the Colorado State Demographer's Office. Due to uncertainties in projections, low, medium, and high scenarios for population projections were developed. The State of Colorado is estimated to grow from approximately 5.1 million people to between 8.6 (low) and 10 (high) million people by 2050.

TABLE 6. POPULATION PROJECTIONS (CWCB 2011)

	2008	2035	2050 LOW	2050 MEDIUM	2050 HIGH	% AVERAGE ANNUAL GROWTH RATE
Archuleta County	12,870	28,295	32,180	34,602	37,517	2.23-2.58
Dolores County	1,993	3,127	3,455	3,692	3,977	1.37-1.69
La Plata County	51,454	87,929	95,803	105,276	116,996	1.49-1.95
Montezuma County	26,127	41,306	45,560	48,529	52,062	1.32-1.62
Montrose County*	4,177	7,787	8,577	9,037	9,661	1.80-2.07
San Juan County	588	683	830	1,098	1,395	0.78-1.95
San Miguel County	7,966	15,509	17,602	22,028	27,368	1.93-2.93
Total	**105,180**	**184,640**	**20,4010**	**224,260**	**248,980**	**1.6-2.1**

*Southwest portion of Montrose County

To estimate current and future municipal demands, water demands were based on the per capita water use rates (provided by water providers throughout the state) multiplied by the projected population for each county. Numerous factors contribute and affect the estimated per capita water use. For a detailed explanation on how these values were determined please reference SWSI 2010 Section 4.2.2.1 2050 M&I Water Demands Methodology. In summary, local water providers provided per capita water use based on their existing customers, which was in turn used

to estimate county-wide water use. Passive water conservation was also taken into consideration and assumed to range from 19 to 33 gallons per capita through the year 2050. The municipal and industrial demands of the Southwest Basin are expected to be between 40,000 and 50,000 AF per year by 2050 (CWCB 2011).

TABLE 7. 2050 MUNICIPAL WATER DEMAND ESTIMATES (CWCB 2011)

	WATER DEMAND (AF/YR)	2050 BASELINE WATER DEMAND (AF/YR)		
	2008	Low	Medium	High
Archuleta County	2,600	6,600	7,100	7,700
Dolores County	540	940	1,000	1,100
La Plata County	9,800	18,000	20,000	22,000
Montezuma County	5,000	8,800	9,400	10,000
Montrose County*	870	1,800	1,900	2,000
San Juan County	120	170	220	280
San Miguel County	2,600	5,700	7,100	8,900
Total	**21,530**	**42,010**	**46,720**	**51,980**

*Southwest portion of Montrose County

An M&I gap within Montrose County (Southwest Basin portion) was identified during the outreach efforts for the development of the BIP. Montrose County representatives provided two IPPs to meet the municipal and industrial needs over the next 50 years; please see Section 4.4 for a summary of the IPPs and Appendix A for the full IPP list. The two Montrose County projects will address the potential 3,200 AF gap between existing water supplies and demands projected to occur by the year 2050 in the west portion of Montrose County.

Another M&I gap that exists throughout the Southwest Basin is the need for water delivery infrastructure. This is not a quantifiable water supply gap but rather related to delivery of safe, reliable potable drinking water. Approximately 35% of the population within the basins are served by covered entities (public water systems serving at least 2,000 AF of water annually), approximately 40% are served by community public water systems (e.g. 15 connections or 25 residents; served year around), with the reminder of the population served by wells, non-community water systems, water hauling, surface water diversions or some combination of these (S. Harris, pers. comm.). Many residents are in need of safe, reliable drinking water that are not living within the service area of an existing water system. The formation of water districts, water authorities, or other entities to serve and construct rural water delivery systems is necessary to serve current residents of the Southwest Basin and to provide for future growth projections. A rural water system can provide reliability and safe drinking water to residents whose needs might otherwise not be met. The Southwest Basin has multiple existing or planned reservoirs to serve

M&I water demands. These reservoirs can provide long term water supply for public water systems.

2.2.3 INDUSTRIAL

SWSI 2010 estimated future self-supplied industrial water needs (SSI) which includes water used by self-supplied industries and municipal water provided to large industries. Subsectors that are included are:

- Large industries such as mining, manufacturing, brewing, and food processing
- Water needed for snowmaking
- Thermoelectric power generated at coal and natural gas fired facilities
- Energy development; such as natural gas, coal, uranium, and oil shale



Snowmaking in Telluride, CO (San Miguel River basin)

For the Southwest Basin, the industries specifically noted were snowmaking (within La Plata and San Miguel counties) and thermoelectric power generation (within Montrose County). SWSI 2010 reported snowmaking water demands are expected to remain constant through 2050 because no resort expansions were planned at time of data collection. For thermoelectric power generation baseline estimates generated through the SWSI I efforts were assumed until 2035, while 2050 estimates were made based on predetermined percent increase for low (5 percent), medium (25 percent) and high (50 percent) range. SWSI 2010 did not include projections of water demands for energy development within the Southwest Basin. Such demands might be worth estimating if drilling of shale beds moves from exploration to production.

SWSI 2010 included these SSI projections within the M&I water demand projections. These projections also include reductions for passive conservation (a range of 19 to 33 gpcd by 2050 was used). Please see the below Table 8 for a quantification of these values.

TABLE 8. 2050 M&I DEMAND PROJECTIONS FOR COUNTIES IN THE SOUTHWEST BASIN (CWCB 2011)

	2008 WATER DEMAND (AF/YR)	2035 WATER DEMAND* (AF/YR)	2050 INCREASE IN M&I AND SSI DEMAND* (AF/YR)		
			Low	Medium	High
Archuleta County	2,600	5,400	3,500	4,000	4,600
Dolores County	540	790	300	400	500
La Plata County	9,800	15,000	6,800	8,600	10,800
Montezuma County	5,000	7,300	3,000	3,500	4,200
Montrose County**	870	1,500	3,000	3,900	5,000
San Juan County	120	120	30	90	100
San Miguel County	2,600	4,800	2,900	4,300	6,000
Southwest Total	**21,530**	**34,910**	**19,500**	**24,800**	**31,200**

*Water demand including passive conservation

**Southwest portion of Montrose County

SWSI 2010 describes the M&I and SSI water supply gap as the difference between the 2050 net new water needs minus the 2050 IPPs (based on the IPP's yield and success rate). SWSI 2010 describes meeting the future M&I demand through growth into existing supplies, as well as through achieving regional in-basin IPPs having a success rate of 100%. A number of IPPs exist to meet the M&I demand projections. For the complete list of IPPs see Appendix A. Within each sub-basin, current municipal IPPs have the potential to meet identified needs if completed as currently described.

Archuleta County has a projected demand increase of 3,500 to 4,600 AF per year. This potential gap could be met by the IPP described as regional in-basin IPPs which is the Dry Gulch Water Storage Facility Project. Infrastructure gaps could be met by the proposed IPPs for the Aspen Springs Distribution System and the Snowball Booster Station with Snowball to Dutton Diversion Pipeline Project.

Dolores County has a projected demand increase of 300 to 500 AF per year. This potential gap could be met by growth into existing supplies and regional in-basin IPPs. The Rico Alluvial Pipeline Water Supply Project was recently completed; the Town of Rico constructed a new groundwater source to meet demands while keeping the existing surface water diversion in place to provide redundancy. The Dolores Project has existing M&I water that is not permanently allocated. The Dolores Project already provides M&I water to the City of Cortez, Montezuma Water Company, Dove Creek, and Towaoc. In addition, a new reservoir is proposed, the Upper Plateau Reservoir decreed for M&I and fisheries purposes, which could also supply M&I demands.

La Plata County has a projected demand increase of 6,800 to 10,800 AF per year. This potential gap could be met by growth into existing facilities and regional in-basin IPPs. The Animas-La Plata Project currently has water allocated for M&I use for the City of Durango, La Plata Archuleta Water District, La Plata West Water Authority, Ute Mountain Ute Tribe, and Southern Ute Tribe. The Florida Water Conservancy District has a multi-purpose IPP providing augmentation water and M&I water for the Florida River basin. New regional in-basin infrastructure IPPs include the Animas Airpark Water Distribution System, La Plata Archuleta Water District Distribution System and the La Posta Road Water Distribution System.



Rico Alluvial Municipal Pipeline Project (Dolores River basin)

Montezuma County has a projected demand increase of 3,000 to 4,200 AF per year. This potential gap could be met by growth into existing facilities. Again, the Dolores Project provides M&I water to water providers within Montezuma County. In the future, Totten Reservoir could be a potential water source to provide M&I water. Within the Mancos watershed, reservoirs currently providing M&I water have enlargements planned to increase capacity and provide additional water supply.

Montrose County has a projected demand increase of 3,000 to 5,000 AF per year. This potential gap could be met by growth into existing supplies and by regional in-basin IPPs. Existing providers are investigating means of providing additional water, firming of existing supplies, and enlargement of distribution systems. The regional in-basin IPP consists of a two-phased IPP; the first phase is to conduct a feasibly study to determine reservoir sites and expected yield, and the second phase is to construct one or more reservoirs.

San Juan County has a projected demand increase of 30 to 100 AF per year. This potential gap can be met by growth into existing supplies. Currently, there are no IPPs listed that provide additional water supply. The existing IPPs relate to infrastructure not supply.

San Miguel County has a projected demand increase of 2,900 to 6,000 AF per year. This potential gap can be met by growth into existing supplies. Existing providers are investigating means of providing additional water, firming of existing supplies, and enlargement of distribution systems.

SECTION 3: CONSTRAINTS & OPPORTUNITIES

3.1 ANALYSIS OF CONSTRAINTS & OPPORTUNITIES BASED ON EXISTING DATA

The purpose of this section is to understand where there appear to be opportunities for new IPPs to meet remaining needs (e.g. gaps) and what some of the constraints may be, based on existing data.

Examples of physical and administrative conditions that may act as constraints and/or present opportunities include:

- Water management and water rights administration (see Section 3.2),
- Current and future hydrology (see Section 3.5),
- Sensitive species and habitat location and quality (see Section 3.3)
- Flows and river gradient (e.g. for whitewater and flat-water boating)
- Reservoir capacity and operation agreements
- Regulations/ Permitting
- Water Quality
- Public Land Management laws or policies (e.g. W&S suitability, Wilderness)

Table 9 provides a summary of general opportunities and constraints that the Roundtable has identified to-date for accomplishing the Goals and Measureable Outcomes in Section 1.

The Roundtable has not yet, but could in the future, consider reviewing existing spatial data to study locations around the Southwest Basin that might present opportunities for attaining all or some of the measureable outcomes. Moreover, as more information about environmental and recreational water needs is gathered, additional IPPs may be identified to meet any updated measurable outcomes. The following sections provide more detail on some of these conditions.



Dusk in the San Juan Mountains (Animas River basin)

TABLE 9. SUMMARY OF OPPORTUNITIES AND CONSTRAINTS ASSOCIATED WITH SOUTHWEST BASIN MEASUREABLE OUTCOMES

THEME	MEASUREABLE OUTCOME	OPPORTUNITIES	CONSTRAINTS
A	1. 100% of new IPPs shall consider from the initial planning stage maintaining and enhancing environmental and recreational needs.	• Incorporate into Southwest Basin funding criteria and expectations. • Partnerships could assist in funding opportunities, and achieving the desired outcomes.	• Jurisdictions. • Timing. • Difficult to assess. • Some of projects have already passed through their initial planning and have reached a stage where difficult; options may be limited for achieving all needs within a given project, requires prioritizing. • Permitting requirements.
A	2. Complete 19 multipurpose IPPs to meet identified gaps.	• Look for project specific opportunities. • Support implementation, to help meet water supply gaps.	• Project specific. • Water availability. • Funding. • Water management and administration. • Permitting. • Legal obligations.
A	3. Initiate and participate in 10 IPPs that promote dialogue, foster cooperation and resolve conflict.	• Areas with high demand for multiple uses and values but which are over appropriated. • Areas with lower demand and more opportunity for common ground among uses, values and jurisdictions.	• Hydrology past present and predicted • Physical realities (topographic, habitat, hydrology). • Habitat. • Water administration (Critical areas map). • Reservoir capacity and contracts. • Compact requirements.

TABLE 9. CONTINUED…

THEME	MEASUREABLE OUTCOME	OPPORTUNITIES	CONSTRAINTS
A	4. At least 50% of sub-basins have existing or planned IPPs that are protective of critical infrastructure and/or environmental and recreational areas and watershed health.	• Although the goal has been met for portions of each sub-basin, additional opportunities exist for forest health, community wildfire protection, water quality, and source water protection planning in portions of each sub-basin.	• Action depends on collaboration between various private, tribal, federal, state and local jurisdictions.
A	5. All towns and major water supply systems with water supply infrastructure have watershed/ wildfire assessments that identify strategies/ treatments necessary to mitigate the impacts that occur to hydrology in a post-fire environment.	• Smaller entities can also benefit. • While each county has a Community Wildfire Protection Plan in place, not every town or major supply system has a CWPP or Source Water Protection Plan specific to its operations.	• Action depends on various private, tribal, federal, state and/or local jurisdictions outside of town or water suppliers' control. • Cost of such assessments.
A	6. All major reservoirs have watershed/ wildfire assessments that identify strategies/treatments necessary to mitigate the impacts that occur to hydrology in a post-fire environment.	• While every county has a CWPP in place, there is opportunity for reservoir specific fire and disaster planning and management efforts.	• Action depends on various private, tribal, federal, state and/or local jurisdictions outside reservoir operators' control.

TABLE 9. CONTINUED…

THEME	MEASUREABLE OUTCOME	OPPORTUNITIES	CONSTRAINTS
B	1. Implement projects (e.g. ATMs, efficiency, etc.) in order to help preserve agriculture and open space values, and to help address municipal, environmental, recreational, and industrial needs; while respecting private property rights.	• These tools could be explored and be useful at some point. • Southwest Basin will take the opportunity to learn from such projects elsewhere in the state.	• Water rights administration. • Tools are still in development. • Not currently active within Southwest Basin.
B	2. Implement strategies that encourage continued agricultural use and discourage permanent dry-up of agricultural lands.	• These tools could be explored and be useful at some point. • Southwest Basin will take the opportunity to learn from such projects elsewhere in the state.	• Water rights administration. • Tools are still in development. • Not currently a high priority need within our basin.
B	3. The water providers in the state that are using dry-up of agricultural land (defined as requiring a water court change case) and/or pursuing a new TMD (as defined by IBCC to be a new west slope to east slope diversion project) shall have a higher standard of conservation. The goal for these water providers is a ratio of 70/30.	• Opportunity for Southwest Basin to achieve outcome and help build support; • Join with Colorado Basin Roundtable in supporting this measure. • Participate in conservation discussions and pursue future legislation.	• Political support/opposition at State level.

TABLE 9. CONTINUED…

THEME	MEASUREABLE OUTCOME	OPPORTUNITIES	CONSTRAINTS
B	4. Implement at least 10 agricultural water efficiency projects identified as IPPs (by sub-basin).	• Many more ditches and districts may also have interest or plans.	• Resources (e.g. funding and match, manpower, expertise). • State water policy. • Lack of financial incentive for efficiency. • Need to adapt state water policy.
C	1. Complete 41 IPPs identified in 2015 IPP list (includes all basins) aimed at meeting municipal water needs.	• Many more public or non-community suppliers may also have need/interest or plans. • Roughly 25% of the population (Harris and Lile, pers. comm.) are not covered by a public water system (e.g. wells, hauling, non-community systems).	• Non-community water systems have not been identified. • Funding.
C	2. Consistently meet 100% of residential, commercial and industrial water system demands identified in SWSI 2010 in each sub-basin.	• Complete the currently listed IPPs, and newly identified needs. • Connect available M&I water supplies with areas of need. • Opportunity for increased outreach to suppliers.	• Funding. • Source water quality. • No central place for data • Depends on hydrology, water rights and administration. • Capital cost versus return ratio.
C	3. Implement projects that protect or enhance the ability of public water supply systems to access and deliver safe drinking water that meets all health-based standards.	• Engage more public water suppliers in Source Water Protection Planning. • Support implementation of identified BMPs from existing plans.	• Funding for implementation. • Interest. • Lack of urgency. • Jurisdictions.

TABLE 9. CONTINUED…

THEME	MEASUREABLE OUTCOME	OPPORTUNITIES	CONSTRAINTS
C	4. Change the ratio of in-house to outside treated water use for municipal and domestic water systems (referred to as water providers herein) from the current ratio of 50/50 to 60/40 for southwest Colorado and the entire State by 2030.	• More useful measure of conservation than per capita use, because per capita use does not fit the same for all communities, and because consumptive use is highest with outside use. • Legislation	• Concerns that one size does not fit all.
C	5. Implement 3 informational events about water reuse efforts and strategies.	• Highlight current reuse efforts in and out of the basin. • Educate about grey water use law and opportunities.	• Legal. • Return flow demand and quality. • State water policy. Historical use.
C	6. The water providers in the state that are using dry-up of agricultural land (defined as requiring a water court change case) and/or pursuing a new TMD (as defined by IBCC to be a new west slope to east slope diversion project) shall have a higher standard of conservation. The goal for these water providers is a ratio of 70/30. Water providers proposing a new TMD shall achieve a 60/40 ratio by 2020 and 70/30 by 2030 (high conservation) as a prerequisite for the Roundtable to consider support of a new TMD.	• Legislation.	

TABLE 9. CONTINUED…

THEME	MEASUREABLE OUTCOME	OPPORTUNITIES	CONSTRAINTS
D	1. Implement 10 projects to benefit recreational values and the economic value they provide.	• Education. • Funding. • Providing safe and appropriate access and address data gaps on flow needs. • Partnerships.	• Hydrology and water administration, private property concerns. • Funding. • Poor recreational etiquette. • Lack of data on flow needs.
D	2. At least 80% of the areas with recreational opportunities have existing or planned IPPs that secure these opportunities and supporting flows/lake levels within the contemporary legal and water management context.	• Incorporating benefits from water administration and management. • Developing data on range of flows to support values.	• Difficult to quantify. • Assessing sufficient protection. Private property rights. • Water availability. • Water quality. • Lack of data.
E	1. Implement 15 IPPs to directly restore, recover or sustain endangered, threatened, and imperiled aquatic and riparian dependent species and plant communities.	• Participation in SJRIP. • Partnerships. • Dialogue. • Developing data on range of flows to support values.	• Water rights. • Private property. • Lack of data on flow needs.
E	2. At least 95% of the areas with federally listed water dependent species have existing or planned IPPs that secure the species in these reaches as much as they can be secured within the existing legal and water management context.	• Partnerships. • Dialogue. • Developing data on range of flows to support values. • Update attribute map. • Jointly identify reaches where opportunities exist.	• Water Rights. • Private Property. • Lack of data on flow needs. • Not currently mapped as attributes (or incorrect). • Difficult to assess sufficiency of IPPs.

TABLE 9. CONTINUED…

THEME	MEASUREABLE OUTCOME	OPPORTUNITIES	CONSTRAINTS
E	3. At least 90% of areas with identified imperiled species (other than ESA species) have existing or planned projects and methods that provide direct protection to these values.	• Partnerships and dialogue. • Update attribute list, mapping. • Developing data on range of flows to support species. • Jointly identify reaches where opportunities exist.	• Water rights. • Private property. • Lack of data on flow needs. • Not currently mapped as attributes (or incorrect). • Difficult to assess sufficiency of IPPs.
E	4. Implement 26 IPPs to benefit condition for fisheries and riparian/wetland habitat.	• Partnerships • Dialogue • Update attribute list and mapping. • Developing data on range of flows to support species. • Jointly identify reaches where opportunities exist.	• Water rights • Private property • Lack of data on flow needs. • Not currently mapped as attributes (or incorrect) • Difficult to assess sufficiency of IPPs.
E	5. At least 80% of areas with environmental values have existing or planned projects and methods that provide direct protection to these values.	• Partnerships. • Dialogue. • Update attribute list/ mapping. • Developing data on range of flows to support species. • Jointly identify reaches where opportunities exist.	• Water rights. • Private property. • Lack of data on flow needs. • Not currently mapped as attributes (or incorrect). • Difficult to assess sufficiency of IPPs.

TABLE 9. CONTINUED…

THEME	MEASUREABLE OUTCOME	OPPORTUNITIES	CONSTRAINTS
F	1. By 2016, replace the following statewide outcomes with outcomes based on the current status of these measures in the Roundtable area.	• Partnerships. • Funding. • More consistent and comprehensive periodic monitoring.	• Funding. • Legislation. • Regulatory policy.
F	2. Implement 6 IPPs to monitor, protect or improve water quality.	• Funding. • Consistent periodic monitoring. • Identifying sources.	• Funding. • Consistency. • Jurisdictions. • Access. • Identifying sources is challenging.
G	1. Water providers proposing a new TMD shall achieve a 60/40 ratio by 2020 and 70/30 by 2030 (high conservation) as a prerequisite for the Roundtable to consider support of a new TMD.	• Opportunity for Southwest Basin to achieve outcome and help build support. • Join with Colorado Basin Roundtable in supporting this measure. Participate in conservation discussions and pursue future legislation.	• Political support/opposition at State level.
G	2. A conceptual agreement is developed between roundtables regarding how approach a potential future TMD from the West Slope to the East.	• IBCC working on it. • Future Use Allocation (FUA). • Develop alternative sources to a TMD to meet future water needs.	• Water supply. • Compact curtailment. • Risk management. • Future west slope development. • Funding.

TABLE 9. CONTINUED…

THEME	MEASUREABLE OUTCOME	OPPORTUNITIES	CONSTRAINTS
G	3. Protect 100% of pre-compact water rights in the Southwest Basin.	• Put to beneficial use. Protect historic consumptive use.	• Listing on abandonment list is a risk. Ability to put to beneficial use in some cases.
G	4. Implement 2 IPPs aimed at utilizing Tribal Water Rights Settlement water.	• Support implementation.	
G	5. Implement 2 IPPs aimed at meeting La Plata River compact.	• Support implementation.	
G	6. Participate in Compact water bank efforts.	• Demand management. • Includes most entities in state interested in water development in CO River.	• Data needs. • Water rights, administration and policy. • Voluntary participation. • Funding.

3.2 WATER MANAGEMENT & WATER ADMINISTRATION

The Southwest Basin encompasses approximately 216,075 irrigated aces (in 2005). These acres are served by rivers, ditches, springs, wells and other bodies of water. Approximately 6,797 decreed points of diversion exist within the Southwest Basin. Another 1,850 decreed wells exist and require administration (CDSS 2014). The Southwest Basin has a variety of water uses that all require proper water management and water administration.

The Southwest Basin's major water export is the San Juan Chama Project. This project is a component of the Upper Colorado River Compact and allows an average annual diversion ranging from 85,000 to 100,000 AF to be provided to New Mexico. In addition there are a number of relatively small, high elevation TMDs from the Southwest Basin to the Rio Grande and Gunnison basins. However, within the Southwest Basin there are many trans-basin diversions from one sub-basin to another.



Winter sunset in the San Juan Mountains (Animas River basin)

In Colorado, the authority to establish water policies of the state, determine the beneficial uses of the water resources, and the administration of water rights pursuant to the Doctrine of Prior Appropriation fall under the jurisdiction of state government. It is recognized that there is a significant amount of land administered by the federal government in Colorado, which creates the potential for conflicts between state and federal laws and policies. Congress and Federal agencies have a long standing deference to state water allocation systems, and Colorado continues to promote state-federal cooperation to avoid contentious water rights issues. Federal policies and actions could affect existing and future water supplies and planning efforts in southwestern Colorado.

Therefore, the Roundtable supports Colorado's system of water rights administration and allocation and the full recognition of tribal rights under the Colorado Ute Indian Water Rights Settlement. The Roundtable also encourages and supports creative solutions sought through collaborative efforts, negotiated settlements, and strengthening the use of State-Federal MOUs, to limit conflicts between state, tribal and federal polices, laws and land management plans. Maintaining opportunities that allow for management solutions that provide for multiple beneficial uses and are protective of environmental and recreational values are critical for the planning and strategic development of the water resources in the State of Colorado.

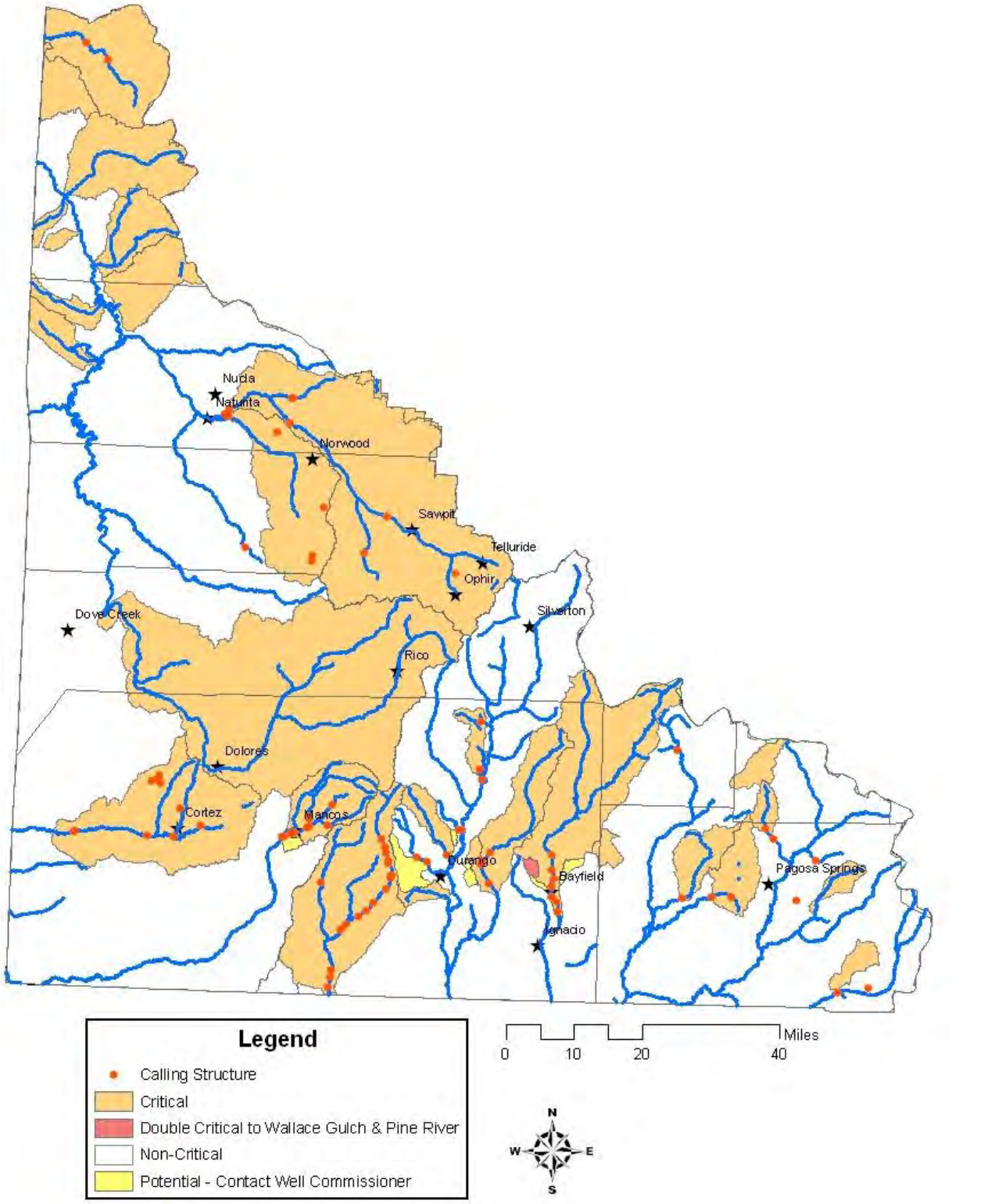
COLORADO DIVISION OF WATER RESOURCES ADMINISTRATION

Two Divisions of Water Resources (DWR) have jurisdiction within the Southwest Basin. The majority of sub-basins are within Division 7, while the San Miguel River and portions of the Dolores River are administered by Division 4.

Water critical areas exist throughout the Southwest Basin and its sub-basins (Figure 4). When an area is designated as critical (e.g. over-appropriated) the State Engineer cannot issue a well permit without water being made available for appropriation by means of an approved augmentation plan (Policy 2004-3: Use of evapotranspiration credit within substitute water supply plans involving the exposure of ground water in ponds or reservoirs not located within the stream bed).

DWR tracks calling structures along with the time period of administration, the water source, structure location, appropriation date, and water amount called. Figure 4 also shows the location of structures that placed calls between November 1, 2000 and October 31, 2013.

FIGURE 4. WATER CRITICAL BASINS AND STRUCTURES PLACING CALLS BETWEEN NOVEMBER 1, 2000 AND OCTOBER 31, 2013 (SOURCE: DIVISION OF WATER RESOURCES)



TRIBAL WATER RIGHTS

In a period from the 1970s through 2006, the Ute Mountain Ute Tribe and the Southern Ute Indian Tribe resolved federal Indian water rights litigation claims through negotiated settlement with the State of Colorado, the United States, water districts, and local water users. The negotiated settlement was viewed as an approach preferable to litigating large, senior priority federal reserved water rights that could potentially disrupt existing, non-Tribal water users upstream of the reservations.

The Settlement established quantities of water rights, priorities of tribal rights, permitting requirements, conditions for changing water rights, conditions for leasing, and other terms including cooperative and coordinated administration of water rights arising under State and federal law. Also as part of the negotiated settlement, each Ute Tribe took new water allocations in federal water storage projects (the Dolores Project and the Animas-La Plata Project) and confirmed their allocations in existing facilities such as Vallecito and Lemon Reservoirs. These facilities and the municipal and agricultural uses developed from them are important parts of southwest Colorado's water management scenario.

The tribal water rights established in the settlement have the potential to play an important role in not only addressing water management issues for the Tribes themselves, but also serving the greater interests of the community of southwest Colorado. Furthermore, the special nature of Tribal water rights may provide opportunities in the future that other water rights do not allow.

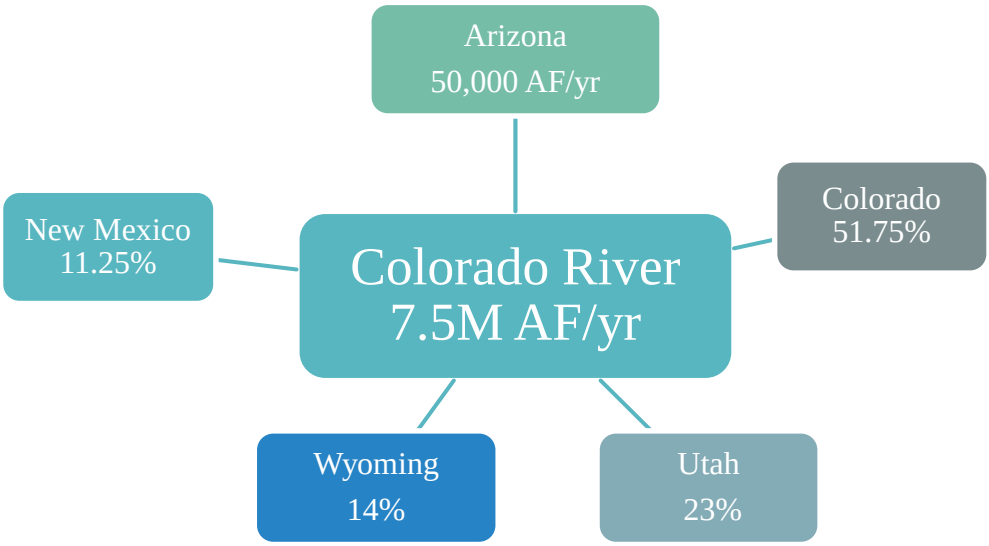
COMPACT COMPLIANCE

The Colorado River Compact of 1922 allocates 7.5M AF of CU annually to: Upper Basin states (parts of AZ, CO, NM, UT, WY above Lee Ferry, AZ) and Lower Basin states (parts of AZ, CA, NV below Lee Ferry, AZ). The compact requires the Upper Basin states to provide on average 7.5M AF during any period of ten consecutive years. The major purposes of this compact are:

- *"Provide for the equitable division and apportionment of the use of the waters of the Colorado River System;*
- *To establish the relative importance of different beneficial uses of water, to promote interstate comity;*
- *To remove cause of present and future controversies;*
- *And to secure the expeditious agricultural and industrial development of the Colorado River Basin, the storage of its waters, and the protection of life and property from floods."*

The Colorado River Basin is thus divided into two basins, with an apportionment of use of portions of the Colorado River System waters is allocated to each of them with provision that future equitable apportionments may be made.

The Upper Colorado River Compact of 1984 allocates 7.5M AF apportionment of consumptive use available to the Upper Basin states as follows:



The La Plata River Compact was signed in 1922 and approved by Congress in 1925. It requires dividing the waters of the La Plata River between Colorado and New Mexico. The river is administered daily except from December 1 through February 15. The Colorado DWR maintains two stream gages, one near Hesperus, CO and one at the Stateline, for administration purposes. The flow of the river between February 15 and December 1 of each year is apportioned between the two states as follows:

- *"Each state shall have the unrestricted right to use all the waters within its boundaries on each day when the mean daily flow at the Interstate station is one hundred cubic feet per second, or more;*
- *On all other days the State of Colorado shall deliver at the Interstate station a quantity of water equivalent to one-half of the mean flow at the Hesperus station for the preceding day, but not to exceed one hundred cubic feet per second;"*

The Animas-La Plata Compact implements the operation of the Animas-La Plata Federal Reclamation Project. This project is a part of the Colorado River Storage Project Act. The Compact allows:

- *"the right to store and divert water in Colorado and New Mexico from the La Plata an Animas River systems, including return flow to the La Plata River from Animas River diversions, for uses in New Mexico under the Animas-La Plata Federal Reclamation Project shall be valid and of equal priority with those rights granted by decree of the Colorado state courts for uses of water in Colorado for that project providing such uses in New Mexico are within the allocation of water made to state by articles III and XIV of the Upper Colorado River Basin Compact." (37-64-101. Animas-La Plata Project Compact)."*

BIOLOGICAL OPINIONS



Razorback sucker (USFWS)

Under Section 7 of the Endangered Species Act (ESA) of 1973, federal agencies must consult with the US Fish and Wildlife Service (USFWS) to avoid jeopardizing listed species or harming critical habitat. When possible, the USFWS does a programmatic consultation that addresses multiple projects. These consultations require that applicants take specific steps to protect endangered species, while also allowing multiple projects to go forward. Two such Biological Opinions touch upon water management in the Southwest Basin: Final Biological Opinion for Navajo Reservoir Operations (USFWS 2005) and the Gunnison River Basin PBO (USFWS 2009).

The actions of two recovery programs provide compliance with the ESA for water development and water management activities. The Upper Colorado River Endangered Fish Recovery Program (Upper Program) and the San Juan River Basin Recovery Implementation Program (SJRIP) are charged with using adaptive management and measures to recover four species of endangered Colorado River fishes while allowing water development activities to continue to meet the needs of the people. Program partners include: State and federal agencies, water and environmental organizations, power customers, and American Indian tribes.

The Dolores River is a tributary to the Colorado River and thus a part of the Gunnison River Basin PBO (USFWS 2009). Releases from the Aspinall Unit reservoirs provide reasonable and prudent alternatives for the Dolores Project as described in the Aspinal Unit operations EIS of 2012.



Colorado pikeminnow (USFWS)

The two recovery programs combined have provided ESA compliance for 2,354 federal, tribal, and non-federal water projects. The Upper Program has provided 1,176 projects ESA compliance for Colorado since 1988 through 2012. These projects total annual depletions are about 2,122,140 AF. The SJRIP has conducted 293 consultations since 1992 through 2012 within Colorado. These projects total annual depletions are about 217,797 AF. ESA consultation is required within the San Juan basin if a proposed project's estimated annual depletions are greater than 100 AF.

3.3 SENSITIVE SPECIES

COLORADO RIVER CUTTHROAT TROUT CONSERVATION STRATEGY

CHECK IT OUT!

http://ndismaps.nrel.colostate.edu/stockingrestrictions/

Maps located at the above website show numerous populations of CRCT that are being managed in accordance with CRCT Conservation Strategy

Colorado River Cutthroat Trout (CRCT) is a state-listed Species of Special Concern in Colorado, Wyoming, and Utah, and also is characterized as a Sensitive Species by federal land management agencies (BLM and USFWS). Colorado Parks and Wildlife (CPW) works closely with UT, WY, and federal land managers to manage for the recovery and persistence of CRCT throughout their historic range, guided by "Conservation strategy for Colorado River cutthroat trout in the states of Colorado, Utah, and Wyoming (CRCT Coordination Team, 2006)".

Implementation of the CRCT Conservation Strategy and showing progress on measurable benchmarks has allowed the USFWS to maintain its opinion that CRCT is 'not warranted' for listing under the ESA. Such a finding has been beneficial to state wildlife management agencies, but is also of critical importance to water managers so that consultation with the USFWS under Section 7 of the ESA is not required for projects in CRCT occupied waters.



Colorado River Cutthroat Trout

THREE SPECIES AGREEMENT

Three native fish species, roundtail chub, bluehead sucker, and flannelmouth sucker, occupy some lower portions of most of the sub-basins represented within the Southwest Basin. Concerns about declines in the three species within the entire Upper Colorado River Basin (including the San Juan River drainage) prompted resource agencies to draft and adopt a multi-state, multi-agency, range-wide conservation, and strategy agreement. Known as "The Three Species Agreement", the agreement provides the framework for conservation actions designed to preserve these species across their historic Colorado and five other Colorado River Basin states. Signatories to the agreement include the Colorado River Basin states, the United States Forest Service (USFS), BLM, BOR, and sovereign tribes.

The range-wide declines described in the Three Species Agreement speak to the species' potential for listing by the USFWS. The Three Species Agreement articulates that within their jurisdictional authority, signatories are responsible for taking action to conserve native fish. The agreement is predicated on the concept that collectively, local, state, federal agencies, and other willing partners can work together with the communities most affected by a potential listing to develop and implement voluntary actions that pre-empt the need for federal listing of any of these species under the ESA.



Roundtail chub (USFWS)

Within the Southwest Basin, these species are present in many low-elevation tributaries to the San Juan River. The Ute Mountain Ute and Southern Ute tribes have been active participants in habitat and flow restoration projects on behalf of these native fish, and a fairly intensive effort was launched in 2010 to preserve these species below McPhee Dam in the Dolores River drainage.

CPW is currently developing a state-specific strategy that describes how Colorado is implementing management actions that will help conserve these species. Monitoring of populations remains critical to determine the status of the fishery and the persistence of threats to these populations.

While these fish tend to be located lower in watersheds that have already undergone upstream water development, it is imperative that fishery managers work cooperatively with water managers to continue to implement the voluntary actions articulated in the Three Species Agreement. In the Southwest Basin, flow protection provided by downstream compact deliveries, ISF appropriations, or voluntary flow agreements may be an important means of maintaining the native fishery.

3.4 HISTORICAL STREAMFLOW

The historical streamflow in the sub-basins of the Southwest Basin has laid the foundation for the values and levels of water use that exist in the Southwest Basin today. The CWCB Historical Streamflow Analysis Tool was used to provide a summary of historical streamflow at key gages (selected by CWCB) within the Southwest Basin for the study period of 1950 through 2012. Hydrologic classifications of "drought", "dry", "average", "wet", and "flood" were given for water years based on the criteria shown in Table 10. Figure 5 shows the Key Stream Flow Gages in Southwest Basin. This tool allows for a snapshot of the last 50 years hydrology.

TABLE 10. HYDROLOGIC CLASSIFICATION CRITERIA

PERCENTILE RANGE	HYDROLOGIC CLASSIFICATION
0.00 – 0.05	Drought
0.06 – 0.24	Dry
0.25 – 0.75	Average
0.76 – 0.94	Wet
0.95 – 1.00	Flood

AVERAGE MONTHLY HYDROLOGIC CLASSIFICATION

The average monthly flows by hydrologic classification are graphed for each stream gage. While this does not tell the whole story, it does show the variability between drought and wet years and the different volumes between average and wet years. The following series of graphs for each stream gage were generated by the Historical Streamflow Analysis Tool.

FIGURE 5. KEY STREAM FLOW GAGES IN SOUTHWEST BASIN

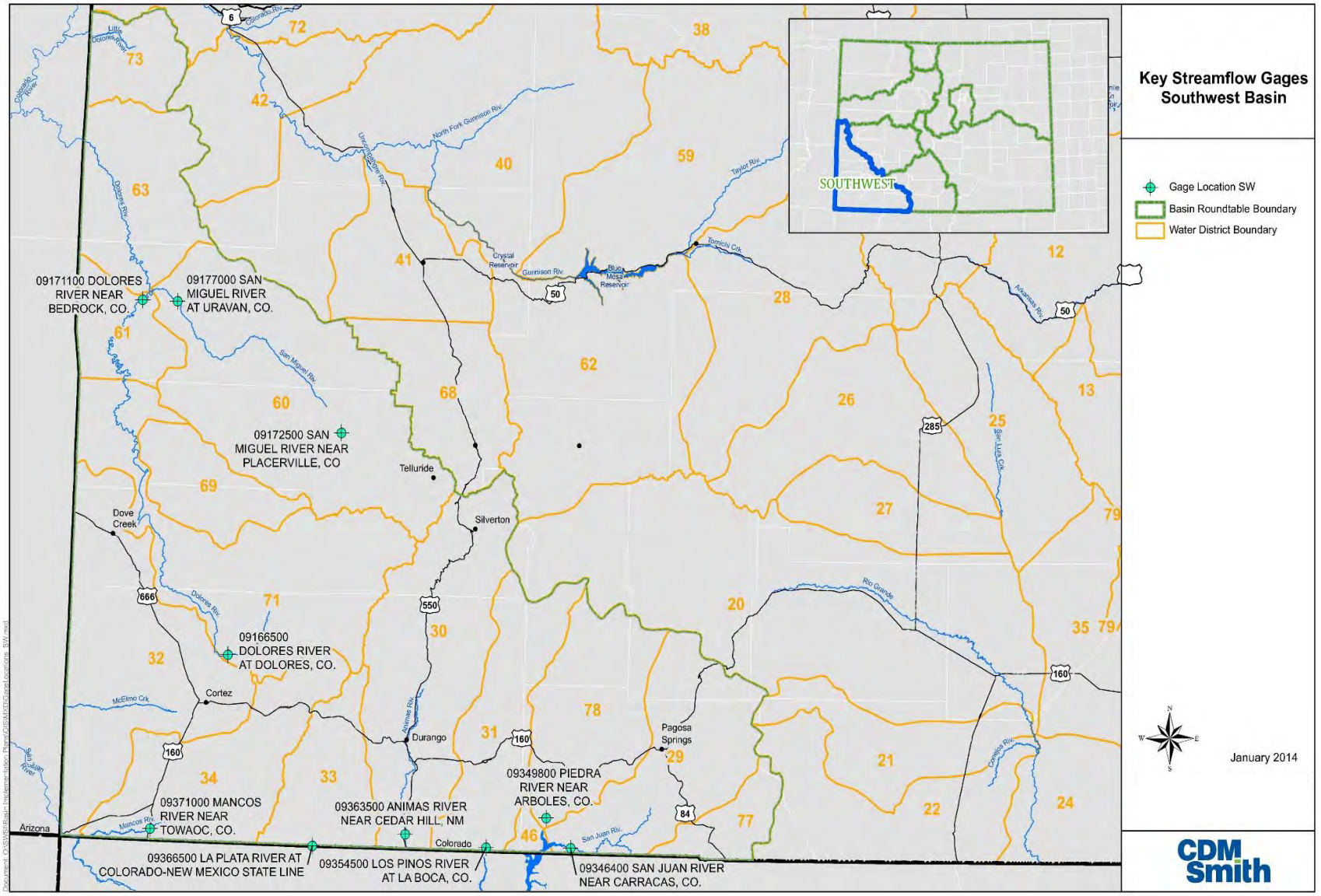
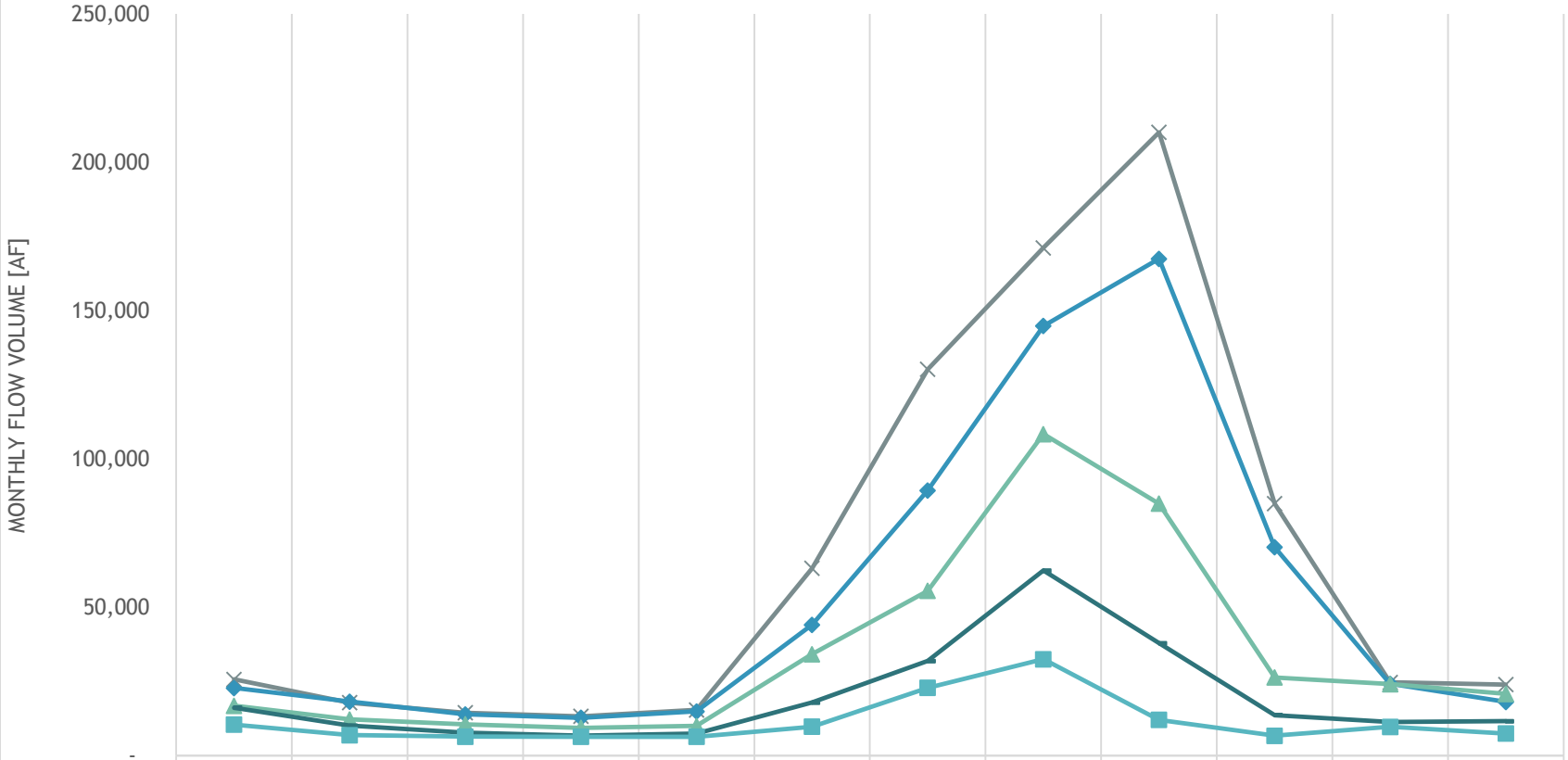


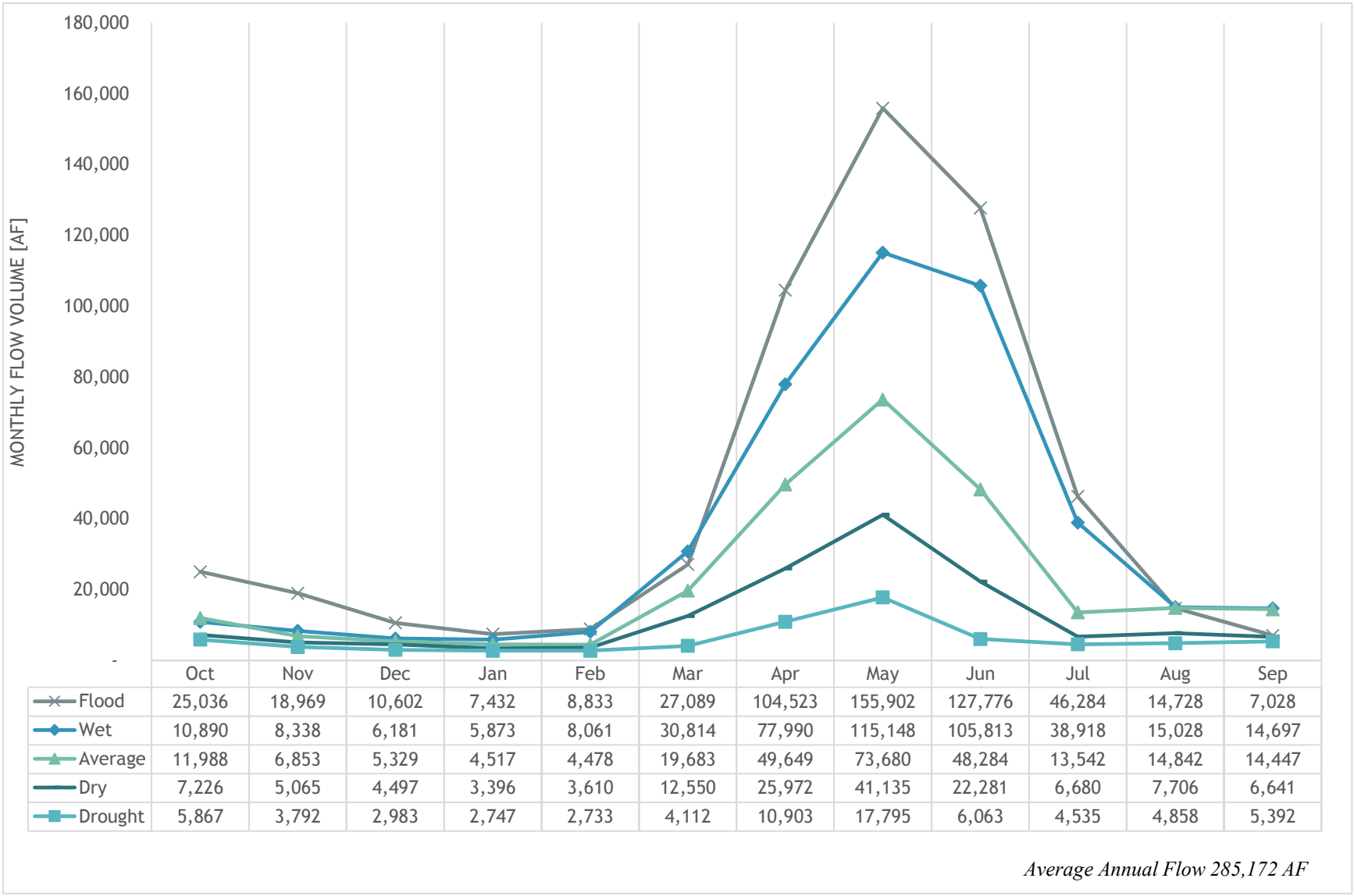
FIGURE 6. SAN JUAN RIVER AT NAVAJO – AVERAGE MONTHLY FLOWS BY HYDROLOGIC YEAR CLASSIFICTAITON (WY 1963-2012)



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flood	25,733	17,902	14,519	13,301	15,470	63,186	130,272	171,196	210,132	84,992	24,775	24,015
Wet	22,850	18,252	13,974	12,832	14,963	44,152	89,403	144,857	167,483	70,281	24,258	18,165
Average	16,882	12,245	10,595	9,409	10,084	34,237	55,568	108,402	85,000	26,383	24,149	20,857
Dry	16,236	10,172	7,830	6,743	7,496	17,957	31,956	62,441	37,944	13,734	11,365	11,654
Drought	10,523	6,963	6,454	6,440	6,407	9,836	22,910	32,541	12,100	6,748	9,740	7,538

Average Annual Flow 433,617 AF

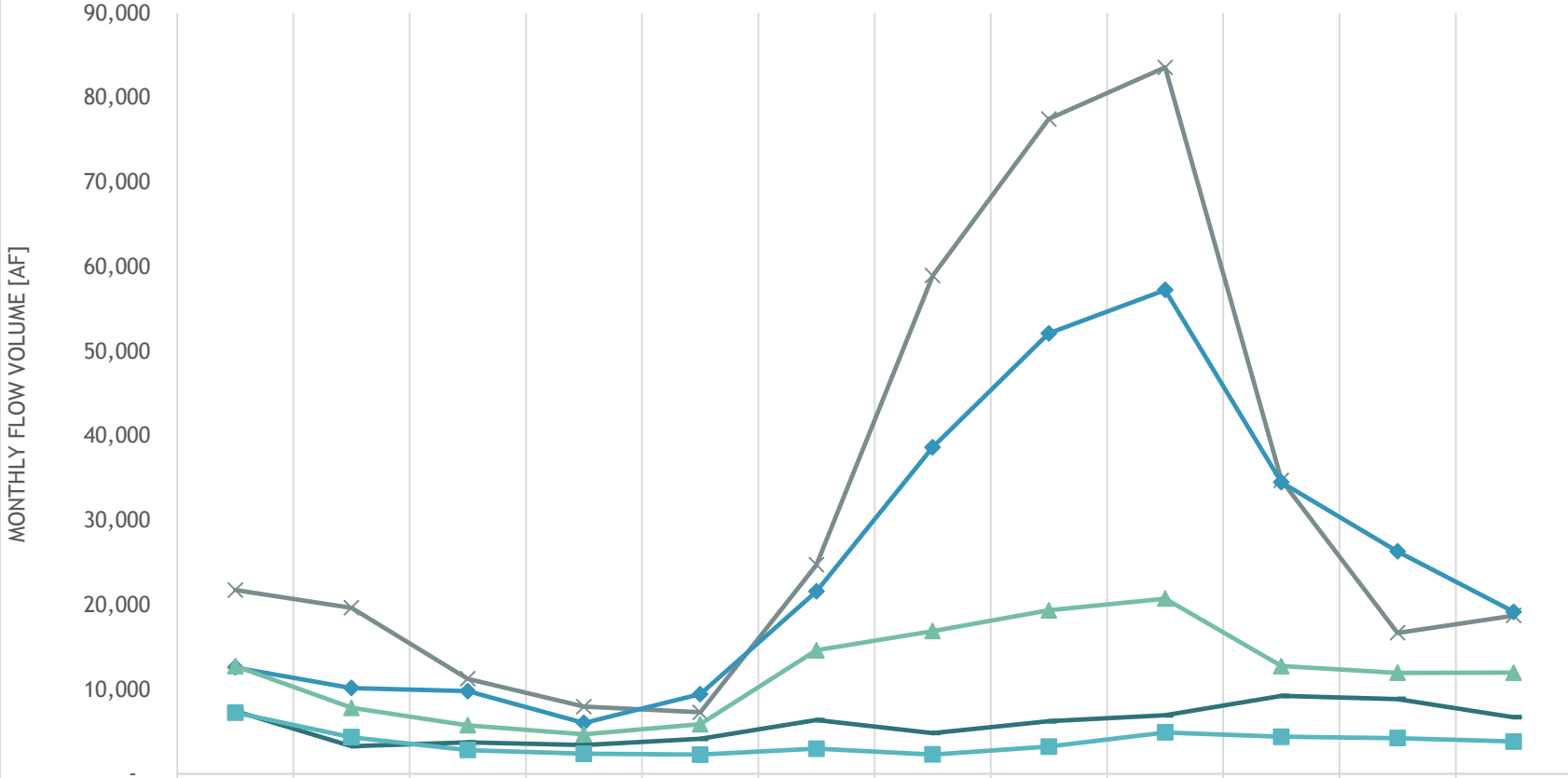
FIGURE 7. PIEDRA RIVER AT ARBOLES – AVERAGE MONTHLY FLOWS BY HYDROLOGIC YEAR CLASSIFICATION (WY 1963 TO 2012)



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flood	25,036	18,969	10,602	7,432	8,833	27,089	104,523	155,902	127,776	46,284	14,728	7,028
Wet	10,890	8,338	6,181	5,873	8,061	30,814	77,990	115,148	105,813	38,918	15,028	14,697
Average	11,988	6,853	5,329	4,517	4,478	19,683	49,649	73,680	48,284	13,542	14,842	14,447
Dry	7,226	5,065	4,497	3,396	3,610	12,550	25,972	41,135	22,281	6,680	7,706	6,641
Drought	5,867	3,792	2,983	2,747	2,733	4,112	10,903	17,795	6,063	4,535	4,858	5,392

Average Annual Flow 285,172 AF

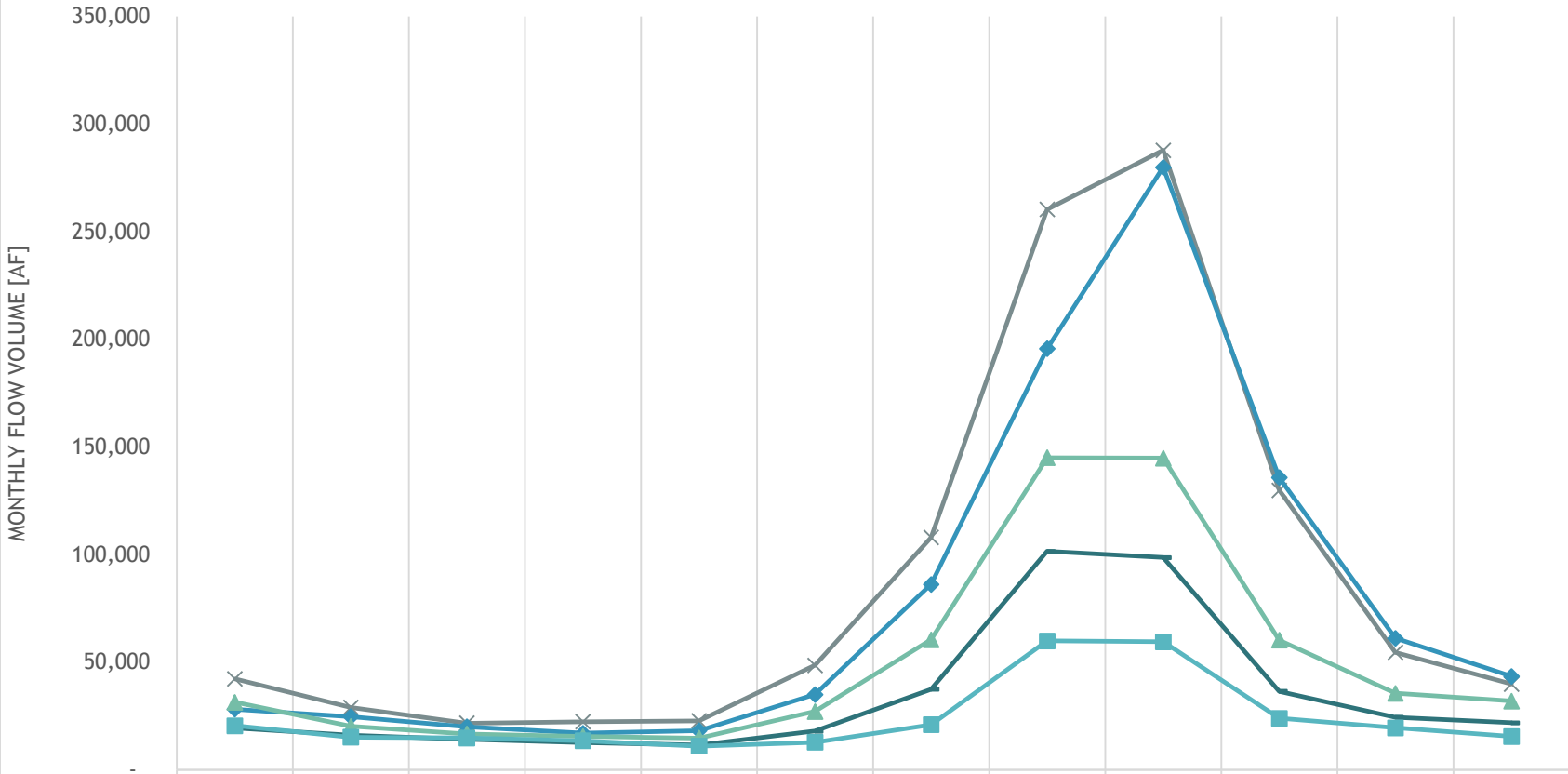
FIGURE 8. PINE RIVER AT BOCA - AVERAGE MONTHLY FLOWS BY HYDROLOGIC YEAR CLASSIFICATION (WY 1952 TO 2012)



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flood	21,752	19,640	11,248	7,959	7,280	24,722	58,940	77,467	83,575	34,731	16,678	18,740
Wet	12,586	10,154	9,792	6,044	9,445	21,588	38,638	52,111	57,240	34,491	26,308	19,173
Average	12,752	7,817	5,758	4,681	5,876	14,629	16,890	19,340	20,744	12,746	11,965	11,975
Dry	7,438	3,293	3,721	3,402	4,152	6,368	4,841	6,222	6,937	9,223	8,863	6,700
Drought	7,256	4,337	2,827	2,386	2,286	2,993	2,295	3,230	4,912	4,400	4,234	3,839

Average Annual Flow 168,316 AF

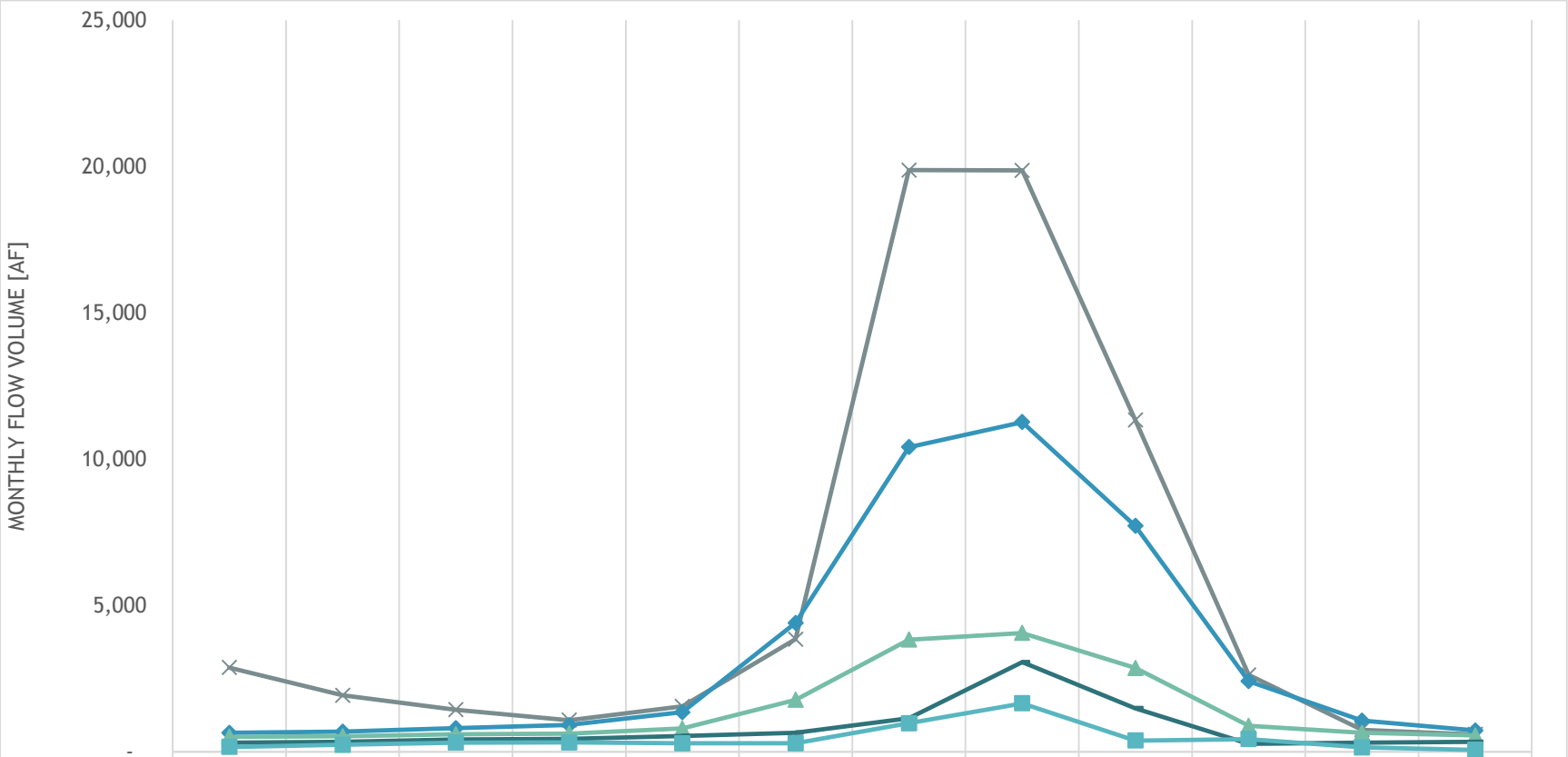
FIGURE 9. ANIMAS RIVER AT THE STATE LINE - AVERAGE MONTHLY FLOWS BY HYDROLOGIC YEAR CLASSIFICATION (WY 1950 TO 2012)



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flood	42,264	28,973	21,601	22,323	22,726	48,540	107,890	260,344	287,766	129,853	54,519	39,848
Wet	28,125	24,668	20,002	17,033	18,208	34,954	86,135	195,587	279,900	135,705	61,122	43,443
Average	31,372	20,206	16,671	15,511	14,728	27,098	60,388	144,984	144,748	60,213	35,538	31,928
Dry	19,451	16,028	14,099	12,676	11,486	17,997	37,387	101,520	98,604	36,415	24,407	21,839
Drought	20,442	15,165	14,794	13,502	10,995	12,781	20,931	59,859	59,456	23,900	19,496	15,489

Average Annual Flow 641,273 AF

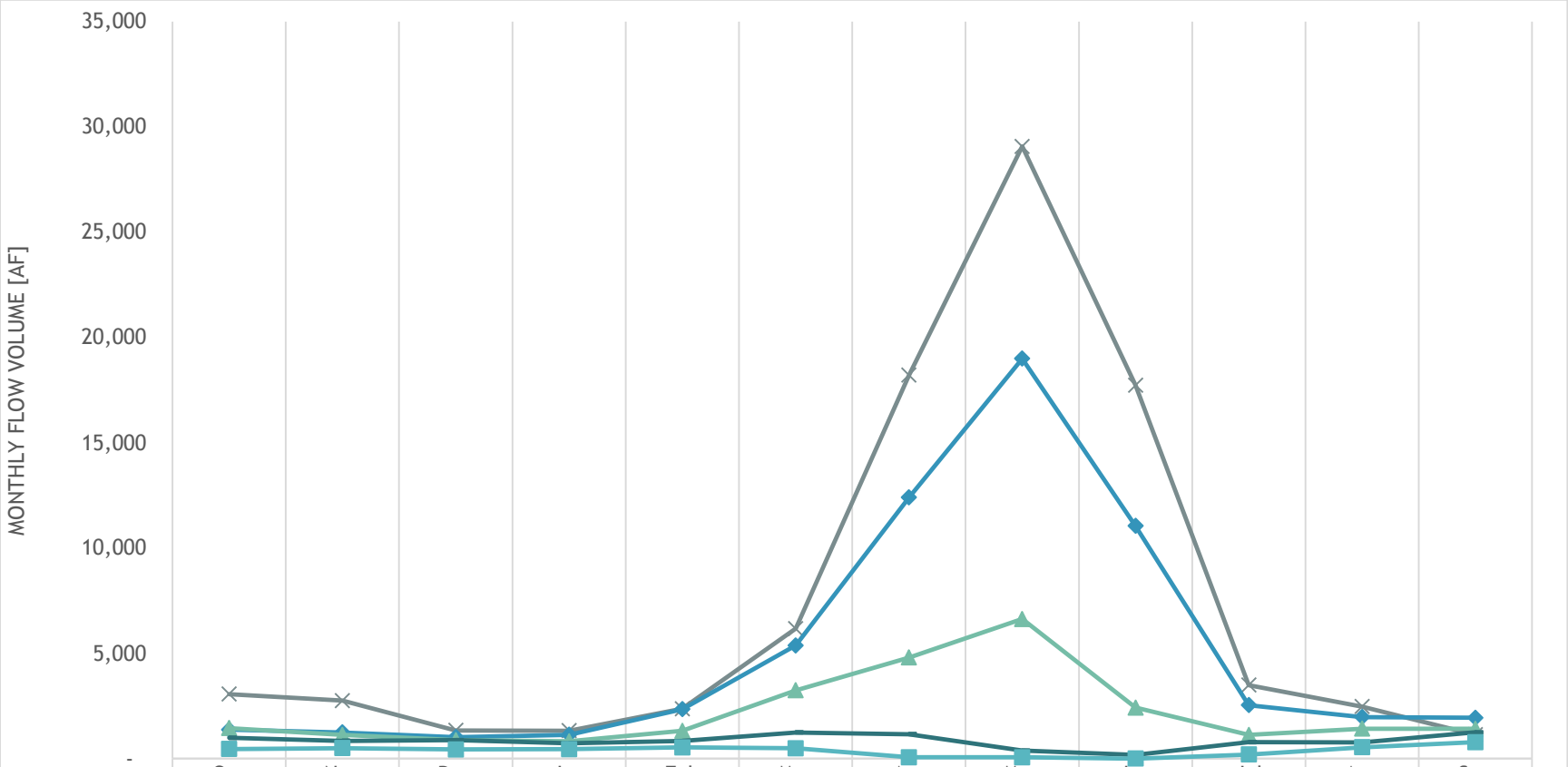
FIGURE 10. LA PLATA RIVER AT THE STATE LINE - AVERAGE MONTHLY FLOWS BY HYDROLOGIC YEAR CLASSIFICATION (WY 1950 TO 2012)



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flood	2,878	1,925	1,434	1,077	1,548	3,843	19,875	19,866	11,332	2,623	750	589
Wet	643	683	802	912	1,349	4,400	10,411	11,263	7,717	2,410	1,061	724
Average	508	527	597	620	791	1,773	3,827	4,056	2,862	882	643	553
Dry	307	335	422	435	538	651	1,139	3,060	1,484	267	305	335
Drought	164	238	311	317	289	287	975	1,654	379	432	150	64

Average Annual Flow 23,153 AF

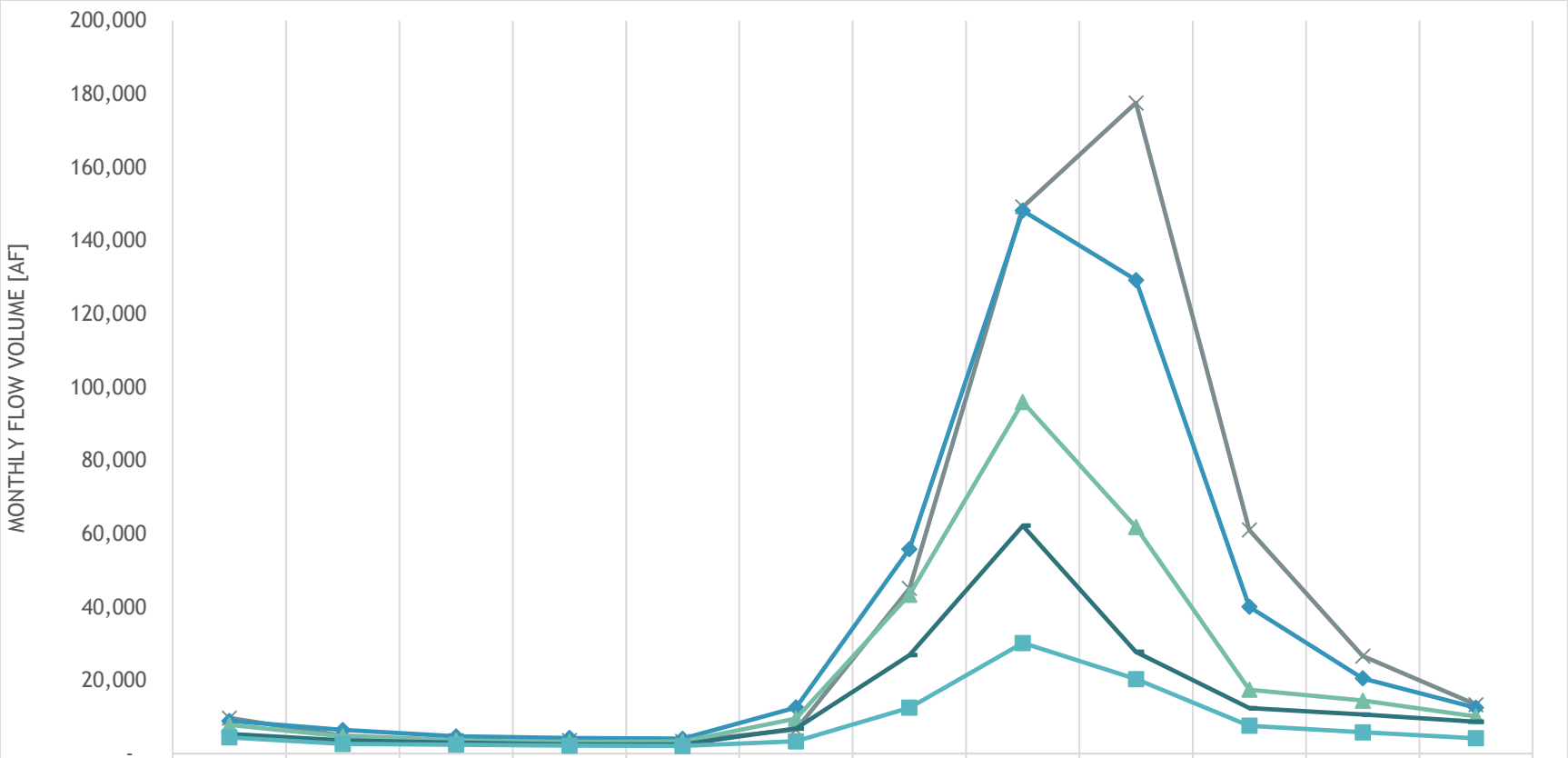
FIGURE 11. MANCOS RIVER AT TOWAOC - AVERAGE MONTHLY FLOWS BY HYDROLOGIC YEAR CLASSIFICATION (WY 1952 TO 2011)



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flood	3,065	2,757	1,342	1,322	2,369	6,176	18,210	29,072	17,733	3,494	2,469	1,135
Wet	1,377	1,244	1,020	1,134	2,344	5,375	12,400	18,997	11,049	2,539	1,977	1,942
Average	1,451	1,123	878	819	1,322	3,240	4,805	6,629	2,423	1,127	1,424	1,413
Dry	989	842	875	733	835	1,245	1,157	384	178	781	775	1,248
Drought	459	495	439	447	532	493	62	66	-	195	538	779

Average Annual Flow 32,688 AF

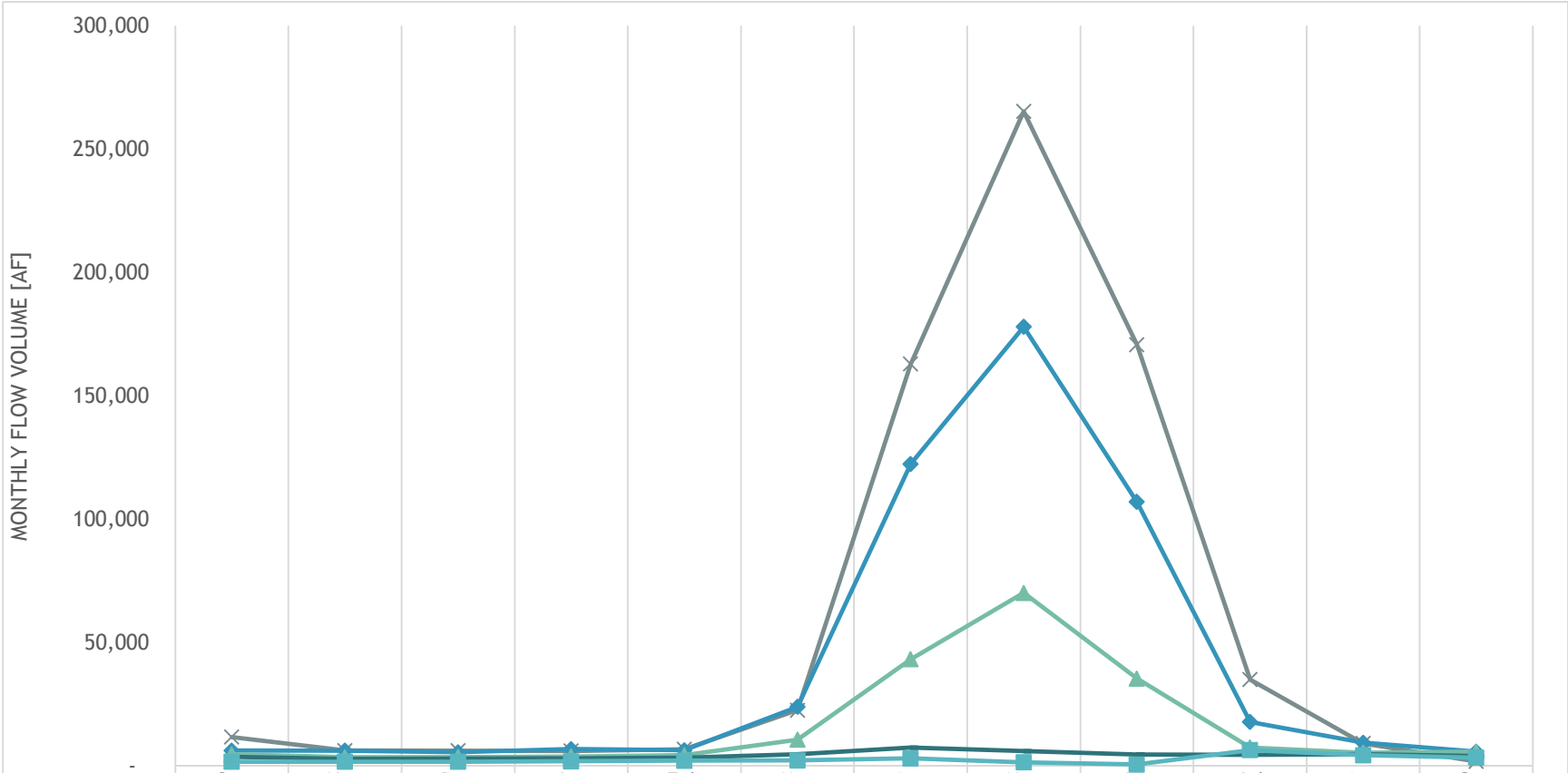
FIGURE 12. DOLORES RIVER NEAR DOLORES - AVERAGE MONTHLY FLOWS BY HYDROLOGIC YEAR CLASSIFICATION (WY 1950 TO 2012)



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flood	9,679	4,872	3,550	3,564	3,308	6,497	45,047	149,167	177,543	60,996	26,586	13,317
Wet	8,898	6,409	4,672	4,223	4,026	12,591	55,816	148,135	129,226	40,054	20,519	12,514
Average	7,777	4,726	3,559	3,187	3,235	9,518	43,317	95,929	61,800	17,435	14,458	10,111
Dry	5,334	3,563	2,989	2,484	2,471	6,826	26,848	62,168	27,724	12,385	10,650	8,694
Drought	4,419	2,630	2,416	2,134	2,048	3,317	12,515	30,166	20,335	7,568	5,804	4,156

Average Annual Flow 291,488 AF

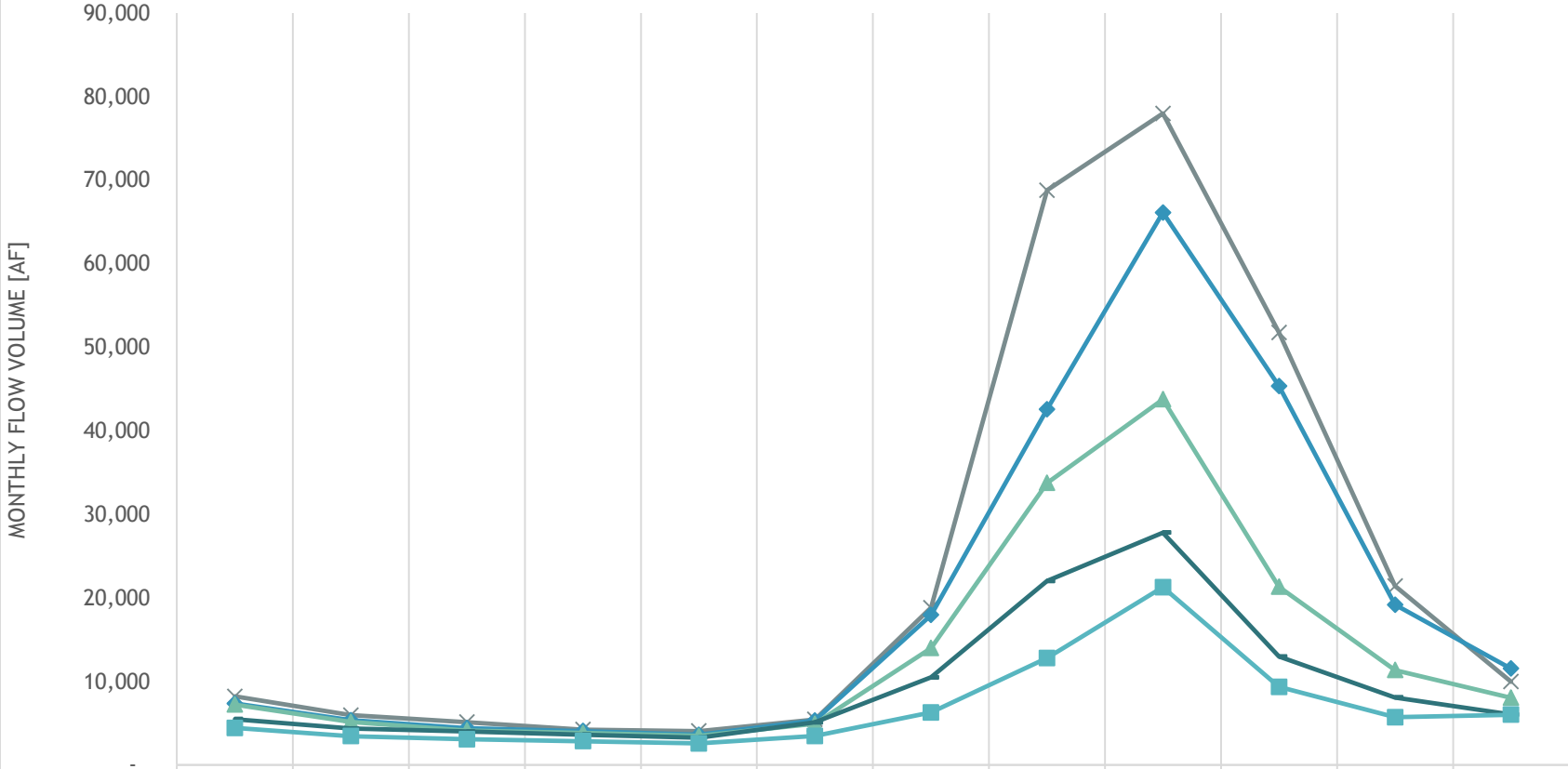
FIGURE 13. DOLORES RIVER NEAR BEDROCK - AVERAGE MONTHLY FLOWS BY HYDROLOGIC YEAR CLASSIFICATION (WY 1972 TO 2012)



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flood	11,610	6,127	6,054	5,907	6,613	22,496	162,805	265,220	170,654	34,879	9,003	1,704
Wet	6,086	6,039	5,391	6,675	6,238	23,837	122,293	177,912	106,916	17,692	9,285	5,658
Average	4,590	3,411	3,462	3,684	4,259	10,550	43,144	70,010	35,311	7,360	5,216	5,623
Dry	3,498	2,742	2,832	2,982	3,146	4,572	7,260	5,895	4,502	4,330	4,647	3,904
Drought	1,599	1,585	1,556	1,736	1,970	2,110	2,938	1,356	452	6,303	4,200	3,257

Average Annual Flow 247,213 AF

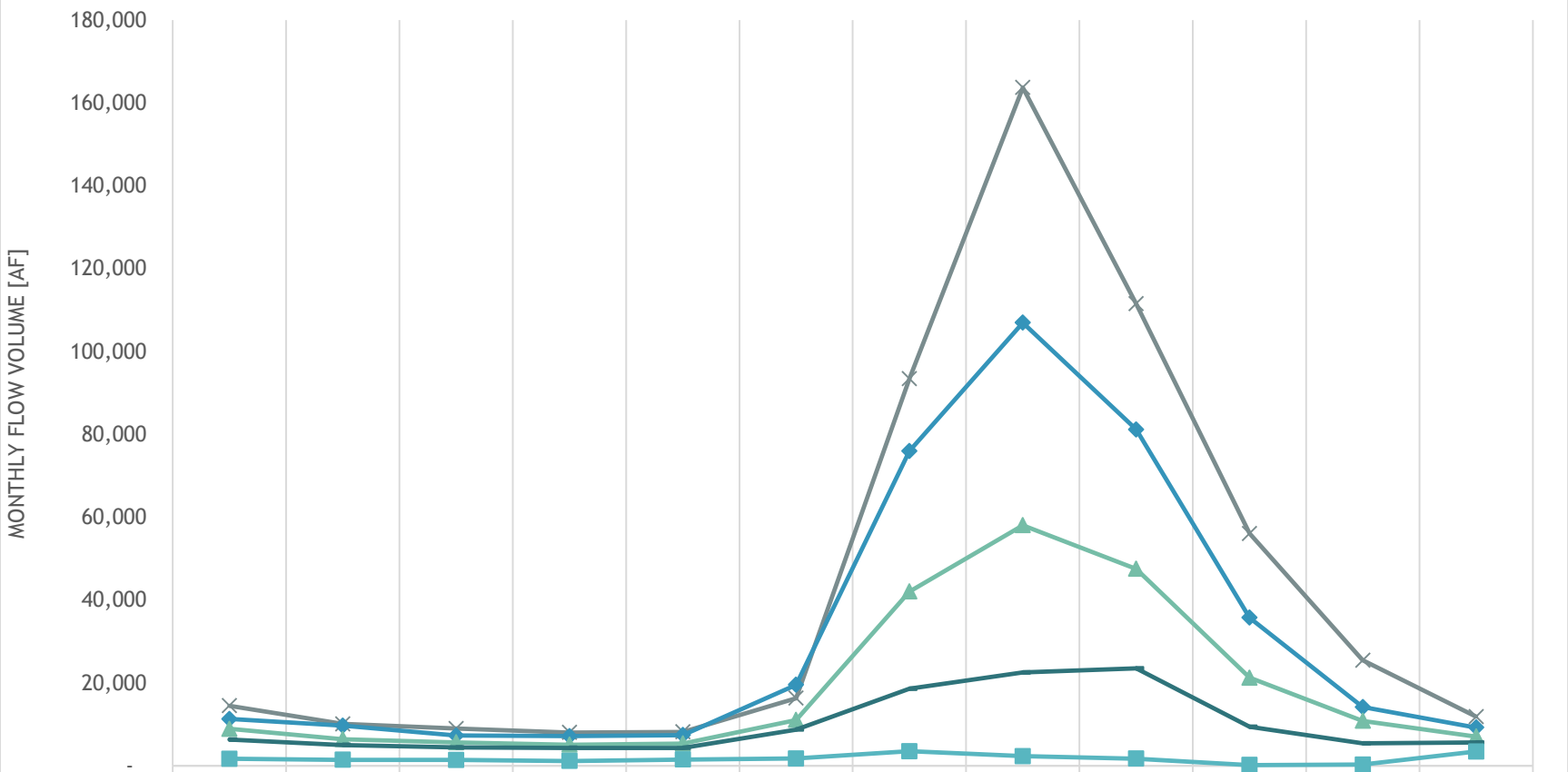
FIGURE 14. SAN MIGUEL RIVER NEAR PLACERVILLE - AVERAGE MONTHLY FLOWS BY HYDROLOGIC YEAR CLASSIFICATION (WY 1950 TO 2012)



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flood	8,203	5,975	5,133	4,243	4,066	5,452	18,819	68,796	77,993	51,777	21,427	9,965
Wet	7,359	5,360	4,426	4,069	3,613	5,324	17,948	42,584	66,126	45,367	19,175	11,533
Average	7,230	5,146	4,134	3,821	3,479	4,935	14,001	33,769	43,780	21,336	11,358	8,051
Dry	5,486	4,359	4,001	3,625	3,270	5,118	10,485	22,034	27,824	12,992	8,090	6,037
Drought	4,443	3,452	3,081	2,844	2,582	3,482	6,280	12,810	21,278	9,342	5,710	6,017

Average Annual Flow 244,390 AF

FIGURE 15. SAN MIGUEL RIVER NEAR URAVAN - AVERAGE MONTHLY FLOWS BY HYDROLOGIC YEAR CLASSIFICATION (WY 1952 TO 2012)



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Flood	14,494	10,111	8,987	8,033	8,182	16,316	93,432	163,692	111,516	56,071	25,470	11,879
Wet	11,286	9,703	7,303	7,154	7,424	19,554	75,975	106,942	81,171	35,746	14,177	9,241
Average	8,919	6,426	5,646	5,108	5,390	11,069	42,065	58,072	47,541	21,260	10,829	7,069
Dry	6,325	5,015	4,410	4,314	4,333	8,735	18,581	22,543	23,514	9,394	5,397	5,608
Drought	1,682	1,432	1,410	1,175	1,507	1,745	3,517	2,316	1,730	188	281	3,439

Average Annual Flow 168,244 AF

3.5 PREDICTED FUTURE HYDROLOGY

Phase I of the Colorado Water Availability Study (CRWAS) considered five climate change scenarios, all treated as if they were equally probable. Preliminary findings of the CRWAS show that compared to current conditions, projected future climate conditions may lead to a number of changes in the Colorado River basin within western Colorado (the "Study Area"). According to the Colorado Drought Mitigation and Response Plan, Annex C. Climate Change Implications (CWCB 2013), some of the projected conditions directly pertinent to the Southwest Basin include changes in temperature, precipitation, crop irrigation requirement, and hydrology as summarized below.

TEMPERATURE

- Each of the five climate projections shows an increase in average annual and monthly temperature within the Study Area, with average annual increases ranging from 1.8°F to 5.2°F.

PRECIPITATION

- Generally increases in the winter months and decreases in the summer months.
- Average winter increases are smaller in the southwestern portion of the Study Area.
- Increase in temperatures causes a shift from snow to rain in the early and late winter months.
- Study Area winter average changes by 102% to 116% of historical.
- Study Area April through October average changes by 82% to 105% of historical.

CROP IRRIGATION REQUIREMENT (BASED ON ACREAGE AND CROP TYPES IDENTIFIED IN A 1993 ACREAGE INVENTORY)

- Increases throughout the Study Area for all climate projections (average annual increase by 1.9 to 7.4 inches depending on projection).
- Increases are primarily due to higher temperature and lower irrigation-season precipitation, which increase the number of growing season days for perennial crops, and crop demand for irrigation water.
- Peak CIR continues to occur in the same month as it has historically.
- Study Area average annual growing season increases by 8 to 32 days.

CLIMATE-ADJUSTED HYDROLOGY

- At over 80% of the sites, the majority of climate cases suggest a decrease in annual flow.
- Annual flow is more likely to increase in parts of the Yampa basin and at some higher elevations.
- Annual flow is more likely to decrease in southwestern watersheds and at lower elevations.

- At 75% of locations, all climate cases showed a shift toward earlier runoff, and at all locations, some climate cases showed a shift toward earlier runoff. Runoff shifts earlier by an average of 8 days.

MODELED STREAMFLOW

- Flows are generally higher than historical in May and June and lower in July through March.
- The historical annual low flow values generally fall within the range of projected low-flow values.

WATER AVAILABLE TO MEET FUTURE DEMANDS

- Upstream locations on main rivers and smaller tributaries generally have less flow available to meet future demands as a percent of modeled streamflow than gages farther downstream that include more tributary inflow.
- Most locations show less water availability for three of the five climate projections, although one projection shows more water available at the locations selected to display CRWAS results.
- Generally more water availability in April and May, corresponding to the shift in natural flow hydrographs.
- The historical annual minimum water availability values generally fall within the range of projected minimum water availability values for 2040 throughout the Study Area.

MODELED RESERVOIR STORAGE

- Earlier peak runoff, reduced flows during the peak irrigation season, and increased crop demands result in more use of water in reservoirs, resulting in more reservoir fluctuation.
- Reservoirs are generally drawn down to lower levels, and generally fill to historical levels.

MODELED CONSUMPTIVE USE

- Average annual consumptive use in the San Juan basin is less for every climate projection.
- Projected consumptive use in the San Juan generally increases in spring months only.

- Total consumptive use for the Study Area is greater than for historical climate conditions for most climate projections.
- Although modeled consumptive use generally increases, not all crop demands are met in any basin. Similar to historical conditions, there continue to be water shortages on tributaries and in the late irrigation season for the projected conditions.

In order to allow a better understanding of how projected, climate-impacted stream flows differ from historic and prehistoric conditions, the 2013 update to the Colorado Drought Mitigation

and Response Plan (CWCB) developed graphs to compare the prehistoric, historical, and projected flows. These graphs provide the long-term context within which to consider the 56-year period experienced from 1950 through 2005. They also suggest the need for adaptations to meet future needs.

The projections of future streamflow were obtained for a number of locations in the Colorado, South Platte and Arkansas rivers' basins. Reconstructions of prehistoric flows have been made for a large number of stream gauges in Colorado (NOAA, 2013). Sixteen locations were selected where both climate change projections and prehistoric reconstructions exist, including the Dolores and Animas rivers in the Southwest Basin.

Figure 16 shows the comparison for the Animas River at Durango and Figure 17shows the comparison for the Dolores River. The 56 year running average of the prehistoric reconstruction (paleo data) is the solid blue line. The end of the solid blue line represents average conditions over the most recent 56 years. The dashed lines show the averages for each climate-impacted flow scenario. Both graphs show that all projected scenarios fall outside of the highest and lowest 56-year average flows in the prehistoric reconstruction, and seven of the eight projected scenarios are below the historical average flow, indicating that the projections of future flows are drier.

The Colorado Drought Mitigation and Response Plan points out that "because there is greater scientific confidence in the quantification of prehistoric flows than in the quantification of projected flows, there is a better scientific basis to support adaptation measures based on the variability of prehistoric flows. On both the Animas and the Dolores rivers, all of the projections fall outside the range of the prehistoric flows, and suggesting that decisions regarding adaptation should primarily consider the projections of future flow in order to develop management strategies that will meet future needs.

The Plan also notes that "it is important to keep in mind that these comparisons use 56 year average flows. Annual droughts, and multi-year spells will be superimposed on the average flows, so the curves and projections do not represent the most severe conditions that may face a system."

FIGURE 16. COMPARISON OF HISTORIC AND PREHISTORIC FLOW RECONSTRUCTION TO AVERAGE FUTURE FLOW PROJECTIONS FOR THE ANIMAS RIVER AT DURANGO, FROM THE COLORADO DROUGHT MITIGATION AND RESPONSE PLAN (CWCB 2013)

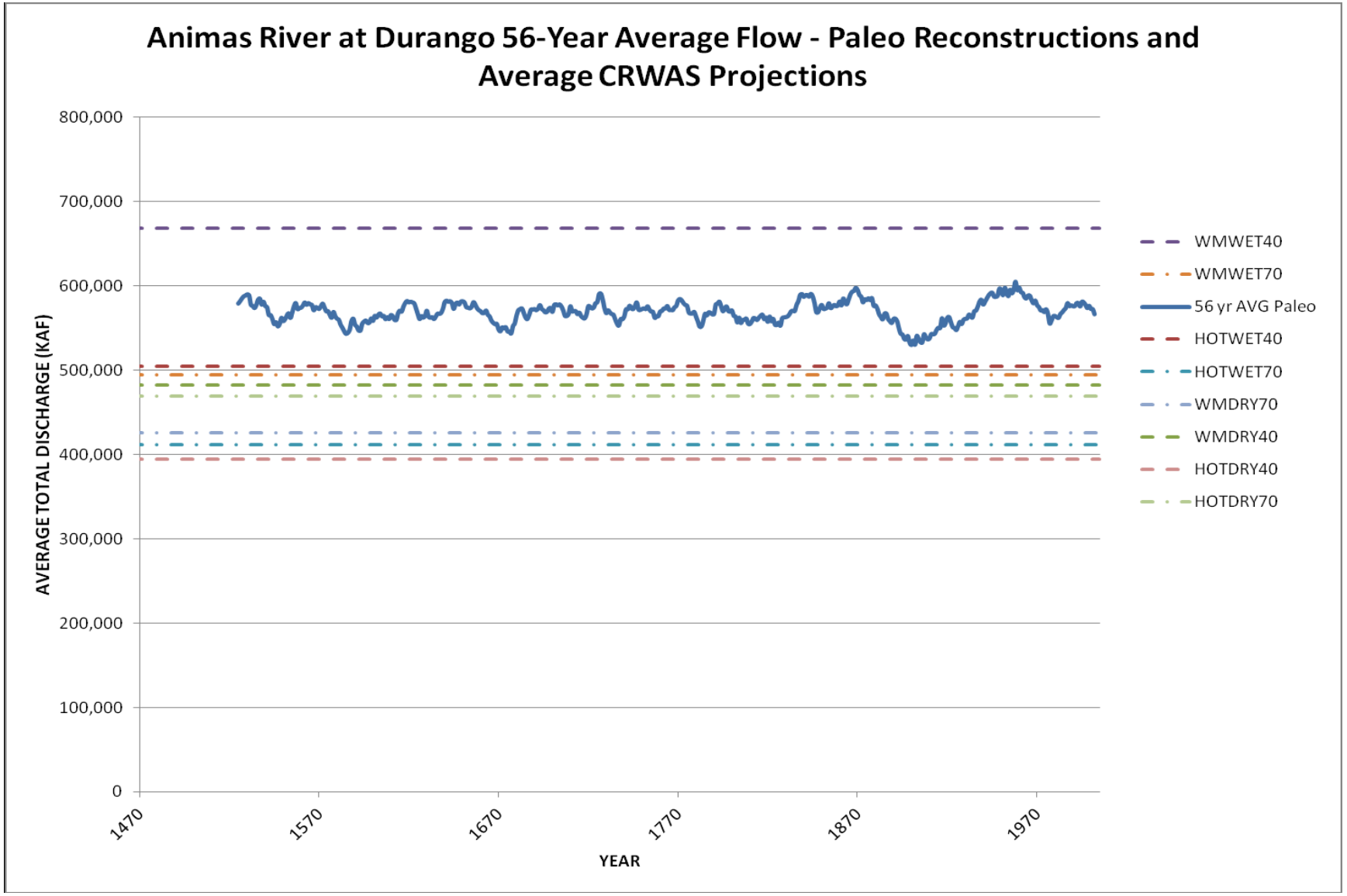
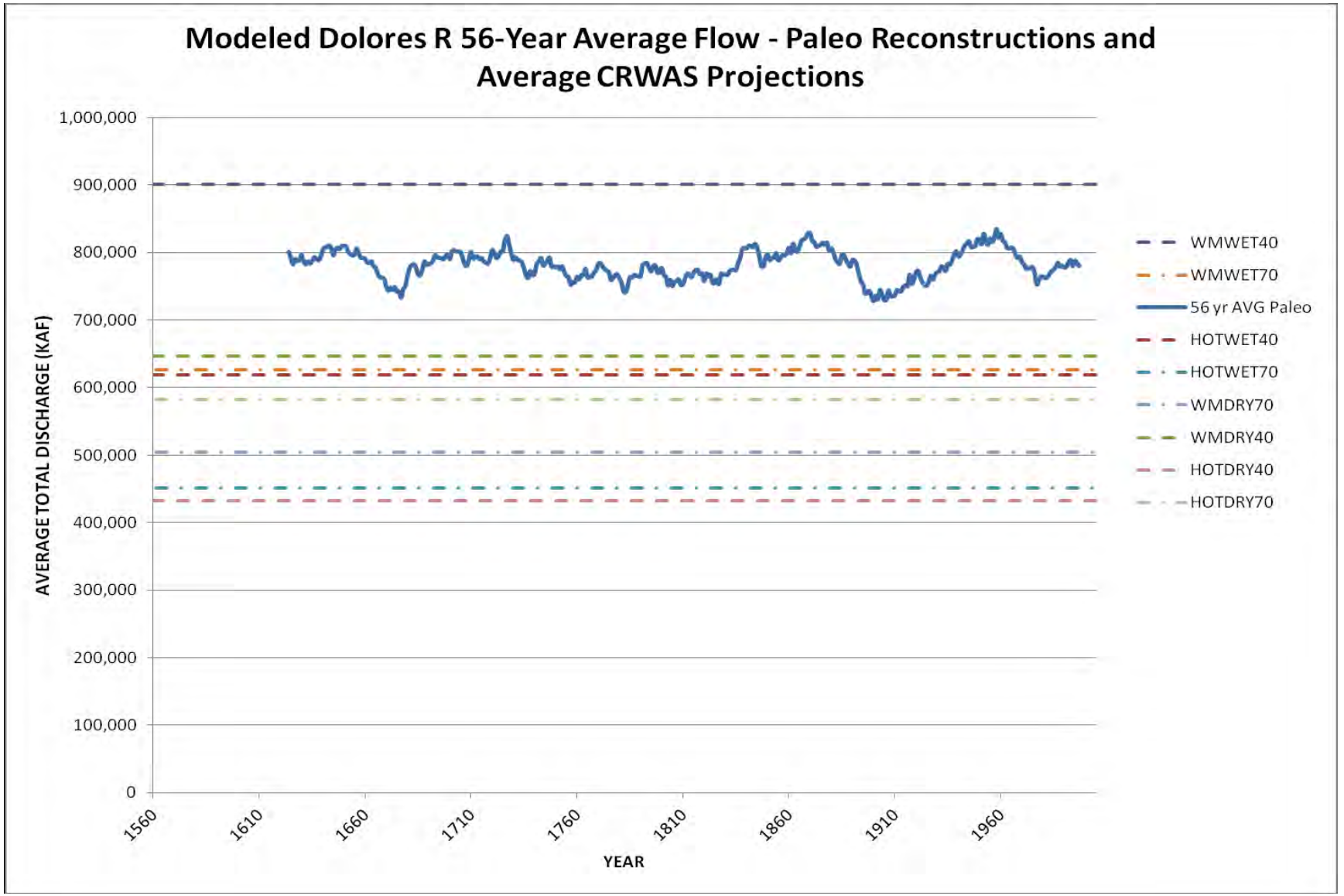


FIGURE 17. COMPARISON OF HISTORIC AND PREHISTORIC FLOW RECONSTRUCTION TO AVERAGE FUTURE FLOW PROJECTIONS FOR THE DOLORES RIVER, FROM THE COLORADO DROUGHT MITIGATION AND RESPONSE PLAN (CWCB 2013)



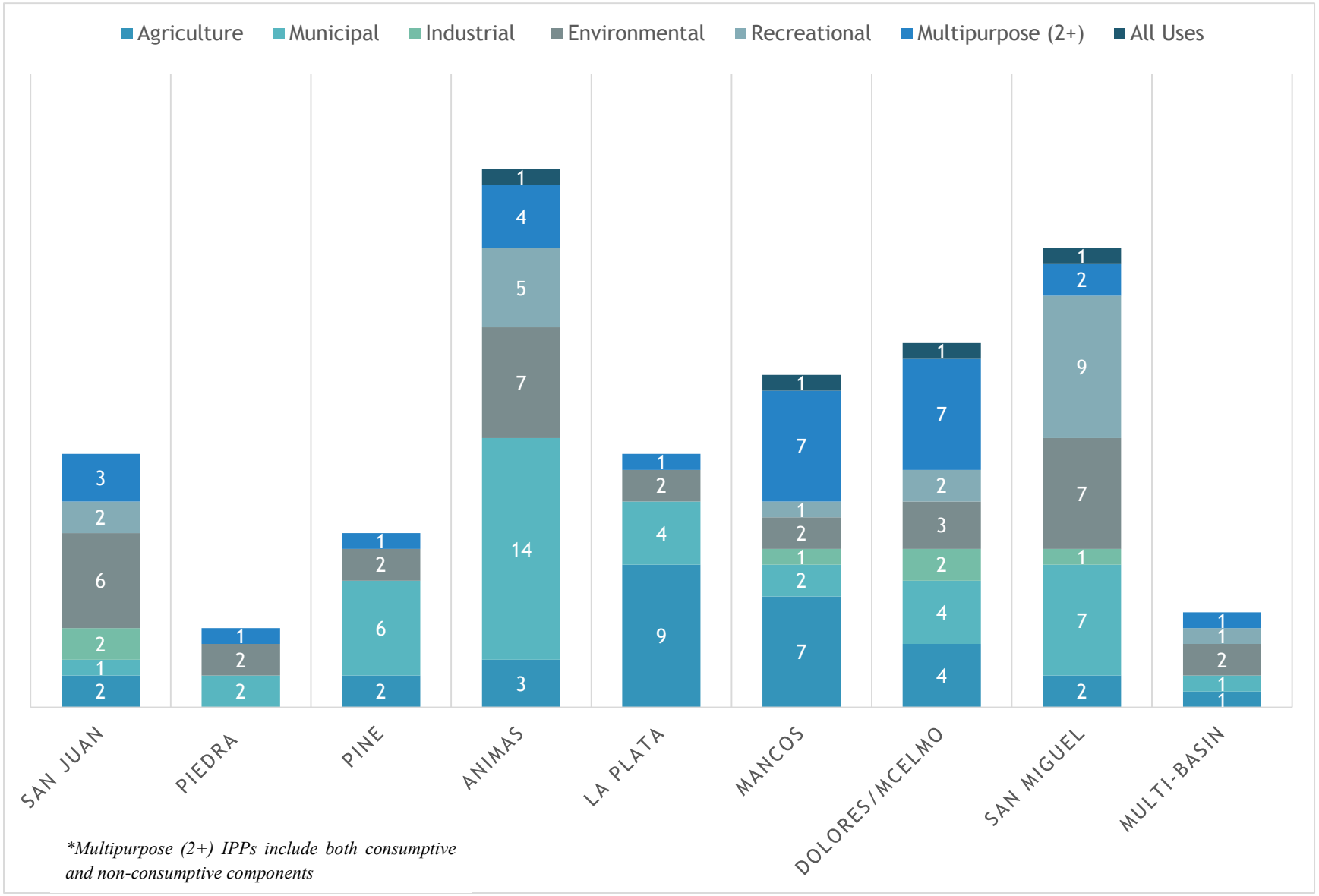
SECTION 4: PROJECTS & METHODS

The SWSI 2010 Identified Projects and Processes (IPP) list went through an in depth updating process for inclusion into the BIP. The BIP consultants outreached to over 200 people across the nine sub-basins requesting updates and identification of new IPPs. The following sections describe outreach efforts, and provide a summary of current IPPs, as well as conceptual IPPs. Conceptual IPPs are ideas for projects or processes that people or entities within the sub-basin have, but which do not yet have a sponsor who is actively pursuing implementation of the concept.

For a complete list of the IPPs for all sub-basins please reference Appendix A. The Roundtable takes a collaborative approach to treat all types of IPP equally and to evaluate them equally for all environmental, agricultural, recreational, municipal, industrial, and multi-purpose needs. Figure 18 presents the IPPs as sorted by sub-basin and type of need. The IPPs are sorted by the following types of need: agricultural, municipal, industrial, environmental, recreational, multipurpose (addressing at least one consumptive and one non-consumptive need), all uses, and multi-basin (e.g. agricultural efficiency projects or hydropower development).

Agricultural IPPs make up about 19% of the total IPPs on the list to date. Municipal and industrial IPPs make up about 29% of the total IPPs on the list to date. Environmental IPPs make up about 21% of the total IPPs while recreational IPPs make up about 12% of the IPPs on the list today. There are about 17% that are considered multipurpose with a consumptive and non-consumptive component. The IPPs are almost equally split between consumptive and non-consumptive projects and/or processes.

FIGURE 18. IPPS SORTED BY SUB-BASINS AND TYPE OF NEEDS



4.1 EDUCATION, PARTICIPATION & OUTREACH

This section provides a summary of the Roundtable Education Action Plan (EAP) activities both completed and planned. Specifically, this section provides information on how the Roundtable informed local decision makers and the public about the CWP. This section includes: number and locations of public meetings (or sessions at regular Roundtable meetings), as well as number of attendees and recorded demographics/professional affiliations; additional engagement mechanisms and related outreach; other notable features of the Roundtable outreach activities; and a 2015 and long-term (2016-2020) EAP, including budget.

NUMBER AND LOCATIONS OF PUBLIC MEETINGS

There is a half hour social networking opportunity before each of the Roundtable meetings that the public is invited to and they are also invited to attend the Roundtable meetings themselves. The demographic/professional affiliations of the general public attendees are recorded in each of the Roundtable meeting minutes. Starting when the BIP planning process began in the fall of 2013. The number of public in attendance at the Roundtable meetings breaks down as follows:

- November 2013: 31 public in attendance; 25 members in attendance
- January 2014: 15 public in attendance; 25 members in attendance
- March 2014: 22 public in attendance; 22 members in attendance
- May 2014: 21 public in attendance; 20 members in attendance
- July 2014: 20 public in attendance; 24 members in attendance
- September 2014: 16 public in attendance; 21 members in attendance
- November 2014: 20 public in attendance; 26 members in attendance
- January 2015: 22 public in attendance; 23 members in attendance

Roundtable members also help conducted four public outreach meetings specific to the BIP and CWP. These meetings were held across the Southwest Basin in the winter of 2014. The meetings provided the public with presentations on the CWP and BIP along with discussion topics to spur public participation and input. The meetings were a great success in understanding the public's concerns and interests as they relate to water development and uses within the Southwest Basin. Appendix B contains meeting presentations, sign in sheets, and meeting notes.

- November 17, 2014 meeting was held in Pagosa Springs; 16 plus people in attendance
- November 19, 2014 meeting was held in Bayfield; 14 plus people in attendance
- December 1, 2014 meeting was held in Mancos; 30 plus people in attendance
- December 9, 2014 meeting was held in Placerville; 15 plus people in attendance

In addition, information about the Interbasin Compact Committee (IBCC)/Roundtable process and the CWP, including updates, has been presented at many local events (e.g. Kiwanis, Rotary, etc.), most local water board meetings (e.g. Animas-La Plata Water Conservancy District, Dolores Water Conservancy District, San Juan Water Conservancy District, Southwestern Water Conservation District, etc.), the annual Water 101 Seminar, and the annual *Water in the West Art Show*. Local presentations included:

- Kate McIntire (CWCB), Kristin Maharg (CFWE), and Denise Rue-Pastin (WIP) conducted a one hour public education and outreach workshop session prior to the November 2013 Roundtable meeting. The majority of roundtable members and some public were in attendance and it was well received. In addition, the importance of public education and outreach was discussed as an agenda item during this meeting.
- Denise Rue-Pastin made a presentation to the Durango Kiwanis Club (approximately 30 in attendance) on November 12, 2013 that provided an extensive discussion of the CWP, including a wide variety of handouts.
- Denise Rue-Pastin provided a presentation at the Durango High Noon Rotary meeting on March 27, 2014 (approximately 50 in attendance) that provided an extensive discussion of the CWP, including a wide variety of handouts.
- Mike Preston, General Manager of the Dolores Water Conservancy District, made presentations (including handout materials) to the Montezuma Valley Irrigation Company Board of Directors and staff (approximately 40 in attendance) on April 8, 2014 and the Dolores Water Conservancy District Board of Directors and staff (approximately 35 in attendance) on April 10, 2014.
- Bruce Whitehead, Executive Director of Southwestern Water Conservation District, provided CWP information at a 4CORE meeting on May 1, 2014 (approximately 15 in attendance).
- Rod Profitt, Board President for San Juan Water Conservancy District, made a CWP presentation on May 7, 2014 to the Pagosa Springs Town Council (approximately 25 in attendance).
- Rod Profit and Val Valentine provided a CWP information session at the Archuleta County Board of Commissioners meeting on May 14, 2014 (approximately 15 in attendance).
- Rod Profitt attended the regularly scheduled June 2014 meeting of the Pagosa Area Water and Sanitation District to provide information on the CWP (approximately 30 in attendance).
- Rod Profitt attended the regularly scheduled June 2014 meeting of the Park Ditch Company to provide CWP information (approximately 20 in attendance).
- Mike Preston presented CWP information at the Club 20 Meeting at La Plata Electric Association on July 31, 2014 (approximately 30 in attendance).
- Mike Preston presented Southwest Basin Roundtable perspectives at the SB115 Legislative Hearing in Durango on August 27, 2014 (approximately 100 in attendance).
- CWP and Roundtable information were presented at the Annual Water 101 Seminar on September 22, 2014 in Telluride (approximately 70 in attendance).
- April Montgomery and Mike Preston provided the Dolores Conservation District with a CWP and Roundtable update at their December 5, 2014 meeting (approximately 25 in attendance).
- Mike Preston provided the Mancos Conservation District with a CWP and Roundtable update at their December 6, 2014 meeting (approximately 20 in attendance).

- Various roundtable members participated in and provided CWP input at the December 18, 2014 West Slope Caucus in Grand Junction (approximately 150 in attendance).
- Bruce Whitehead presented CWP information to the Kiwanis on February 12, 2015 in Durango (approximately 50 in attendance).
- Rod Proffitt presentation to the Archuleta Board of County Commissioners, which updated them on Dry Gulch, noting that Dry Gulch is an IPP and part of BIP in the CWP (approximately 25 in attendance).
- Bruce Whitehead presented CWP information to the Pagosa Springs Rotary on February 19, 2015 (approximately 50 in attendance).

ADDITIONAL ENGAGEMENT MECHANISMS AND RELATED OUTREACH

Area newspapers are invited to each of the Roundtable meetings and various local papers periodically ran information pieces related to the CWP and the importance of public input. Examples include the Cortez Journal (Circulation: 7,500; Geographic area: Predominantly the Cortez/Dolores/Mancos areas), the Durango Herald (Circulation: 9,400; Geographic area: Nine-county Dolores/San Juan River Basin), and the Pine River Times (Circulation: 1,600; Geographic area: Predominantly the Bayfield area). The WIP website has over 100 newspaper articles posted that specifically reference the CWP. A sampling of those articles includes:

- February 12, 2015: Colorado water plan can't create more H20 (Aspen Daily News)
- December 14, 2014: Colorado needs this water plan (Times Call)
- December 10, 2014: Colorado water plan draft goes to Hickenlooper to address shortfall (Denver Post)
- December 9, 2014: Southwest Basin Water Roundtable holds meetings to discuss plan (Cortez Journal)
- November 26, 2014: Statewide water plan taking shape (Pine River Times)
- November 6, 2014: State water planning is 'evolutionary' (Grand Junction Sentinel)
- October 14, 2014: 18,000 Coloradans call on water board for strong conservation and efficiency in state water plan (Groundfloor Media)
- October 11, 2014: How will Colorado's water plan address West-East water transfers? (Post Independent)
- September 11, 2014: State water plan must include recreation economy (Post Independent)
- September 4, 2014: State Water Plan draws crowd (Pine River Times)
- August 13, 2014: Colorado's Water Plan (KRCC)
- July 29, 2014: The importance of the Colorado Water Plan (ColoradoPols.com)
- July 17, 2014: Colorado's river basin users discuss statewide water plan (KUNC)
- July 9, 2014: Water plan would weigh new diversion projects (Post Independent)
- June 15, 2014: Take the opportunity to make your voice heard in state's water planning (Grand Junction Sentinel)
- June 1, 2014: Conservation, efficiency key to water plan (Soapbox)

- May 29, 2014: Can the state water plan bridge the gap? (Summit Voice)
- May 24, 2014: Draft plan for state's water future released (Aspen Daily Times)
- May 5, 2014: Water planning: What Colorado could learn from Texas (Durango Herald)
- April 11, 2014: Water supply concerns dominate regional seminar (Pine River Times)
- April 8, 2014: Haven't heard of the Colorado Water Plan? (Durango Herald)
- March 7, 2014: Governor pushes state water plan (Durango Herald)
- January 23, 2014: Colorado continues to wrangle over last drop (Durango Telegraph)
- January 30, 2014: Anxiety builds over state water plan (Durango Herald)
- October 30, 2013: Protecting Colorado's water future by Bruce Whitehead (Durango Herald and Southwestern Water Conservation District)



In addition, a local radio station, K-WUF, provided coverage and information on the CWP in May 2014. K-WUF serves all of Archuleta County and parts of La Plata, Hinsdale, and Mineral Counties in Colorado, as well as portions of northwest New Mexico. Moreover, the WIP website provides information on the IBCC/roundtable process, as well as links to provide public input to the CWP.

OTHER NOTABLE FEATURES OF THE ROUNDTABLE OUTREACH ACTIVITIES

The Roundtable wanted local decision makers and the public to understand the status of the Southwest Basin's consumptive and non-consumptive needs as well as planned projects. Related to this, the Roundtable hired a consulting team to work on their BIP. The consultants met with numerous individuals and organizations to obtain input to update the Southwest Basin's consumptive and non-consumptive needs assessment, as well as planned projects related to the BIP. To-date, the BIP consultants have met with and talked to over 200 individuals and organizations throughout the Southwest Basin. The consultants reviewed and have incorporated all public input comments into this BIP.

It should be noted, too, that the Roundtable wanted to promote partnerships for new projects and methods. Therefore, each funding application to the Roundtable is required to provide information related to collaborative efforts, including cost-sharing. Over the years, too, the Roundtable has made numerous recommendations to applicants about potential future partners. Moreover, the BIP consultants continually worked to obtain input and promote partnerships.

In addition, the Roundtable felt it was important that the public understand how they are represented on the Roundtable. Related to this, the CWCB produced a very informative Frequently Asked Questions (FAQs) and fact sheet related to the IBCC and Roundtable process that explained how they are represented. Both pieces were regularly distributed at each of the Roundtable bi-monthly meetings throughout 2013 and 2014. Also, in early January 2014 the CWCB produced a Roundtable fact sheet and that has been disseminated at each of the Roundtable meetings. It was

also sent to the entire Roundtable email list which is distributed to more than 100 individuals and organizations. Roundtable members and the public were asked to widely share the FAQs and fact sheets with their constituents. This information is also available at the WIP office in Durango and has been used extensively and disseminated at various public events.

Due to the natural variability of river flows and the hydrologic cycle, the Roundtable thought it was important that local decision makers and the public understand the potential for dry as well as wet years. Information pieces related to this were disseminated at each of the Roundtable meetings, as well as various events and presentations. Some of those pieces came from or included:

- Cech, T. V. (2010). *Principles of water resources* (3rd ed.). Hoboken, NJ: John Wiley & Sons. [Note: Chapter 3 surface water hydrology, to include river components and morphology]
- Colorado Foundation for Water Education. (2009). *Headwaters: Administering Colorado's water resources scarcity rules.* Denver, CO: Author.
- Grigg, N. S. (2008). *Total water management: Practices for a sustainable future*. Denver, CO: American Water Works Association. [NOTE: Chapter 9—laws and regulations]
- Maxwell, S. (Ed.). (2008). *The business of water: A concise overview of challenges and opportunities in the water market*. Denver, CO: American Water Works Association.

In addition, the CWCB developed a drought factsheet that was continually disseminated at each of the Roundtable meetings. This factsheet, as well as additional informational pieces related to variations in the hydrologic cycle, is available on the WIP website and at the WIP office. They have been disseminated at various functions throughout the roundtable process.

OUTREACH PLAN

It will be important to continue to provide information to local decision makers and the public about the BIP so that people understand the BIP's context and are better able to connect to their role in implementing the BIP. In addition, the Roundtable believes it is important to plan for educational programs that allow for deeper exploration of the important water issues within the Southwest Basin. To those ends, the following provides an outreach/education action plan and budget for 2015, as well as a broader, long-term (five year) plan for outreach:

- Continue with Roundtable meetings currently scheduled for: January 14, 2015, April 8, 2015, July 8, 2015, and October 14, 2015.
- Continue with the public education and participation outreach activities identified in Section 4.1 of this BIP (e.g. local presentations, Annual Water 101 Seminar, newspapers, radio, website, etc.).
- Continue with all of the other notable features of Roundtable outreach activities to include keeping local decision makers and the public informed about consumptive and non-

consumptive needs and planned projects, promoting partnerships, providing information about how they are represented on the Roundtable, and disseminating information on natural variability of river flows and the hydrologic cycle.

The Roundtable's overall goals and priorities for education, participation, and outreach including target audiences are presented in Section 1 of this Plan, a synopsis of which is provided as follows:

Short-Term Goals

- Encourage education and conservation to reduce demand.
- Implement informational events about [water conservation and land-use planning] and water reuse efforts, tools and strategies.
- Promote wise and efficient water use through implementation of municipal conservation strategies to reduce overall future water needs.

Ongoing Activities

- Implement IPPs to benefit recreational values and the economic value they provide.
- Implement IPPs to directly restore, recover or sustain endangered, threatened, and sensitive aquatic and riparian dependent species and plant communities.
- Implement IPPs to monitor, protect or improve water quality.
- Participate in Compact Water Bank efforts.
- Support agricultural water efficiency projects identified as IPPs.
- Support and participate in IPPs that promote dialogue, foster cooperation and resolve conflict.

Mid-and Long-Term Targets

- Mid-Term: Promote 60% in-house use and 40% outside use (60/40 ratio) for Southwest Colorado and the entire State by 2020.
- Long-Term: Promote 70% in-house use and 30% outside use (70/30 ratio) for Southwest Colorado and the entire State by 2030.

One strategy to achieve the short-term goals of conservation, land-use planning (which will include coverage and discussion of the 60/40 and 70/30 ratios referenced above), and water reuse is to implement a pilot conservation and land-use planning session in 2015. Initially it is anticipated that this would be a two to four hour workshop for local decision makers and water utility personnel. Between local water professionals, including a land-use planner and the WIP Coordinator, it is believed the session can be effectively conducted and facilitated at a reasonable cost. Depending upon input from the Roundtable, PEPO funds (estimated to be about $1,200) could be used for this effort. If the first year pilot is successful, the session could be annually

rotated throughout the basin (e.g. Cortez, Telluride, Pagosa Springs, etc.) similar to the Water 101 Seminar. The Roundtable would also like to pursue a similar water conservation workshop approach, to include water-wise landscaping for the general public, however these details have yet to be determined. Strategies to achieve ongoing activities are discussed in the following partnerships section. Mid-and long-term goals will be incorporated in with the short-term water conservation, land-use planning, and reuse workshop already discussed. A breakdown of the budget and schedule to achieve the Roundtable educational goals is provided in Attachment C.

Moreover, the Roundtable will continue with key components identified in their original EAP to include:

- Consumptive Projects: Relay gap information, to include an action plan and public participation process, communicate statewide implications of IPPs, engage diverse stakeholders, and provide assistance and information to the Roundtable members and public related to prioritizing projects.
- Non-Consumptive Projects: Keep the public and Roundtable members informed about non-consumptive projects and help to bridge the consumptive and non-consumptive communities while highlighting progressive, multi-purpose solutions.
- Roundtable Member Education: Provide Roundtable members information and education related to a wide variety of water-related issues and interests (e.g. climate change, drought planning, groundwater hydrology, interstate compacts, water quality regulation, etc.).
- Support and utilize existing water education efforts.

It should be noted, that in addition to all of the Roundtable members and their associated organizations, future partners that could be involved in assisting with educational programming may include the Colorado DWR, CWCB, Animas Watershed Partnership, Mountain Studies Institute, San Juan Citizen's Alliance, Trout Unlimited, and Southwestern Water Conservation District.

This section provided a summary of the Roundtable EAP activities that were conducted in the 2013 to 2014 timeframe. The goal of Roundtable EAP outreach activities to date has been to inform decision makers and the public about the Roundtable process and how they can effectively participate in the CWP. Thus far, it is conservatively estimated that nearly 3,000 members of the public, plus Roundtable members in the Southwest Basin have been informed and/or involved in the CWP and public input process. Constituent support for the BIP will be important to meet future water supply needs. The Roundtable believes that well informed members and the public will help to execute this BIP. The Roundtable plans to continue their public education, participation, and outreach activities well into the future.

TABLE 11. SOUTHWEST BASIN ROUNDTABLE 2015 EAP AND BUDGET

GOAL	OBJECTIVE/TASK	LEAD	TIMELINE	EXPENSE	ONGOING?	COMMENTS
Educate decision makers in the SBR area about how they are represented	a) Regularly distribute FAQs and fact sheet related to the IBCC and roundtable process. b) Purchase and distribute Headwaters Colorado Water Plan issue. c) Purchase and distribute information about the IBCC/roundtable process and the State Water Plan at local events, local water board meetings, and the annual Water 101 Seminar.	Denise Rue-Pastin	Throughout 2015	$800	Yes	
Educational priority	Pilot conservation and land-use planning session	Denise Rue-Pastin	Late Fall 2015	$1,200	Pilot	
Roundtable members and general public information and education related to consumptive and non-consumptive projects and CWP	a) Notify all area papers of Roundtable meeting dates, time, and location; including 'open to the public' invitation	Denise Rue-Pastin	Quarterly meetings 2015	$108	Yes	WIP Coordinator time est.
	b) Post all consumptive and non-consumptive related activities and meetings on WIP website	Denise Rue-Pastin	Throughout 2015	$108	Yes	
	c) Presentations to various local organizations	Varies	Throughout 2015	$125	Yes	Copies and materials
	d) Roundtable information is provided at each Annual Water 101 Workshop	Denise Rue-Pastin	Throughout 2015	$225	Yes	Copies & 75 issues of the CFWE Water Law
	e) Other/Misc			$100		
Roundtable Members Education	a) Drought planning information at Roundtable meeting	Handouts; Speaker TBD	TBD	$125	No, but info needs will be continually assessed	Copies and materials
	b) Climate change information at Roundtable meeting	Handouts; Speaker TBD	TBD	$125	No, but info needs will be continually assessed	Copies and materials
	c) Water quality regulation or groundwater hydrology information at Roundtable meeting	Handouts; Speaker TBD	TBD	$125	No, but info needs will be continually assessed	Copies and materials
	d) Interstate compacts information at Roundtable meeting	Handouts; Speaker TBD	TBD	$125	No, but info needs will be continually assessed	Copies and materials
	e) Other/Misc: Current river operations and opportunities, constraints associated with different hydrologic cycles			$100		
TOTAL				$3,266		

TABLE 12. SOUTHWEST BASIN ROUNDTABLE 2016 TO 2020 EAP AND BUDGET

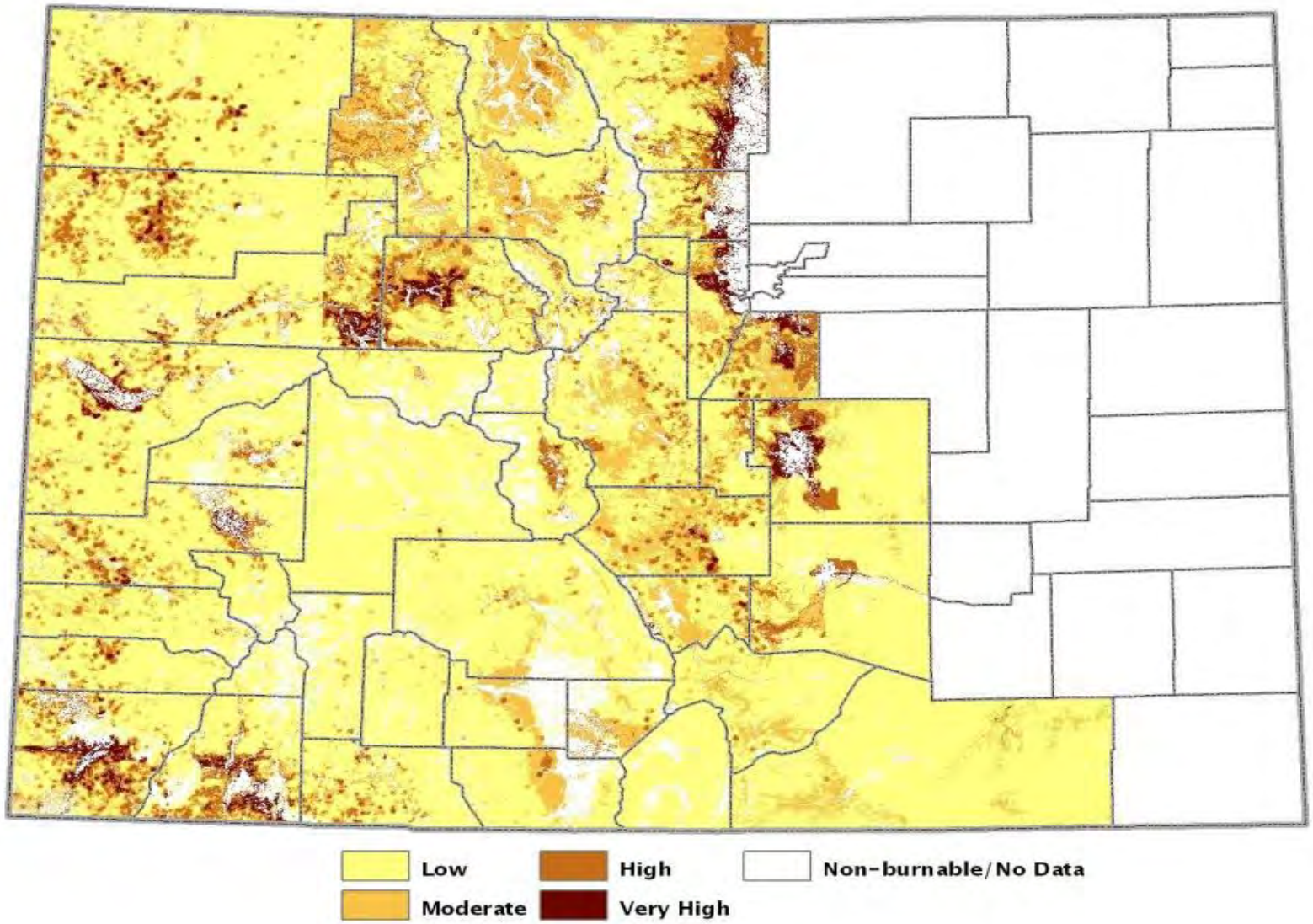
GOAL	OBJECTIVE/TASK	LEAD	TIMELINE	EXPENSE	ONGOING?	COMMENTS
Educate decision makers in the SBR area about how they are represented	a) Regularly distribute FAQs and fact sheet related to the IBCC and roundtable process. b) Purchase and distribute Headwaters Colorado Water Plan issue. c) Purchase and distribute information about the IBCC/roundtable process and the State Water Plan at local events, local water board meetings, and the annual Water 101 Seminar.	Denise Rue-Pastin	2016-2020	$2,400	Yes	
Educational priority	Water conservation workshop, to include water-wise landscaping for the general public	Denise Rue-Pastin	Starting in 2016	$1,200	Pilot	
Roundtable members and general public information and education related to consumptive and non-consumptive projects AND CWP	a) Notify all area papers of Roundtable meeting dates, time, and location; including 'open to the public' invitation	Denise Rue-Pastin	Quarterly meetings 2016-2020	$541	Yes	WIP Coordinator time est.
	b) Post all consumptive and non-consumptive related activities and meetings on WIP website	Denise Rue-Pastin	2016-2020	$541	Yes	
	c) Presentations to various local organizations	Varies	2016-2020	$625	Yes	Copies and materials
	d) Roundtable information is provided at each Annual Water 101 Workshop	Denise Rue-Pastin	2016-2020	$1,125	Yes	Copies, plus 75 issues of the CFWE Water Law
	e) Other/Misc			$500		
Roundtable members education	a) Information on a variety of topics at Roundtable meetings	Handouts; Speaker TBD	TBD	$625	No, but info needs will be continually assessed	Copies and materials
	b) Other/Misc:			$500		
Support and utilize existing water education partners and efforts	a) All Roundtable meetings are posted on WIP website and in quarterly newsletters	Denise Rue-Pastin	2016-2020	$541	Yes	WIP Coordinator time est.
	b) There is a Roundtable update section in each of the WIP quarterly newsletters	Denise Rue-Pastin	2016-2020	$947	Yes	WIP Coordinator time est.
	c) There is a Roundtable tab/section on the WIP website	Denise Rue-Pastin	2016-2020	$947	Yes	WIP Coordinator time est.
	d) Water information provided at each of the Roundtable meetings on an information table	Denise Rue-Pastin	2016-2020	$625	Yes	Copies
	e) Other organizations that could help with efforts (e.g. CDWR, CWCB, SJCA, SWCD, etc.)	Varies	2016-2020	N/A	Yes	
	f) Other/Misc.			$500		
TOTAL				$11,617		

4.2 WATERSHED HEALTH & WATER QUALITY

CHECK IT OUT!
http://www.coloradowildfirerisk.com/

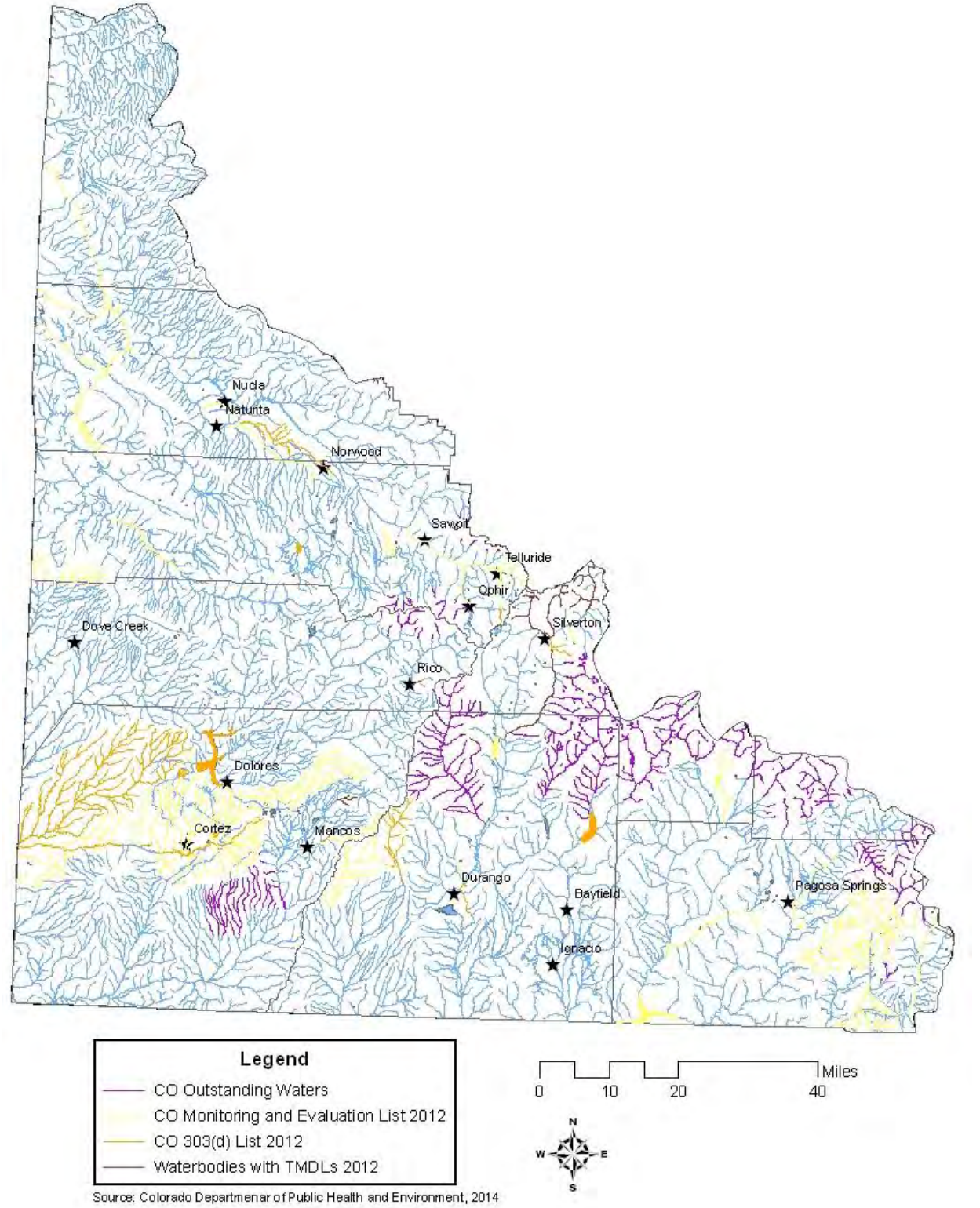
Wildfire, water quality degradation and other issues related to watershed health can impact and endanger critical water supplies through impacts to water supply infrastructure, environmental or recreational values, and/or water quality. The Colorado Wildland Fire Susceptibility Index (Figure 18), developed by the Colorado State Forest Service, provides one tool for gaging levels of fire risk within the Southwest Basin. Go to the website to obtain fire risk information for specific locations.

FIGURE 19. COLORADO WILDLAND FIRE SUSCEPTIBILITY INDEX (COLORADO STATE FOREST SERVICE 2008)



The protection, maintenance, and restoration of Colorado's water resources are managed by the Clean Water Program within the Colorado Water Quality Control Division (WQCD). Colorado's water quality is assessed periodically in conjunction with the WQCD's triennial review of water quality standards, the development of discharge permits, the 303(d) List and Total Maximum Daily Loads, and the completion of special studies. Water bodies are listed as "impaired" under Section 303(d) of the Clean Water Act when monitoring data demonstrates that the water quality standard for a pollutant or pollutants is being exceeded. Figure 20 shows the waterbodies listed as impaired in the Southwest Basin, as well as those with Outstanding Waters designation and those on the Monitoring and Evaluation List for impairment.

FIGURE 20. COLORADO WATER QUALITY CONTROL DIVISION WATER QUALITY LISTINGS AND DESIGNATIONS FOR WATERBODIES IN THE SOUTHWEST BASIN



Source: Colorado Departmenar of Public Health and Environment, 2014

CURRENT IPPS

Watershed health protection projects and methods are occurring or have been completed within each of the Southwest Basin's nine sub-basins. These efforts range from broad collaborative watershed groups, to collaborative groups focused on forest health or water quality, to more focused community wildfire mitigation plans aimed at protecting property and source water protection plans to protect drinking water supplies. The dialogue and action fostered by these efforts can help protect critical water supplies from harm by fire, contaminants or other hazards.

In the San Juan River basin, there are two groups working on forest and watershed health focused on public and private lands. The San Juan Headwaters Forest Health Partnership includes people and organizations representing multiple interests working to strengthen understanding of methods for improving forest health and long-term resilience of the watersheds of the Upper San Juan River Basin, to broaden knowledge of current conditions and opportunities, to develop and implement a set of management approaches and projects, as well as monitoring and adaptive management.

CHECK IT OUT!
http://www.sanjuanchama.org/

The Chama Peak Land Alliance formed the San Juan–Chama Watershed Partnership to engage public and private stakeholders in collaborative planning and decision making in the Navajo River and Rio Blanco River watersheds of Colorado (as well as the Chama River watershed in New Mexico). These watersheds are at very high risk for wildfire and insect and disease mortality; yet they sustain agricultural operations, tourism based economies, wildlife populations and public recreation, as well as supply over 50% of the water supply for Santa Fe and Bernalillo counties in New Mexico, via the San Juan Chama Diversion.

In the Animas River basin two collaborative groups are working on water quality issues. In the upper watershed, the Animas River Stakeholders Group (ARSG) is focused on water quality challenges related to historic mining and natural mineralization in the upper Animas River watershed. The ARSG's mission is to improve water quality and aquatic habitats in the Animas River watershed through a collaborative process designed to encourage participation from all interested parties. Focusing lower in the basin, the Animas Watershed Partnership (AWP) works to protect and improve the quality of water resources in the Animas River. AWP's efforts to date have focused on nutrient, sediment, and bacterial levels based on recent and current sampling efforts, including the Animas Watershed Based Plan (2011). The Microbial Source Tracking and Nutrient Sampling Project aims to identify the animal sources of bacterial contamination in the Animas River close to the Southern Ute/New Mexico Boundary, as well as to measure and compare the concentrations of E. coli, total nitrogen, and total phosphorus in the Animas River and the Florida River close to their confluence.

THE ASSESSMENT IS AVAILABLE AT:

http://www.utemountainuteenvironmental.org/index.cfm/water-quality/surface-water/monitoring-assessment/

In the Mancos River basin, four efforts focus on water quality and watershed health. The Ute Mountain Ute Tribe and the Mancos Valley Watershed Group have completed watershed and water quality assessments and implement projects aimed at improving watershed health. The Ute Mountain Ute Tribe Environmental Programs Department recently completed its Mancos River Water Quality Assessment: 2011-2012 (Ute Mountain Ute Tribe 2013).

The Mancos Valley Watershed Group completed the Mancos Watershed Plan in 2011. The group was formed in 2006 and brings together private landowners, environmentalists, recreationalists, government agencies, and concerned community members to address goals including improvement of fishing, reduction of copper loading in the East Mancos, working with irrigators to improve diversions, improvement of the ecological function of the river, and improvement of summer flows through the town of Mancos and downstream. In addition as part of the BOR's Colorado River Salinity Control Program, the U.S. Department of Agriculture Natural Resource Conservation Service's Environmental Quality Incentives Program (EQIP) provides cost share assistance to landowners in the Colorado River basin, including all sub-basins of the Southwest Basin, who install salinity control measures. Finally, the Mancos Water Conservation District plans to conduct Natural Disaster Planning.

In the Dolores River watershed several groups are focusing on different aspects of watershed health. The Dolores River Dialogue is a coalition of diverse interests, whose purpose is to explore management opportunities, build support for and take action to improve the ecological conditions downstream of McPhee Reservoir while honoring water rights, protecting agricultural and municipal water supplies, and the continued enjoyment of rafting and fishing. The Dialogue has completed several assessments, including A Way Forward and the Dolores River 319 Plan. A Legislative Subcommittee has also been formed from this effort, which lead to an Implementation Team developing an Implementation, Monitoring, and Evaluation Plan (IM&E Plan). This IM&E Plan is part of the foundation for draft National Conservation Area legislation to protect native fish, downstream values, water rights, and Dolores Project allocations.

The Dolores River Restoration Partnership is a public-private collaboration "working to remove invasive plants whose extensive growth has displaced native plant communities, impaired wildlife habitat and forage, hindered recreational opportunities, and increased risks associated with wildfire." Their goals include to "increase the number of acres of sustainable, healthy riparian and floodplain plant communities in the watershed while reducing those dominated by tamarisk and other invasive, non-native plant species," and to "increase opportunities for the next generation of stewards; increase public safety both by reducing wildfire-related risks and improving highway safety; and improve aesthetics." They have completed the Dolores River Restoration Action Plan

(Dolores River Restoration Partnership 2010) which identified the riparian and floodplain locations where restoration activities should focus.

Trout Unlimited is currently developing the Upper Dolores River Assessment. This is an assessment of fisheries and riparian conditions of the Upper Dolores Watershed aimed at applying the best science to support restoration activities, including identification of possible restoration and irrigation infrastructure improvement partnerships in the Dolores River watershed, reaches of the Dolores River main stem for possible restoration work, monitoring, reconnection, and/or reintroduction projects on important tributary streams for native and wild trout.

In the San Miguel River basin, the San Miguel Watershed Coalition works to "advance the ecological health and promote the economic vitality of the watershed through the collaborative efforts of the entire community. Our ultimate goal is to realize a watershed that is healthy in every respect while offering a sustainable and quality lifestyle for all who live in it." The coalition periodically compiles and issues a watershed health assessment entitled the San Miguel Watershed Report Card.

Also pertinent to water quality in a tributary of the San Miguel River are the Carbenaro Mine Adit Reclamation and the Carribou Mine Tailings and Adit Reclamation Projects, both aimed at mitigating heavy metal loading to Howard's Fork.

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http://uplandscape.org/

The Uncompahgre Plateau Collaborative Restoration Project (UP CFLRP) is a collaborative effort engaging public and private partners in efforts "to enhance the resiliency, diversity and productivity of the native ecosystem of priority National Forest System lands on the Uncompahgre Plateau, Colorado using best science available and collaboration." The group is active in forest health issues across the Uncompahgre Plateau, including portions of the San Miguel and Dolores river watersheds. The UP CFLRP is completing projects including "active restoration on 160,000 acres that involves prescribed burns, mechanical treatments, timber harvests, invasive species treatments, native plant establishment, trail and road relocations (sediment control), riparian restoration and improvements for Colorado cut throat trout."

In La Plata, Archuleta, and Montezuma counties, FireWise of Southwest Colorado has Chapter Coordinators working with home and property owners to help them understand their fire risk and recommend actions they can take to mitigate that risk. The organization does education/outreach, planning, and some implementation activities (such as creation of demonstration sites, grant writing, incentives for homeowners, etc.).

The main "planning" effort that FireWise of Southwest Colorado is currently supporting is the development of Community Wildfire Protection Plans (CWPPs). There is a CWPP in place for each of the five counties in Southwest Colorado, as well as 17 subdivision-level plans in place and another 12 such plans underway.

While the CWPP plans focus primarily on what the subdivision can do, many of them also make recommendations for actions to be taken on public lands that adjoin the subdivision. Although the primary emphasis of these CWPPs is on creating defensible space for homes, the wildfire mitigation they promote also helps support healthy forests and healthy watersheds.

FireWise of Southwest Colorado works closely with the Colorado State Forest Service, BLM/USFS, fire departments, Offices of Emergency Management, NRCS, Conservation Districts, and other non-profits like the Southwest Conservation Corps and San Juan Headwaters Partnership (P. Wilson, Pers. Comm.).

Finally, Source Water Protection Plans promote protection of public water systems from fire and other potential hazards/sources of contamination. These are voluntary planning efforts that public water suppliers can pursue with funding support available through CDPHE and technical/planning support provided by the Colorado Rural Water Association. In developing these plans, participating public water suppliers identify their water sources and planning areas, inventory and prioritize potential hazards /sources of contamination, and identify Best Management Practices that they or partners can implement to protect their sources of drinking water.

In the Southwest Basin, 23 public water suppliers have completed or are in the process of developing Source Water Protection Plans for their surface and/or groundwater intakes. These plans cover the following planning areas:

- In the Animas River basin, the Florida River watershed upstream of the Durango-La Plata Airport's water intake, the Animas River watershed upstream of the City of Durango's water intake, and the Falls Creek and Dyke Creek drainages.
- In the Mancos River basin, the source areas for the Mancos Rural Water Company, Mesa Verde National Park, and the Town of Mancos.
- In the Dolores River basin the source areas for The town of Rico, Town of Dolores, City of Cortez, Montezuma Water Company, and the Town of Dove Creek.



Missionary Ridge Fire North of Durango 2002 (Animas River basin)

4.3 CONSERVATION PROJECTS & PROCESSES

CURRENT IPPS

Currently the Southwest Basin does not identify any municipal water conservation projects on the IPP list. This lack of identified IPPs should not be interpreted to mean that there are no efforts in place or planned to enhance levels of conservation in the Southwest Basin, as not every municipality or public water supplier responded to requests for updates and additions to the IPP list.

IPP CONCEPTS

In the course of the interviews gathered around the Southwest Basin to identify existing IPPs, project concepts also were discussed and compiled. These are ideas for projects or processes that people or entities within the Southwest Basin have, but which do not yet have a sponsor who is actively pursuing implementing the idea. One IPP concept identified during the planning process is to work with public water suppliers, including municipalities, to assess their current indoor to outdoor water use ratio and to incentivize attainment of the 60/40 ratio included in the Southwest Basin Measureable Outcome B3. Another IPP concept is the development of irrigation efficiency programs.

4.4 NEW MULTI-PURPOSE, COOPERATIVE, & REGIONAL PROJECTS & PROCESSES

The BIP will be used to foster multi-purpose, cooperative, and regional IPPs. Throughout the efforts of updating the IPP list, new partnerships have formed and new IPPs were identified. While all sub-basins strive towards multi-purpose, cooperative, and regional IPPs not all sub-basins identified new projects during these outreach efforts. Some sub-basins may have existing IPPs, developed during the SWSI 2010 efforts, which already encompass the essence of Section 4.4. Below are specific IPPs that are highlighted for IPPs that demonstrate new multi-purpose and cooperative efforts towards implementation of projects and processes.

SAN JUAN RIVER BASIN

A Geothermal Greenhouse Partnership (GGP) has formed within the San Juan River basin. The GGP mission is as stated: *"Harnessing intrinsic renewable solar and geothermal energy to grow safe, sustainable, reliable and affordable food for local people, and provide an attraction for visitors, year around. In doing so, create educational opportunities, nurture local businesses, create jobs and cultivate pride and economic vitality*."

The project consists of three phases: 1) Development of partnership and building capacity within the organization; 2) Construction of the project will commence and utilization of the facilities; and 3) Expanding the influence of the GGP and further education and outreach efforts. The GGP has relationships with local, state, national, public, and private entities such as: Pagosa

Springs Town Council, Archuleta County Board of County Commissioners, Archuleta School District 50-Jt, U.S. Senator Mark Udall, Southwest Organization for sustainability, Growing Spaces, Pagosa Verde, 4Core – Four Corners Office for Resource Efficiency, Davis Engineering Service, and Reynolds & Associates Architecture Engineering.

Also with in the San Juan River basin multiple processes have formed. Each having a diverse group of stakeholders working together to address multiple known needs. The Chama Peak Land Alliance seeks conservation minded landowners to work collaboratively together to practice and promote ecological and economical sound land management. The San Juan Headwaters Forest Health Partnership is committed to collaborative approaches to improve the health and long-term resilience of mixed-conifer forests and the communities associated with these forests.

MANCOS RIVER BASIN

The Ute Mountain Ute Tribe has received a grant to develop a Water Conservation and Management Plan. The plan is a process to discuss development of the Ute Mountain Ute Tribe allocations in the La Plata, Mancos, San Juan, and McElmo river basins. This includes development with non-tribal partners within the Mancos River valley, development into western La Plata County and eastern Montezuma County, as well as additional needs from the Dolores Project in the amount of 4,000 AF.

Mancos Water Conservancy District has an IPP describing the need to conduct planning for natural disasters such as fire, floods, etc. This project is in the initial planning stages and will try to address protection of water supply and water quality for all values if a natural disaster were to occur.

DOLORES AND MCELMO RIVER BASINS

The Dolores Water Conservancy District and the Ute Mountain Ute Tribe are jointly pursuing the development of an energy dissipating structure (EDS) hydropower project. This is a collaborative process between users of the Dolores Project. The EDS site is located on the Towaoc Highline Canal at the transition between Reaches 2 and 3. The EDS would be a source of renewable energy and annual revenue for the two parties. This IPP combines renewable energy with existing agricultural delivery practices.

Another IPP the Dolores Water Conservancy District is a proponent of is an optimization study for the Dolores and McElmo river basins. The study plans to review the available water supplies to evaluate whether the water is being used as effectively as possible while using existing facilities. The study will recommend additional management methods and/or facilities that may improve effectiveness. This study will collaborate with users of the Dolores Project, upper and lower Dolores River, and McElmo Creek users.

SAN MIGUEL RIVER BASIN

Montrose County provided a new multi-purpose IPP for the portion of the county within the Southwest Basin. The Montrose County Firming Project will consist of two phases. The purpose of the project is to provide a reliable source of water for municipal and industrial demands over the next 50 years. The first phase is to be completed by 2018, which is a feasibility level engineering study of proposed storage sites and diversion points pursuant to recent water right filings. The second phase of the project will be to construct one or two reservoirs, in addition to the Nucla Town Reservoir Enlargement, and the direct flow points of diversion as determined by Phase 1. The project will address the 3,200 AF gap between existing water supplies and demands projected to occur by 2060 in the western portion of Montrose County. The reservoirs release will also provide non-consumptive piscatorial use and water quality improvements.

4.5 M&I PROJECTS & PROCESSES

Throughout the efforts of updating the IPP list, existing M&I IPP's were updated when applicable and new M&I IPPs were identified. While all sub-basins have M&I needs, not all sub-basins identified new IPPs during these outreach efforts. Below are specific IPPs that demonstrate the types of M&I IPPs existing or planned within the Southwest Basin.

The IPP list consists of about 25% municipal projects and/or processes. Every sub-basin has a need for safe, reliable water supplies and adequate infrastructure. Types of M&I IPPs are water diversion structures construction, improvements to infrastructure, construction of new infrastructure, and storage facilities (new and existing), to name a few.

The Dry Gulch Water Storage Facility Project is a noteworthy project for providing municipal water supply. It will incorporate both consumptive and non-consumptive uses for state and local purpose. The primary proponent of the project is presently San Juan Water Conservancy District. The off stream facility will have storage capacity of up to 11,000 AF. The project will utilize gravity flow and syphoning to fill and maintain water levels; this is a cost effective and environmental friendly approach. The project is the preliminary stages and is currently resolving land ownership issues and securing funding.

Across all sub-basins, the potential for micro-hydropower is being explored. As the technologies for hydropower progress so does the potential for production. These potential hydropower projects could be associated with irrigation infrastructure and/or other multi-purpose projects. Multiple sub-basins have specific IPPs addressing the development of hydropower. Within the San Juan River basin, a small hydropower project associated with the Dry Gulch Water Storage Facility Project (utilizing Park Ditch delivery infrastructure) would be developed in conjunction with



Dolores Project (Dolores River basin)

the dam project. The Florida Water Conservancy District within the Animas River basin listed hydropower as need to be meet during utilization of a new water right (other needs addressed as well). Within the Mancos River basin, there is potential for hydropower facilities within the canals and ditches within the Mancos River valley.

The Dolores and McElmo river basins already have existing hydropower facilities with two new additions to the IPP list. As described previously in Section 4.4, the EDS Hydropower Development is jointly pursued by the Dolores Water Conservancy District and Ute Mountain Ute Tribe. The Dolores Water Conservancy District is also pursuing a development of a Plateau Pumpback Project. This project would utilize water released from an upper reservoir through a penstock to generate hydropower and be pumped back to the upper reservoir during off-peak demand.

4.6 AGRICULTURAL PROJECTS & PROCESSES

Throughout the efforts of updating the IPP list, existing agricultural IPP's were updated when applicable and new agricultural IPPs were identified. While all sub-basins have some agricultural IPPs, not all sub-basins identified new IPPs during these outreach efforts. Below are specific IPPs that are highlighted to demonstrate the types of agricultural IPPs existing or planned within the Southwest Basin.

One overarching concept for all sub-basins is the need for ditch company improvements and efficiency projects. A plethora of irrigation systems exist in the Southwest Basin; this leads to not all systems being represented on the IPP list. To account for these systems, a multi-basin IPP exists as a place holder for irrigation systems utilizing open ditches to deliver water. There is potential to upgrade these ditches (by lining or piping) to conserve water. Other efficiency projects may exist and should be developed as needed. Along with this overarching concept, specific IPPs exist for ditch companies that have identified planned improvements and efficiencies. These projects include ditch linings and headgate improvements.

Multiple reservoirs exist within the Southwest Basin. The majority of these reservoirs provide some quantity of agricultural water supply. Agricultural water delivered from a reservoir may require pumping stations, canals, ditches, piping, and delivery boxes for connection with irrigators. All these components require routine maintenance and upgrades. Efficiency improvements are made to conserve water and potentially provide additional water supplies.

Vallecito Reservoir provides agricultural, municipal, tribal, and environmental flows year around. Two IPPs are listed regarding the reservoir and infrastructure repairs. Along with these repairs, continued improvements are being made to the delivery systems and on-farm irrigation practices that utilize Pine River Irrigation District shares.

Florida Water Conservancy District has multiple needs within the Florida River drainage (a tributary of the Animas River). One of the many components of their IPP is irrigation system improvements by the Florida Mesa Ditch Companies that would firm up agricultural delivery and

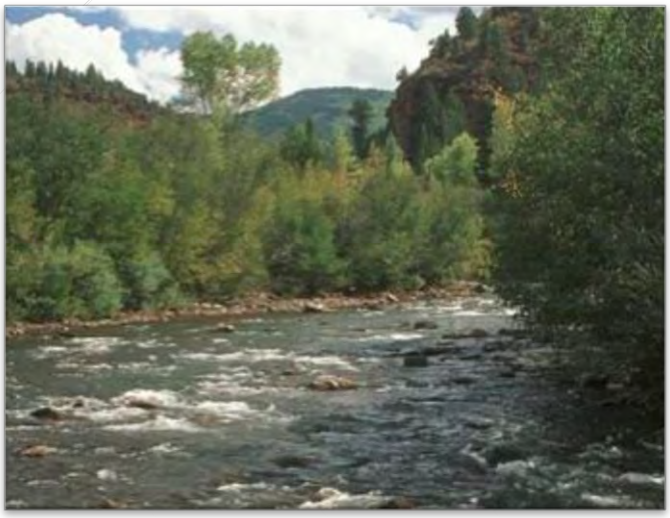
provide additional water supply for those other uses in Lemon Reservoir through the reduction of losses in the delivery system. Currently, nearly all of the irrigation system delivering water from Lemon Reservoir consists of old, open ditches. To date 3 miles of ditches have been lined, with future plans to continue these upgrades.

Long Hollow Reservoir is a 5,400 AF storage project in Long Hollow (a sub-basin of the La Plata River) with construction scheduled to be completed in the fall of 2014. This reservoir will be used for La Plata River Compact compliance and as a source of exchange water for irrigation water supply. Potential uses for augmentation and exchange for domestic wells exist too. Along with the reservoir construction, a water delivery study will be conducted to better meet La Plata River Compact requirements to the State of New Mexico.

Southwester Water Conservation District holds water rights in the Animas River that are decreed and available to meet irrigation demands within the La Plata River basin. This water supply could potentially provide supplemental water for existing irrigated lands and water supply for full service lands that are currently not in production and/or dry-land farmed.

The Mancos Water Conservancy District provided multiple new IPPs. These range from reservoir enlargements, inlet rehabilitation for reservoirs, river measuring stations to improve water management, and ditch piping to improve conservations.

Irrigators in McElmo Canyon have expressed the need for agricultural water in the early part of the irrigation season. A pilot project was conducted for a single year utilizing Totten Reservoir to provided releases for agricultural uses during the early months of the irrigation season. For this to become permanent release, improvements to Totten Reservoir must be made.



San Miguel River

Multiple reservoirs exist within the San Miguel River basin that have IPPs ranging from reservoir improvements to enlargements. These reservoirs provide agricultural water to their surrounding areas as well as water for other uses. It is important to maintain these reservoirs so supplemental irrigators needs are meet.

4.7 ENVIRONMENTAL PROJECTS & PROCESSES

This section provides an overview of the environmental IPPs currently identified in the Southwest Basin. In the San Juan and Piedra river basins, IPPs aim to restore and improve stream, wetland and CRCT habitat. Six IPPs focus on restoration of aquatic and riparian habitat, and

channel stability. These include the Cat Creek Watershed Project, San Juan River Bank Stability Project, the Navajo River Restoration, Spring Creek Restoration, San Juan River Village MD River Restoration, and the Lower Piedra from Hwy 160 to Navajo Lake Projects. Two projects aim to enhance or create wetlands: Crowley Ranch Reserve Wetland Enhancement and the Sambrito Project. Two projects focus on working with private landowners to improve habitat for CRCT Conservation Populations. These are on Himes Creek and Headache Creek.

In the Pine River basin, the River Ranch Pine River Habitat Improvement Project plans to restore aquatic and riparian habitat and channel stability. The Vallecito Reservoir Instream Flow Project aims to allow donation of an instream flow to the CWCB to enhance fish habitat.

In the Animas River basin IPPs aim to improve stream habitat, CRCT habitat and water quality. Four projects focus on improving riparian habitat, aquatic habitat, and/or water quality, including the Salmonid Habitat Improvement Animas above Howardsville, Animas River Vegetation Management, Florida River Water Quality Initiative, El Rancho Florida Florida River Riparian and Aquatic Habitat Improvement, and the Florida River Habitat and Water Quality Improvement Projects. Two projects focus on native fish. The Hermosa Creek CRCT Metapopulation Project works to create and sustain habitat for CRCT, while the Florida River Habitat Assessment hopes to work with private landowners to assess habitat for native warm water fish.

In the La Plata River basin two projects aim to control invasive species: the Southern Ute Indian Tribe Management of Invasive Riparian Species and Long Hollow Reservoir Non-Native Fish Control.

In the Mancos River basin, three projects aim to improve aquatic habitat for native warm water and non-native trout, and/or riparian habitat. These include the Mancos Fishing Habitat Improvements, Mancos River Habitat and Diversion Project - Phase II, the Ute Mountain Ute Tribe's Mancos River Restoration (riparian and aquatic natives). The Habitat Assessment of the Mancos River is focused on assessing the quality of the lower Mancos for native warm water fish.

In the Dolores and McElmo river basins three IPPs have the potential to help address flow needs for native warm water fish while meeting other needs. These include the Dolores Water Conservancy District Optimization Study, the Upper Plateau Storage Reservoir, and the Proposed ISF on the Dolores River. The Dolores River Restoration Partnership and the Dolores Project McPhee Reservoir Aquatic Nuisance Species Protection aim to maintain and improve riparian and aquatic habitat respectively by controlling non-native species. The Upper Dolores River Assessment will evaluate riparian and aquatic habitat quality. The Redburn Ranch will improve aquatic habitat connectivity for the non-native trout fishery. The Future River Stewards project will engage in water quality sampling and river stewardship education to benefit all uses.

In the San Miguel river basin four IPPs address maintenance of flows for environmental values. These include the Naturita Creek Proposed ISF, Flow Protection for Area of Critical Environmental Concern, San Miguel ISF, and Suitability - Wild and Scenic Rivers Act. Three

projects focus on improving habitat for native fish species: one for CRCT (Woods Lake CRCT Refuge), and two for native warm water fish (Tabeguache Creek Native Fish Barrier Removal Project, CCC-Ditch Fish Ladder Repair). The Valley Floor River Channel Restoration project will improve both aquatic and riparian habitat. Three IPPs focus on developing new reservoirs which in addition to meeting municipal and agricultural needs, could include benefits to environmental values. These are the Montrose County Firming Project Phase 1 and 2, and the San Miguel Project.

In addition several projects are multi-purpose processes focused on watershed and forest health, and/or water quality. These have the potential to benefit multiple values, including environmental values. These IPPs are covered in depth in Section 4.2.

4.8 RECREATIONAL PROJECTS & PROCESSES



Rafting on the Dolores River

IPPs that have recreational benefits have been identified throughout the Southwest Basin. Three IPPs help maintain or improve whitewater boating recreation. These include the Four Corners Paddle Trail (Animas River basin) Upper Dolores River Recreation Access, San Miguel Potential Recreational In-Channel Diversion, San Miguel Suitability - Wild and Scenic Rivers Act, and the CCC-Ditch Fish Ladder Repair. An IPP concept is to update the identification of boatable reaches and boatable days and flows for the rivers in each sub-basin.

The following three IPPs will benefit flat-water boating recreation as well as fishing and waterfowl viewing opportunities: the Dry Gulch Storage Facility Project, Lake Nighthorse Recreation, and Dolores Project McPhee Reservoir Aquatic Nuisance Species Protection. In addition, eight IPPs plan specifically to improve fishing, waterfowl viewing, and/or hunting opportunities around the Southwest Basin. These include the San Juan River Village MD River Restoration, the Spring Creek Restoration, the Crowley Ranch Reserve Wetland Enhancement, River Ranch Pine River Habitat Improvement, Salmonid Habitat Improvement Animas above Howardsville, Mancos Fishing Habitat Improvements, Upper Dolores River Assessment, and Rehabilitation of Priest Lake.

Finally, several water quality IPPs described in Section 4.2 have the potential to benefit all uses, including Recreation.

SECTION 5. STRATEGIES & TOOLS

In order to implement this BIP, address the identified challenges and opportunities within the Southwest Basin and ensure reliable water supplies into the future the Roundtable has identified a suite of strategies and tools. Included are the overarching strategies considered by the Roundtable in development of the IPPs discussed in the following sections. Also included are big picture tools for implementation of the IPPs. The Roundtable recommends and supports these strategies and tools for implementation of IPPs and cross-basin cooperation.

5.1 STRATEGIES

The water supply in the Southwest Basin, as in the entire Colorado River Basin, is highly variable from year to year. Tree ring data for nearly 1,200 years indicates that the water supply has historically had decades long wet and dry cycles. These overarching strategies attempt to set a framework for how the Southwest Basin will "live" through these fluctuating water supplies while implementing our IPPs.

- The Roundtable treats and evaluates all IPPs equally, whether they are consumptive, non-consumptive, projects, or processes. This approach strengthens the foundation of collaboration and dialogue that already exists within the Southwest Basin, as well as the opportunities for partnerships to address existing and future water supply challenges. The potential to build partnerships across a range of interests and needs is identified as a key opportunity and strategy for achieving all of the goals and many of the measureable outcomes identified in this BIP.
- The Roundtable encourages sponsors to pursue a broad set of potentially complementary funding sources and to consider funding their projects from more than one source.
- The Roundtable intends to continue to cooperate with other Basin Roundtables to implement components of this BIP, as well as to address new challenges and pursue new opportunities that may arise in the future.
- Education and outreach about water values, water supplies, available funding options, and new information and tools will be a critical component for the implementation of this BIP. Education and outreach are specifically identified as strategies in measureable outcomes, IPPs or opportunities relating to M&I water conservation and reuse, agricultural water projects, recreational uses, water quality and watershed health.
- Continually improving water management and conservation by all water users is critical to meeting water demands of any type. At times there is simply not enough water to meet even one demand without considering all of the possible demands. Specific IPPs have not been developed for all possible management and conservation opportunities but overall strategies include:
    - Maintain and improve irrigation delivery facilities in order to reduce shortages, keep in production irrigated lands especially lands using pre-Compact water rights, and where possible leave additional flows in streams.

- Continue to reduce the amount of water needed for municipal, domestic, and industrial purposes through conservation efforts to meet the Roundtable's goal and measureable outcome herein.
- Investigate ways to maintain the desired values with available water supplies.

5.2 STRATEGIES RELATED TO NEW TRANSMOUNTAIN DIVERSIONS

The Roundtable is concerned about any new TMD. A new TMD would increase the risk of a Colorado River Compact curtailment, as well as the risk of contingency measures to address serious conditions such as the inability to generate power from Lake Powell or levels of Lake Mead dropping below Las Vegas's municipal water supply intake. An increase in such risks jeopardizes the Southwest Basin's ability to develop water supplies to meet needs in the Southwest Basin and puts additional pressure on the Southwest Basin's agriculture to meet downstream water needs for compact compliance and/or obligations.

The Roundtable recognizes that these increased risks are not limited to conveyance of west slope water through construction of new infrastructure. These risks can also be increased right now by new purchases of existing west slope water rights, including buy and dry of pre-1922 west slope agricultural water rights. Such purchases could conceivably occur in any basin along the west slope and be delivered across the divide by means of exchange, through existing infrastructure. This risk of buy and dry of west slope water to meet east slope demands is one of the concerns behind the Southwestern Water Conservation District's participation as a member of the Water Bank Working Group to develop a Compact Water Bank.

As a result of the concerns and risks described above, the Roundtable agrees on eight factors that must be addressed prior to considering a new TMD.

1. Municipalities receiving water from a new TMD must meet a high water conservation goal. The Roundtable has proposed specific conservation goals in the measurable outcomes of Section 1 of this BIP.
2. As part of any proposed TMD project package, funding to design and construct compensatory projects on the West Slope shall be included.
3. Additional development of the Colorado River basin involves more risk to all users, including pre and post Compact water rights. Implementation of risk management strategies is necessary to understand and provide some level of protection for existing water rights holders and users.
4. Discussions should occur to determine whether allocations for each sub-basin of the Colorado River basin, similar to sub-alllocation of the Colorado River Compact, are appropriate.
5. Municipalities receiving water from a new TMD will fully develop their existing water supplies within their basin (such as reuse strategies, storage, etc.).
6. A new TMD will not negatively impact the quality of life on the West Slope.
7. A new TMD will not be a headwaters diversion and may require development of a pumped back type of delivery system.
8. The state of Colorado shall present their position on administration of a compact curtailment on a basin level.

In addition to the factors the Roundtable has developed the following statement:

> *A new TMD must be considered in conjunction with alternative water sources that do not rely on the Colorado River basin water supplies.*

The Roundtable expresses serious concerns over a new TMD because of the potential impacts of the over-development of Colorado River Basin supplies could have on the economy, agriculture, and quality of life of west slope communities. Due to the lingering drought, the Colorado River Basin is looking less and less like a reliable source of water to support Colorado's urban development. Recently there has been significant concern about the water levels in Lakes Powell and Mead and there are on-going efforts through "system conservation" and "demand

management" to attempt to put more water into Lake Powell through curtailment of existing users. This drought is not an unusual situation based on the tree ring study from 760 to 2010 that shows droughts commonly occur for decades.

The IBCC has developed 7 points as a framework (IBCC Draft Conceptual Agreement; July 2014) for further discussion of a new TMD, one of them is "The East Slope is not looking for a firm yield from a new TMD project and would accept hydrologic risk for that project." The conceptual thinking has been that the East Slope would only divert when conditions at Lake Powell or the Colorado River Basin were above a yet to be determined trigger amount. Based on the current conditions, Lake Powell hasn't been much above 50% since 2002. Even without knowing what the trigger content might be, it is unlikely that water would have been available for most of the last 15 years under any trigger amount or scenario. In other words, billions of dollars could be spent on a new TMD without achieving the goal of supplying water to the Front Range while minimizing agricultural dry-up and removing the threat to west slope communities.

The Roundtable continues to firmly believe that conservation and reuse must be a major means to reduce demand and address future gaps and that no TMD should proceed unless high level conservation goals are achieved. However, assuming a new east slope municipal water source is required to minimize agricultural dry-up, there needs to be a thorough analysis of alternative water sources with criteria that include: annual cost per acre-foot of firm yield; benefits to entire state or just a portion of the state (since broader benefits allow costs be spread to more sectors); net environmental benefits; etc. For this to be a meaningful comparative analysis it needs to be led by the state and "Alternative Water Sources" must be more broadly defined to include not just the Colorado River basin and alternatives involving storage on the Front Range, but other reliable alternative water sources with strong emphasis on in-state alternatives. BOR's "Colorado River Basin Water Supply and Demand Study" provides a list of potential water sources north and east of the Colorado River basin such as the Missouri River and Mississippi River for comparison to the Colorado River basin.

Assuming an alternative water source can be developed and is needed, it will be sometime in the 2040's before any project can be constructed and operational. The other three "legs of the stool", especially conservation (e.g. municipal and agricultural) will be essential to meeting the interim water demand. The Roundtable maintains that meeting high level conservation goals and reuse is essential and no alternative water sources project should proceed without high levels of municipal conservation. Repayment of construction costs needs to be commensurate with benefits received.

Roundtable asserts that these evaluations are a statewide issue and need to be conducted by the state (probably CWCB) because some of the alternative water sources will involve state to state discussions and in some cases compact obligations. For this reason, the Colorado Water Plan should include the evaluation of alternative water sources. Individual or collective water providers are not appropriate entities to represent Colorado in these types of discussions. By having multiple alternatives to consider, the state can play a neutral role in critical comparative evaluation, without

being "pre-decisional" concerning potential outcomes. Leadership on the part of the state in a rigorous comparative evaluation process will provide a foundation for the Basin Roundtables, IBCC, CWCB, along with water providers, recreational and environmental advocates to work toward a statewide consensus.

In summary, the Roundtable does not make this proposal to delay a new TMD but to make sure the billions of dollars that will be spent on a new municipal water source actually provides a firm water supply that will minimize agricultural dry-up. The current drought in the Colorado River Basin indicates that a new TMD may also require significant agricultural dry-up to provide a firm supply. Therefore, a new TMD must be considered in comparison with alternative water sources that do not rely on Colorado River Basin water supplies. Any such new supply must be designed to minimize impacts on users throughout Colorado. The Colorado Water Plan needs to include planning for evaluation of such alternatives.

5.3 TOOLS FOR IMPLEMENTATION OF IPPS

EDUCATION

Key audiences for outreach about resources and tools to meet water needs include municipalities, drinking water suppliers, mutual ditch companies and irrigation districts, water conservation districts, water conservancy districts, recreational companies, resource agencies, non-governmental organizations, and the people of the Southwest Basin and the State of Colorado. Such education efforts can occur on many levels throughout the Southwest Basin, from individual water users and suppliers around the basin, to collaborative watershed groups, to the basin-wide level of the Southwestern Water Conservation District and the Water Information Program. Continued funding for the Water Information Program will help ensure that consistent information is shared and disseminated around the basin to all users and interests.

FUNDING MECHANISMS

It is clear that additional funding strategies and mechanisms will be needed to fully implement this BIP. One novel strategy with potential to develop and fund more multipurpose projects and potentially support multiple IPPs in one funding effort is the idea of "bundling" a package of proposals (e.g. bundling IPPs). Such a bundle might seek funding for a number of different projects within the Southwest Basin, within a sub-basin, or at a specific site. As an example, a municipal supply project could be "bundled" with an effort to benefit flows or aquatic habitat for a sensitive species elsewhere in the same sub-basin. Such a strategy might take a watershed health approach to meeting a broader set of watershed needs. The advantage of such a strategy is that it might be more easily funded due to the multipurpose nature of the packaged projects.

Using two or more complimentary funds from different levels of private, local, state and/or federal funding will often be helpful in obtaining the funding match required by any one source. Examples of some sources that may be complementary and could work well together depending on the IPP include:

Local	State	Federal
•Private Funds •Southwestern Water Conservation District •Southwest Basin Roundtable WSRA •Local governments	•Water Supply Reserve Account Grants from CWCB through the Roundtable •Loans from CWCB •Colorado Non-Point Source Program Grants •Southwest Wetland Focus Area Funding from CPW •Source Water Protection Planning Grants from CDPHE •Colorado Parks and Wildlife Grants (HPP, Fishing is Fun, etc) •Loans from the Colorado Water Resources and Power Development Authority for municipal water systems	•Working Lands for Wildlife Funds from the NRCS and USFWS •RCPP, EQIP, WIP, or CREP cost-share funds from NRCS •Water SMART grants (BOR). •Partners for Fish and Wildlife

This is NOT an exhaustive list. Grant funding programs come and go over time. Their availability changes with budgetary constraints and other factors. It is important to check early and often with individual agencies to see what funding options they may have available and when the deadlines are for application.

RECOMMENDATIONS

In addition to these strategies, the Roundtable submits three recommendations to the State of Colorado:

WSRA funds are a secure and important source of funds for implementation of the Southwest BIP. CWCB should not manage these funds on a "use it or lose it" basis. The Roundtable is concerned that doing so would discourage the development of more thoughtful and high quality IPPs by forcing the Roundtable to disperse these funds in a more quick and potentially indiscriminant fashion. The Roundtable recognizes that there are gaps in the data and understanding regarding the flows and other conditions necessary to sustain the environmental and recreational values identified in the Southwest Basin. The Roundtable also recognizes that the tools currently available to help maintain those conditions are limited. The Roundtable has identified

two IPPs, described below under "Partnerships", to help address and bridge this need for additional information and tools. These IPPs should be considered on even priority with other IPPs when considered for basin and state WSRA funding. Though the WSRA Supplemental Scoring Matrix describes a scoring matrix for ranking funding, this should only be used as one of many criteria and should NEVER be used as the sole criteria for funding.

PARTNERSHIPS

Developing partnerships and collaborative efforts can be an effective tool for accomplishing multi-purpose IPPs. Partnerships are particularly well suited to combine with two or more funding sources mentioned above. Partnering with different interests has the potential to expand the funding opportunities such as partnering with the Southern Ute Tribe and/or Ute Mountain Ute Tribe to support implementation of the Tribal Settlement and other mutually beneficial IPPs.



Hermosa Creek (Animas River basin)

The Roundtable specifically plans to use partnerships and collaboration to implement the following two IPPs developed by the Roundtable to help evaluate environmental and recreational gaps:

1. Evaluation of environmental and or recreation gaps is planned to be conducted for improvement of non-consumptive resources and/or in collaborative efforts with development of consumptive IPPs. The evaluations may be conducted by a subgroup of the Roundtable or by individuals, groups, or organizations with input from the Roundtable. The evaluation may utilize methodologies such as the southwest attribute map, flow evaluation tool, R2 Cross, and any other tools that may be available.
2. Where environmental and/or recreational gaps are identified, a collaborative effort will be initiated to develop innovative tools to protect water identified as necessary to address these gaps.

ADDITIONAL INFORMATION AND ANALYSIS

In developing this BIP, the Roundtable identified three key data gaps that need to be addressed in order to significantly improve the Southwest Basin's ability to plan for and ensure reliable water supplies for all uses into the future. The questions behind these data gaps are:

1. What are the current demands and future needs for water to serve all major industrial uses in the Southwest Basin (e.g. snowmaking, mining, oil and gas development, etc.)?
2. What are the water supply related needs of the non-community nonpublic water systems in the Southwest Basin? How can the Roundtable identify and improve communication and outreach to these systems?

3. What are the flows and other conditions necessary to sustain environmental or recreational values associated with specific reaches around the Southwest Basin? What are boatable flows for segments that support recreational whitewater boating values?
4. What new or existing tools can be developed and employed at the reach, local, basin and/or state level to maintain the conditions that sustain environmental or recreational values on segments around the Southwest Basin?
5. What specific stream and lake segments currently support environmental and recreational values within the Southwest Basin? What are those values? The segments and values mapped for SWSI 2010 need to be brought up to date.

By addressing these questions, the Roundtable plans to develop tools to fill data or analysis gaps that challenge the Southwest Basin's ability to adequately plan for and maintain water supplies for all values and uses within the Southwest Basin.

CROSS-BASIN COOPERATION

The Southwest Basin intends to continue its involvement in two current cross-basin cooperative efforts. One is the IBCC's effort to develop a conceptual agreement between roundtables regarding how to approach a potential future TMD from the west slope to the east, including the discussion of a possible future use allocation. The Southwest Basin is actively engaged in the West Slope Caucus discussions and supports further refinement of the seven points of framework (IBCC Draft Conceptual Agreement; July 2014). The Roundtable would like the opportunity to review and comment on any future refinements to said Framework.

The Southwest Basin's cooperative effort is through the Southwestern Water Conservation District's participation as a member of the Water Bank Working Group to develop a Compact Water Bank.

SECTION 6. HOW THE BIP MEETS THE ROUNDTABLE'S GOALS & MEASUREABLE OUTCOMES

The Roundtable has crafted the BIP to represent the values and goals of the Southwest Basin. The BIP's implementation will meet identified gaps and water supply needs as related to these goals and measurable outcomes. Where water supply needs and gaps are not known, the BIP provides for a process to develop the information and a loop back to revise the BIP as needed, consistent with the Roundtable's principle that the BIP is a "living document."

Since SWSI 2010, the Roundtable success rate for completing IPPs is 44%. A total of 55 projects were completed since the drafting of the SWSI 2010 list. While many projects are now complete, through the BIP outreach process over 80 projects were added to the list. Table 13 shows the breakdown of completed IPPs to date by sub-basin. At the end of 2014, the Roundtable had granted $1,906,626 from the Southwest Basin account and $5,162,859 from the statewide account.

TABLE 13. IPPS COMPLETED TO DATE

SUB-BASIN	IPPS OUTSTANDING FROM SWSI 2010	NEW IPPS	COMPLETED SINCE 2010	SUCCESS RATE FOR 2015 LIST
San Juan	4	12	3	43%
Piedra	3	2	7	70%
Pine	4	7	16	80%
Animas	16	18	13	45%
La Plata	6	10	0	0%
Mancos	6	15	4	40%
Dolores/McElmo	11	12	4	27%
San Miguel	21	8	8	28%
Total	**71**	**84**	**55**	**44%**

To date the list totals about 160 IPPs for all sub-basins. Of these 160, about 50% of the IPPs are for needs such as agricultural, municipal, and industrial while the remaining 50% of the IPPs are for environmental and recreational needs.

MEETING THEME A, B, C, AND F GOALS AND MEASUREABLE OUTCOMES

Table 14 shows how IPPs listed in Appendix A will address the following goals identified by the Roundtable in Section 1, assuming they are completed by 2050.

A. Balance All Needs and Reduce Conflict
B. Maintain Agriculture Water Needs
C. Meet Municipal and Industrial Water Needs

TABLE 14. HOW THE SOUTHWEST BASIN IMPLEMENTATION PLAN IPPS ADDRESS THEME A, B, C, F, AND G GOALS AND MEASUREABLE OUTCOMES

THEME	MEASUREABLE OUTCOME	SOUTHWEST BASIN IMPLEMENTATION PLAN
A	1. 100% of new IPPs shall consider from the initial planning stage maintaining and enhancing environmental and recreational needs.	Not known.
A	2. Complete 19 multipurpose IPPs to meet identified gaps.	19 IPPs on list to date.
A	3. Initiate and participate in 10 processes that promote dialogue, foster cooperation and resolve conflict.	10 IPPs on list to date.
A	4. At least 50% of sub-basins have existing or planned IPPs that are protective of critical infrastructure and/or environmental and recreational areas and watershed health.	100% of sub-basins have existing or planned IPPs.
A	5. All towns and major water supply systems with water supply infrastructure have watershed/ wildfire assessments that identify strategies/ treatments necessary to mitigate the impacts that occur to hydrology in a post-fire environment.	100%
A	6. All major reservoirs have watershed/ wildfire assessments that identify strategies/treatments necessary to mitigate the impacts that occur to hydrology in a post-fire environment.	100%
B	1. Implement agricultural sharing projects in order to help preserve agriculture and open space values, and to seek other means to address municipal, environmental, recreational, and industrial needs; while respecting private property rights.	No IPP.
B	2. Implement strategies that avoid permanent agriculture transfers.	No IPP.

TABLE 14. CONTINUED…

THEME	MEASUREABLE OUTCOME	SOUTHWEST BASIN IMPLEMENTATION PLAN
B	3. The water providers in the state that are using dry-up of agricultural land (defined as requiring a water court change case) and/or pursuing a new TMD (as defined by IBCC to be a new west slope to east slope diversion project) shall have a higher standard of conservation. The goal for these water providers is a ratio of 70/30.	For 2013: Pagosa (75/25) Durango (57/43) Cortez (60/40).
B	4. Implement at least 10 agricultural water efficiency projects identified as IPPs (by sub-basin).	10 IPPs.
C	1. Complete 41 IPPs identified in 2015 IPP list (includes all basins) aimed at meeting municipal water needs.	41 IPPs (about 30% of total IPP list).
C	2. Consistently meet 100% of residential, commercial and industrial water system demands in each sub-basin.	Unknown.
C	3. Implement projects that protect or enhance the ability of public water supply systems to access and deliver safe drinking water that meets all health-based standards.	1 SWPP IPP.
C	4. Change the ratio of in-house to outside treated water use for municipal and domestic water systems (referred to as water providers herein) from the current ratio of 50/50 to 60/40 for southwest Colorado and the entire State by 2030.	
C	5. Implement 3 informational events about water reuse efforts and strategies.	No IPP.

TABLE 14. CONTINUED…

THEME	MEASUREABLE OUTCOME	SOUTHWEST BASIN IMPLEMENTATION PLAN
C	6. The water providers in the state that are using dry-up of agricultural land (defined as requiring a water court change case) and/or pursuing a new TMD (as defined by IBCC to be a new west slope to east slope diversion project) shall have a higher standard of conservation. The goal for these water providers is a ratio of 70/30. Water providers proposing a new TMD shall achieve a 60/40 ratio by 2020 and 70/30 by 2030 (high conservation) as a prerequisite for the Roundtable to consider support of a new TMD.	Included in TMD criteria.
F	1. By 2016, replace the following statewide outcomes with outcomes based on the current status of these measures in the Roundtable area.	.
F	2. 60% of stream miles and 40% of reservoir acres attain water quality standards and support all designated uses.	TBD.
F	3. 15% of impaired stream miles and reservoir acres are restored to meet all applicable water quality standards.	TBD.
F	4. 50% of stream miles and 30% of reservoir acres are attaining water quality standards.	TBD.
F	5. 100% of existing direct use and conveyance use reservoirs attain the applicable standards that protect the water supply use classification.	TBD.
F	6. Implement 6 IPPs to monitor, protect or improve water quality.	6 IPPs.

TABLE 14. CONTINUED…

THEME	MEASUREABLE OUTCOME	SOUTHWEST BASIN IMPLEMENTATION PLAN
G	1. Water providers proposing a new TMD shall achieve a 60/40 ratio by 2020 and 70/30 by 2030 (high conservation) as a prerequisite for the Roundtable to consider support of a new TMD.	See above.
G	2. A conceptual agreement is developed between roundtables regarding how approach a potential future TMD from the West Slope to the East.	In progress.
G	3. Protect 100% of pre-compact water rights in the Southwest Basin.	Protected by current DWR policy on pre-22 rights.
G	4. Implement 2 IPPs aimed at utilizing Tribal Water Rights Settlement water.	2 IPPs.
G	5. Implement 2 IPPs aimed at meeting La Plata River compact.	2 IPPs.
G	6. Participate in Compact water bank efforts.	SWCD is participant in Water Bank Working Group.

MEETING THEME D AND E GOALS AND MEASUREABLE OUTCOMES

In order to begin to gage how well this BIP may address the goals and measureable outcomes identified to meet environmental and recreational water needs, the map of 2015 environmental and recreational IPPs (including multipurpose IPPs) (Figure 20 & 21) was overlaid onto Figures 2 and 3, the maps of Southwest Basin environmental and recreational attributes with no identified flow protections. This mapping allows an assessment of the stream reaches where environmental and recreational values exist with some level of protection, project, or process that could benefit the values to some extent, and of the stream reaches where no such protections, projects, or processes appear to exist.

FIGURE 21. MAP OF ALL 2015 ENVIRONMENTAL, RECREATIONAL OR MULTIPURPOSE IPPS; IDENTIFIED FLOW PROTECTIONS; AND RECREATIONAL ATTRIBUTES WITHOUT IDENTIFIED FLOW PROTECTIONS

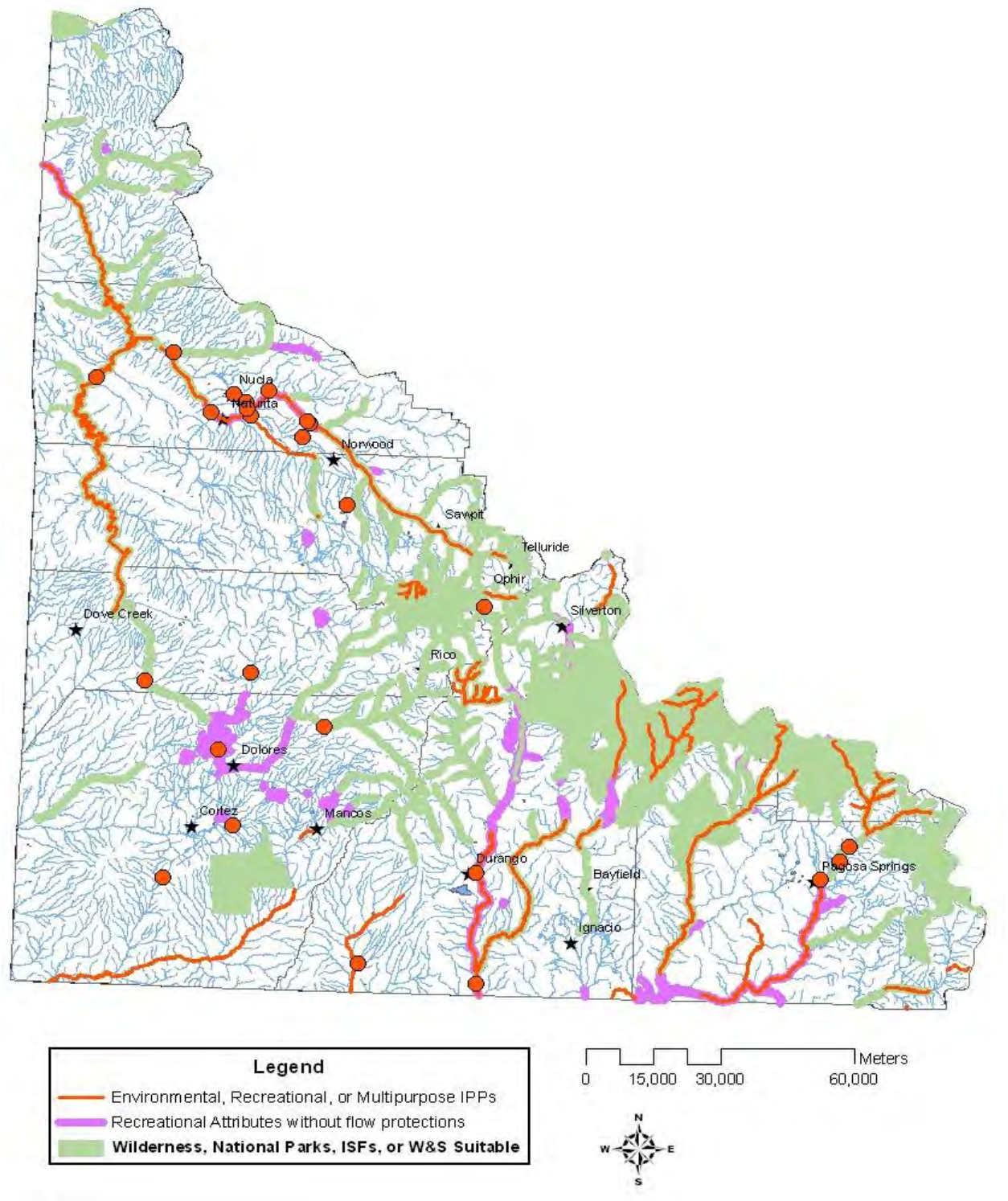
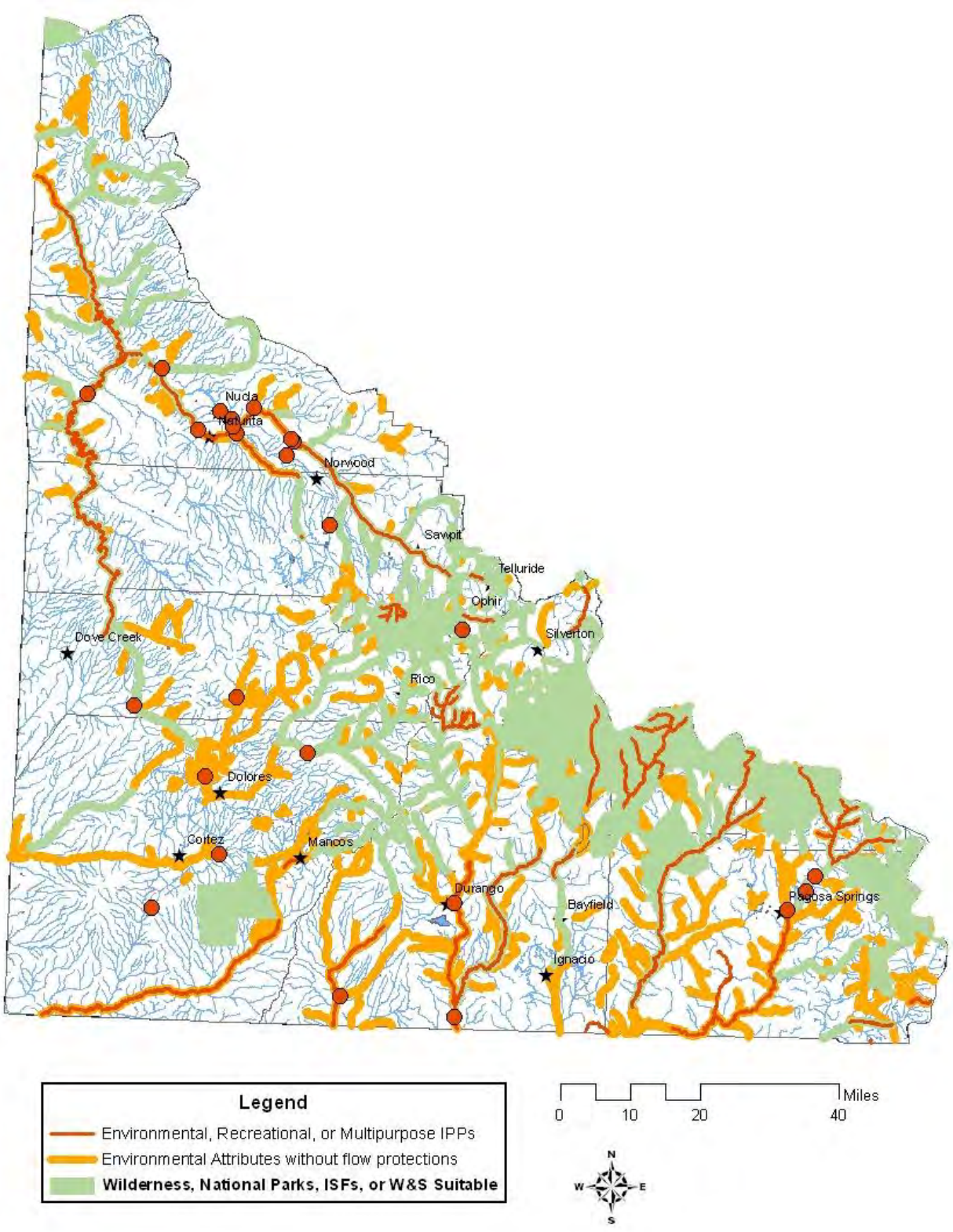


FIGURE 22. MAP OF ALL 2015 ENVIRONMENTAL, RECREATIONAL OR MULTIPURPOSE IPPS; IDENTIFIED FLOW PROTECTIONS; AND ENVIRONMENTAL ATTRIBUTES WITHOUT IDENTIFIED FLOW PROTECTIONS



The Roundtable recognizes that there are significant gaps in the data and understanding regarding the flow regimes (stream flow frequency, magnitude, duration, and timing) and other conditions necessary to sustain many of the environmental and recreational values identified in the Southwest Basin. The Roundtable also recognizes that the tools currently available to help maintain those conditions are limited. Therefore the Roundtable cautions against any assumption that the presence of an existing protection (e.g. ISF) or of an IPP is sufficient to maintain or sustain the attribute(s) identified in that reach. Assessment of the sufficiency of such measures depends on the particular attributes, the condition of the stream reach and the measures in place, and is better conducted on a reach by reach basis. The Roundtable has identified two IPPs that it hopes can help address and bridge these needs for more information and additional tools (Sections 4 and 5).

Table 15 summarizes available information about how well this BIP may address the suite of Theme D and Theme E goals and measureable outcomes identified in Section 1 upon completion of the environmental and recreational IPPs in Appendix A. The analyses of stream miles in this table makes use of the information on values developed in SWSI 2010, maps of the existing flow protections in the Southwest Basin (e.g. ISFs, Minimum Lake Levels, RICDs, Wilderness and National Park Service lands, and Wild and Scenic Suitability), and the Southwest Basin 2015 updated IPP list.

It is important to note that the stream mile percentages in Table 15 do not necessarily measure anticipated progress toward the corresponding measureable outcome upon implementation of the 2015 IPPs. Rather, these percentages represent only the miles out of all the stream miles occupied by a specific value, where some level of protection, benefit or attention from existing protections, or from current IPPs may exist upon completion of those IPPs. The Roundtable cannot measure the sufficiency of these protections or the anticipated projects and processes at this time.

TABLE 15. HOW THE SOUTHWEST BASIN IMPLEMENTATION PLAN IPPS MAY ADDRESS RECREATIONAL (THEME D) AND ENVIRONMENTAL (THEME E) MEASUREABLE OUTCOMES

THEME	MEASUREABLE OUTCOME	BASIN IMPLEMENTATION PLAN
D	1. Implement 10 IPPs to benefit recreational values and the economic value they provide.	There are 10 IPPs currently listed that involve education about, enhancement of, protection of, or access to recreational uses.
D	2. At least 80% of the areas with recreational opportunities have existing or planned IPPs that secure these opportunities and supporting flows/lake levels within the contemporary legal and water management context.	While the level to which they may be secure is unknown, the percent of total stream miles for each recreational attribute that have some level of protection, benefit or attention from existing protections or from existing or planned IPPs is: Whitewater Boating: 83% Flatwater Boating: 4% Gold Medal Trout Streams: 1% Other fishing Streams and Lakes: 60% Audubon Important Bird Areas: 8% Waterfowl Hunting /Viewing Parcels: 52% Ducks Unlimited Projects: 22% (Note: these cannot be added together for a total percentage because some attributes are found within the same reach.)
E	1. Implement 15 IPPs to directly restore, recover or sustain endangered, threatened, and imperiled aquatic and riparian dependent species and plant communities.	There are 10 IPPs listed that aim to restore, recover or sustain endangered, threatened, or imperiled aquatic or riparian dependent species or plant communities.
E	2. At least 95% of the areas with federally listed water-dependent species have existing or planned IPPs that secure the species in these reaches as much as they can be secured within the existing legal and water management context.	TBD. Not currently known because we do not currently possess maps of the habitat for these species.

TABLE 15. CONTINUED….

THEME	MEASUREABLE OUTCOME	BASIN IMPLEMENTATION PLAN
E	3. At least 90% of areas with identified sensitive species (other than ESA species) have existing or planned projects and methods that provide direct protection to these values.	While the level to which they may be protected is unknown, the percent of total stream miles for each sensitive species that have some level of protection, benefit or attention from existing protections or from existing or planned IPPs is: Colorado River Cutthroat Trout: 72% Roundtail Chub: 43% Bluehead Sucker: 49% Flannelmouth Sucker: 54% River Otter: 66% Northern Leopard Frog: 32% Active Bald Eagle Nests: 40% Rare Plants: 42% (Note: these cannot be added together for a total percentage because some attributes are found within the same reach.)
E	4. Implement 26 IPPs to benefit the condition of fisheries and riparian/wetland habitat.	There are 26 IPPs that aim to benefit the condition of fisheries, riparian or wetland habitat.
E	5. At least 80% of areas with environmental values have existing or planned projects and methods that provide direct protection to these values.	Not known.

REFERENCES

Bureau of Reclamation. 1979. Animas-La Plata Project Definite Plan Report Appendix B: Water Supply.

Colorado State Forest Service. 2008. Colorado Statewide Forest Resource Assessment: A Foundation for strategic discussion and implementation of forest management in Colorado. *Available online at http://csfs.colostate.edu/pages/statewide-forest-assessment.html.*

CRCT Coordination Team, 2006. Conservation strategy for Colorado River cutthroat trout (*oncorhynchus clarkii pleuriticus*) in the States of Colorado, Utah, and Wyoming. Colorado Division of Wildlife, Fort Collins, CO, 24p. http://cpw.state.co.us/Documents/Research/Aquatic/pdf/CRCT_Conservation_Strategy_Jun06.pdf.

Dolores River Restoration Partnership. 2010. Dolores River Riparian Action Plan (DR-RAP): Recommendations for Implementing Tamarisk Control & Restoration Efforts. Available online: http://www.tamariskcoalition.org/programs/dolores-river-restoration-partnership.

Utah Department of Natural Resources. 2006. Range-Wide Conservation Agreement and Strategy for Roundtail Chub *Gila Robusta*, Bluehead Sucker *Catostomus Discobolus*, and Flannelmouth Sucker *Catostomus Latipinnis*", Utah Department of Natural Resources, Division of Wildlife Resources, Publication Number 06-18, 2006. see: http://cpw.state.co.us/Documents/WildlifeSpecies/SpeciesOfConcern/RecoveryPlans/ChubSuckerRangewideConservationAgreementandStrategy01-04-07.pdf

Water Information Program. (2012). *Southwest Basin Roundtable outreach action plan*. Durango, CO.

APPENDIX A

- **DRAFT IPP LIST MACH 2015**
- **COMPLETED IPP LIST MARCH 2015**

Updated: 7/31/2014

Multi-Basin IPPs

ID	Date	Sub Basin	NC/C/B	Description	County	Status	Remaining Steps	Need Addressed	IPP Contact Information: Sponsors	IPP Contact Information: Lead contact & Source of Info.	Project vs. Process	Project ready for implementation NOW?	Does the need exist today?	Already received some WSRA funding?
1-MB	Mar-14	All Basins	NC	Environmental and Recreational Needs. Evaluation of environmental and/or recreational gaps is planned to be conducted for improvement of non-consumptive resources and/or in collaborative efforts with development of consumptive IPPs. The evaluations may be conducted by a subgroup of the Roundtable or by individuals, groups, or organizations with input from the Roundtable. The evaluation may utilize methodologies such as the southwest attributes map, flow evaluation tool, R2Cross, and any other tools that may be available.	All	Not Complete		Environmental needs, Recreational needs		Source: BRT feedback Lead: Ann Oliver	Process & Project	Maybe	Yes	No
2-MB	Apr-14	All Basins	NC	Environmental and Recreational Needs. Where environmental and/or recreational gaps are identified, a collaborative effort will be initiated to develop innovative tools to protect water identified as necessary to address these gaps.	All	Not Complete		Environmental needs, Recreational needs		Source: BRT feedback Lead: Ann Oliver	Process & Project	Maybe	Yes	No
3-MB	SWSI 2010	All Basins	C	Rural Water Supply. Assumed 5 to 10 percent of future demand in Southwest Basin will be in rural areas not covered by public water systems and groundwater or hauling water may be the only options and alternatives will not be developed.	All	Not Complete	Investigate possible areas of demand	Municipal water supply (infrastructure and water quantity)	Unincorporated areas of Southwest Basin not covered by a water provider	Source: BRT feedback Lead: Carrie Lile	Project	N/A	Maybe	No
4-MB	SWSI 2009	All Basins	C	Ditch Company Improvement and Efficiency Projects. Currently multiple irrigation systems deliver water in old open ditches. There is the potential to upgrade these ditches (lining and piping) to conserve water.	All	Not Complete		Agriculture (infrastructure)		Source: BRT Feedback Lead: Carrie Lile	Project	N/A	Yes	No
5-MB	SWSI 2010	All Basins	NC	Implementation of the Range-Wide Conservation Agreement and strategy for Roundtail Chub, Flannelmouth Sucker, and Bluehead Sucker.This Conservation Agreement signed in 2004 initiated formal inter-state consultation and cooperation to conserve these species. CO still drafting strategy document to coordinate implementation of conservation measures for these native fish, which are present in the lower reaches of the SW sub-basins.	Western Slope	Ongoing		Roundtail Chub, Flannelmouth Sucker, Bluehead Sucker	CO, AZ, NM, UT, NV, WY; BOR, BLM, USFS	Source: David Graf (CPW)	Project	Yes	Yes	No
6-MB	Jul-14	All Basins	C	Water Bank Working Group. Southwestern Water Conservation District participates in the water bank working group.	All	Not Complete		Agriculture water supply, Compact compliance	SWCD	Source: Carrie Lile	Process & Project	Yes	Maybe	No

Concept Ideas

ID	Date	Sub Basin	NC/C/B	Description	County	Status	Remaining Steps	Need Addressed	IPP Contact Information: Sponsors	IPP Contact Information: Lead contact & Source of Info.	Project vs. Process	Project ready for implementation NOW?	Does the need exist today?	Already received some WSRA funding?
1	13-Nov	All Basins	NC	Micro Hydropower. Potential hydropower projects associated with irrigation infrastructure and/or other multipurpose projects.	All	Not Complete	Investigate possible projects	Renewable Energy		Source & Lead: Ann Oliver	Project	N/A	Maybe	No
2	Nov-13	La Plata	NC	Long Hollow Reservoir Non-Native Fish Control. Work with partners to develop plan for control of non-native fish in Long Hollow Reservoir and the lower La Plata river. The La Plata River, together with the Mancos River, hosts the most genetically intact native fish community on the West slope of Colorado, due largely to the lack of invasion by non-native fish species.	La Plata	Not Complete	Identify key partners; Agree to effort	Native fishery	CPW	Source: Jim White	Project	No	Yes	No

Updated: 7/31/2014

San Juan River Basin Draft IPP List

PROPOSED IPPs

ID	Date	Sub Basin	NC/C/B	Description	County	Status	Remaining Steps	Need Addressed	IPP Contact Information: Sponsors	IPP Contact Information: Lead contact & Source of Info.	Project vs. Process	Project ready for implementation NOW?	Does the need exist today?	Already received some WSRA funding?
1-SJ	updated from SWSI 1, updated from Rod 9/17/13	San Juan	B	Dry Gulch Water Storage Facility Project. This Project is an off-stream water storage facility planned for a capacity of 11,000 AF of water. It will incorporate both consumptive and non-consumptive uses for State and local purposes. The primary proponent of the project is presently San Juan Water Conservancy District. Preliminary cost estimates for construction of this project approximate $60 Million.	Archuleta	Not Complete	Resolve ownership and financing issues, Complete NEPA reports, Resolve land issues with FS, Resolve beneficial uses	Municipal water supply (need for storage), Recreation	San Juan Water Conservancy District	Source: SJWCD Lead: Rodney Proffitt	Project	No	No	Yes
2-SJ	Updated from Renee 9/17/13	San Juan	C	Snowball Booster Station with Snowball to Dutton Diversion Pipeline Project. This project will eliminate the need to upgrade the Snowball Water Treatment Plant in the next 15 years and allow us to feed the Snowball Diversion water into our lake system. This project provides water security to the Town of Pagosa Springs area, total system redundancy, and greater access to the water in our lake system. The project will provide year round senior water rights to the system of lakes. The gap this project meets is water security for Town of Pagosa Springs area, which we are currently realizing as a need due to wildfire and allows us to treat lake water that we currently cannot use thus adding to the amount of accessible water in the basin.	Archuleta	Not Complete	Evaluate the integrity of the water treatment	Municipal water supply (infrastructure)	Pagosa Area Water and Sanitation District	Source & Lead: Renee Lewis	Project	No (Within the next 7 to 10 years with proper planning)	Yes	No
3-SJ	Sep-13	San Juan	C	Crowley Irrigation System Dam. Correct deficient outlet conduct and gate control on the outlet works to meet New Mexico Office of the State Engineer dam safety regulations.	Archuleta	Not Complete	Resolve interstate funding challenges	Agricultural (water supply and infrastructure)	Shahan Family, Crowley Reserve	Lead: Don Shahan Source: Ann Oliver	Project	Yes	Yes	No
4-SJ	SWSI 2010 Nov-13	San Juan	NC	Cat Creek Watershed. This watershed has some serious soil erosion and grazing management issues. Cat Creek itself is very unstable in many places with down cutting of the channel bottom and erosion of stream banks taking place. Efforts to restore the creek would have to include addressing resource problems on the uplands as well as the creek. We have done very little in this watershed but plan to explore the possibility of developing a watershed management project if there is enough landowner interest.	Archuleta	Not Complete	Secure support from landowners, Implement project	Habitat quality	Private landowners, NRCS	Lead & Source: Jerry Archuleta	Project	Yes	Yes	No
5-SJ	SWSI 2010	San Juan	NC	San Juan River Bank Stability. There are bank stability issues all along the San Juan River from Pagosa Springs to Navajo Lake. The problem seems to worsen the further you go downstream towards Navajo Lake, but an assessment would need to be done to determine if this is actually the case. We have completed work on some properties but this would be a very large project and would probably have to be broken down into smaller section.	Archuleta	Not Complete	Assessment of issues, Secure support from landowners, Implement project	Habitat quality, Water quality	District Conservationist, Pagosa Springs Office	Source: Jerry R. Archuleta	Process	Yes	Yes	No
6-SJ	Jun-11	San Juan	C	Pagosa Lakes Property Owners Association. The purpose of this project is to rehabilitate a failing outlet pipe on Village Dam.	Archuleta	Not Complete		Agricultural water supply (infrastructure)	Pagosa Lakes Property Owners Association	Lead & Source: Larry Lynch	Project	Yes	Yes	Yes
7-SJ	Nov-13	San Juan	B	Geothermal Greenhouse Partnership. The project will serve as a center for K-12 Science Education and for advance study in agriculture and renewable technology; will provide a test site for the commercialization of organic crops at high altitude using a geothermal resource; provide year-round community gardens and local food.	Archuleta	Not Complete	Secure funding, Construct	Education, Renewable Energy	Geothermal Greenhouse Partnership, Inc.	Source & Lead: Pauline Benetti and Sally High	Project	Yes (concept)	Yes	No

San Juan River Basin Draft IPP List Continued…

PROPOSED IPPs

ID	Date	Sub Basin	NC/C/B	Description	County	Status	Remaining Steps	Need Addressed	IPP Contact Information: Sponsors	IPP Contact Information: Lead contact & Source of Info.	Project vs. Process	Project ready for implementation NOW?	Does the need exist today?	Already received some WSRA funding?
8-SJ	Nov-13	San Juan	NC	Park Ditch Hydropower Project. Small hydropower project associated with Park Ditch and Dry Gulch. The project could be developed prior to construction of the dam or pump station, or in conjunction with the dam project.	Archuleta	Not Complete	Secure partners, Feasibility study	Renewable Energy		Source: Val Valentine	Project	No (concept)	No	No
9-SJ	Jan-14	San Juan	NC	Spring Creek Restoration. Restore riparian habitat and water quality in a highly incised ephemeral stream, passing through Crowley Ranch Reserve green space.	Archuleta	Not Complete	Funding, Implementation	Recreation, Riparian habitat, Water quality	Crowley Ranch Reserve, NRCS, RMBO, USFWS	Lead: Jerry Archuleta Source: Martin Moses	Project	Yes	Yes	No
10-SJ	Jan-14	San Juan	NC	Crowley Ranch Reserve Wetland Enhancement. Enhance existing ponds and associate riparian areas on Reserve's green space.	Archuleta	Not Complete	Design, Funding, Implementation	Recreation, Wetland habitat	Crowley Ranch Reserve, NRCS, RMBO, USFWS	Lead: Jerry Archuleta Source: Martin Moses	Project			
11-SJ	SWSI 2010 Jan-14	San Juan	NC	Navajo River Restoration. Stream channel restoration on 9 miles of in-stream and stream-side riparian restoration on the Navajo River below the Oso Diversion am with private landowners.	Archuleta	Not Complete	Develop landowner interest	Habitat quality, Water quality, Agriculture	San Juan Conservation District, NRCS, RMBO, CPW, Landowners, USFWS, Chama Peak Land Alliance	Lead: Jerry Archuleta Source: Jerry Archuleta &Martin Moses	Project	Yes	Yes	No
12-SJ	Jan-14	San Juan	B	San Juan River Village MD River Restoration. Improve 1000 feet of San Juan River. Bank stability, instream habitat and recreational values in common use area (green space). Upstream of a diversion for MD and irrigation use by increasing channel stability .	Archuleta	Not Complete	Final engineering, Funding for implementation	Aquatic habitat quality, Water quality riparian, Recreation	NRCS, MD	Lead: Martin Moses, Cynthia Purcell Source: Martin Moses	Project			
13-SJ	Jan-14	San Juan	C	Water Conservation and Management Plan. The plan is a process to discuss development of water rights on the San Juan River (near Four Corners).	Montezuma	Not Complete	Complete planning process	Agricultural water supply, Potentially other water supply needs	Ute Mountain Ute Tribe	Lead & Source: Celene Hawkins	Process	Yes	Yes	Yes
14-SJ	Jan-14	San Juan	B	Chama Peak Land Alliance. Conservation minded landowners working collaboratively to practice and promote ecologically and economically sound land management in the southern San Juan Mountains of Colorado and northern New Mexico.	Archuleta	Ongoing			Chama Peak Land Alliance	Lead & Source: Monique DiGiorgio	Process	Yes	Yes	No
15-SJ	Apr-14	San Juan	B	San Juan Headwaters Forest Health Partnership. The Partnership is committed to collaborative approaches to improving the health and long-term resilience of mixed-conifer forests and the communities located near them in southwest Colorado. The Workgroup will focus on strengthening, understanding, sharing knowledge and lessons learned, developing management approaches, imitating high priority projects, and monitoring results using an adaptive framework.	Archuleta	Ongoing		Forest Health	Ecologists, Forest-related businesses, Fire personnel & EMS, Home Owners' Associations, Representatives from Federal, State, & County governments & entities, Consultants, Conservationists, Pagosa Range District Office, and Citizens	Lead & Source: Aaron Kimple	Process	Yes	Yes	No
16-SJ	Jul-14	San Juan	B	River Protection Workgroup Regional Process. The workgroups of 5 rivers from the San Juan to Animas and Hermosa lead a local process involving the public in protecting natural values while allowing water development to continue. Watershed values were defined and a final report was generated. The process continues today in the form of regional discussions with potential project outcomes. The process may convene the subbasin workgroups in the future.	Archuleta, Hinsdale, Mineral, La Plata, San Juan	Ongoing			SWCD, SJCA, TU, TWS, SUIT, DWR, CWCB, USFS, SJPL, 4 Corners Backcountry Horseman, Private landowners and Citizens	Lead: River Protection Workgroup Source: Ann Oliver	Both	N/A	N/A	No

Updated: 7/31/2014

Piedra River Basin Draft IPP List

PROPOSED IPPs

ID	Date	Sub Basin	NC/C/B	Description	County	Status	Remaining Steps	Need Addressed	IPP Contact Information: Sponsors	IPP Contact Information: Lead contact & Source of Info.	Project vs. Process	Project ready for implementation NOW?	Does the need exist today?	Already received some WSRA funding?
1-P	SWSI 2010	Piedra	C	Aspen Springs Water System The Metro District includes over 2,000 lots most of which are currently undeveloped. Eventually a pipe distribution system will be necessary to supply water.	Archuleta	Not Complete	Design of distribution system	Municipal water supply (infrastructure and water quantity)	Aspen Springs Metro District	Lead: Pat Ulrich Source: Steve Harris	Project	No	Yes	Yes
2-P	SWSI 2010	Piedra	NC	Lower Piedra from Hwy 160 to Navajo Lake. Some landowners have started to look at working together to treat a complete section of the river and hopefully this will progress to the stage that a comprehensive project could be developed (stabilization work). The project's focus is on stream bank stability, improved irrigation water diversions and improved riparian area conditions.	Archuleta	Not Complete		Habitat quality, Water quality	Southern Ute Tribe, NRCS & Private landowners	Source: Jerry Archuleta	Project	Yes	Yes	Yes
3-P	Fall 2013	Piedra	NC	Sambrito Project. Restore infrastructure to improve, deliver, and manage water to sustain wetlands at Navajo State Park.	Archuleta, La Plata	Not Complete	Restore infrastructure	Habitat quality and quantity	CPOW, BOR, SW-WFAC, Friends of the Navajo	Lead & Source: Catherine Ortega	Project	Yes	Yes	No
4-P	Nov-13	Piedra	C	La Plata Archuleta Water District. LAPLAWD's distribution system will consist of over 200 miles of pipeline, multiple storage tanks, water loading stations and other necessary infrastructure.	La Plata	Not Complete	Construction has begun	Municipal water supply (infrastructure and water quantity)	La Plata Archuleta Water District	Lead & Source: Ed Tolen, GM	Project	Yes	Yes	Yes
5-P	Jul-14	Piedra	B	River Protection Workgroup Regional Process. The workgroups of 5 rivers from the San Juan to Animas and Hermosa lead a local process involving the public in protecting natural values while allowing water development to continue. Watershed values were defined and a final report was generated. The process continues today in the form of regional discussions with potential project outcomes. The process may convene the subbasin workgroups in the future.	Archuleta, Hinsdale, Mineral, La Plata, San Juan	Ongoing			SWCD, SJCA, TU, TWS, SUIT, DWR, CWCB, USFS, SJPL, 4 Corners Backcountry Horseman, Private landowners and citizens	Lead: River Protection Workgroup Source: Ann Oliver	Process & Project	N/A	N/A	No

Updated: 7/31/2014

Pine River Basin Draft IPP List

PROPOSED IPPs

ID	Date	Sub Basin	NC/C/B	Description	County	Status	Remaining Steps	Need Addressed	IPP Contact Information: Sponsors	IPP Contact Information: Lead contact & Source of Info.	Project vs. Process	Project ready for implementation NOW?	Does the need exist today?	Already received some WSRA funding?
1-LP	SWSI 2010	Pine	C	La Plata Archuleta Water District Water Source. LAPLAWD master plan recommends two raw water sources, with one in the Pine River basin. LAPLAWD would utilize water from Vallecito Reservoir through PRID with joint treatment plant with the Town of Bayfield.	La Plata	Not Complete	Joint treatment plant between Bayfield & LAPLAWD will be constructed in 2014	Municipal water supply (infrastructure and water quantity)	La Plata Archuleta Water District	Lead & Source: Ed Tolen, GM	Project	Yes	Yes	Yes
2-LP	Nov-13	Pine	C	La Plata Archuleta Water District. LAPLAWD's distribution system will consist of over 200 miles of pipeline, multiple storage tanks, water loading stations and other necessary infrastructure.	La Plata	Not Complete	Construction has begun	Municipal water supply (infrastructure and water quantity)	La Plata Archuleta Water District	Lead & Source: Ed Tolen, GM	Project	Yes	Yes	Yes
3-LP	SWSI 1	Pine	NC	Vallecito Reservoir Flow Donation Agreement. The three entities have filed for a new water right in Vallecito Reservoir to allow a donation to the instream flow program in the Pine River and for other purposes. The new water right would also allow "exchange" water to provided to users outside of the PRID service area, such as upstream of Vallecito Reservoir.	La Plata	Not Complete	Water right needs to be finalized in court; Agree and approval by SUIT council	Fish habitat	Pine River Irrigation District, Southern Ute Indian Tribe, CWCB	Lead & Source: Steve Harris	Project	Yes	Yes	No
4-LP	SWSI 2010	Pine	C	Forest Lakes Metro District. Future issue is cost of contract water from Vallecito Reservoir.	La Plata	Not Complete		Municipal water supply	Forest Lakes Metro District	Source: Steve Harris, Janice Sheftel, John Porter	Project			No
5-LP	SWSI 2010	Pine	C	Southern Ute Indian Tribe. Source of water and treatment is Southern Ute Indian Tribe water rights. Tribe treats water, but each has own distribution systems.	La Plata	Not Complete		Municipal water supply	Southern Ute Indian Tribe, Town of Ignacio	Source: Steve Harris, Janice Sheftel, John Porter	Project			No
6-LP	Nov-13	Pine	C	Town of Bayfield. Future demands on the system will require infrastructure improvements and expansions/enlargements to the distribution system, treatment facilities and storage facilities.	La Plata	Not Complete	Design and Construct improvements	Municipal water supply (infrastructure)	Town of Bayfield	Source: Carrie Lile	Project	No	No	No
7-LP	Nov-13	Pine	C	Town of Ignacio. Future demands on the system will require infrastructure improvements and expansions/enlargements to the distribution system, treatment facilities and storage facilities.	La Plata	Not Complete	Design and Construct improvements	Municipal water supply (infrastructure)	Town of Ignacio	Source: Carrie Lile	Project	No	No	No
8-LP	Jan-14	Pine	NC	River Ranch Pine River Habitat Improvement. Improve instream and riparian habitat along 0.75 mile reach through POA green space.	La Plata	Not Complete	Design, Fund and Construct	Aquatic habitat, Riparian habitat	River Ranch POA, NRCS, USFWS, RMBO	Lead: NRCS				
9-LP	Nov-14	Pine	C	Vallecito Reservoir Spillway Floor Repair. The spillway floor is in need of repair sometime in the near future. Could be in 5 to 10 years. No estimates yet on cost but it's expected to be quite expensive.	La Plata	Not Complete	Design, Fund and Construct	Water supply (all uses), Safety	Pine River Irrigation District	Source & Lead: Mike Canterbury	Project	No	No	No
10-LP	Dec-14	Pine	C	Vallecito Reservoir East Spillway Repair. The east spillway wall next to the #3 radial gate needs repair. Erosion is taking place behind the two sections closest to the east radial gate which is pushing the concrete against the gate. This is affecting the gate operation dramatically. The radial gates open to about 15 feet. Because of the binding issue with gate #3 they can only open that gate up to about 4 feet before their is a risk the gate is getting stuck.	La Plata	Not Complete	Design, Fund and Construct	Water supply (all uses)	Pine River Irrigation District	Source & Lead: Mike Canterbury	Project	No	YEs	No
11-LP	Jul-14	Pine	B	River Protection Workgroup Regional Process. The workgroups of 5 rivers from the San Juan to Animas and Hermosa lead a local process involving the public in protecting natural values while allowing water development to continue. Watershed values were defined and a final report was generated. The process continues today in the form of regional discussions with potential project outcomes. The process may convene the subbasin workgroups in the future.	Archuleta, Hinsdale, Mineral, La Plata, San Juan	Ongoing			SWCD, SJCA, TU, TWS, SUIT, DWR, CWCB, USFS, SJPL, 4 Corners Backcountry Horseman, Private landowners and Citizens	Lead: River Protection Workgroup Source: Ann Oliver	Both	N/A	N/A	No

Animas River Basin Draft IPP List

Updated: 7/31/2014

PROPOSED IPPs

ID	Date	Sub Basin	NC/C/B	Description	County	Status	Remaining Steps	Need Addressed	IPP Contact Information: Sponsors	IPP Contact Information: Lead contact & Source of Info.	Project vs. Process	Project ready for implementation NOW?	Does the need exist today?	Already received some WSRA funding?
1-A	Jul-13	Animas	C	Animas-LA Plata Project. Utilization of Animas-LA Plata Project water supplies for multiple purposes by Southern Ute Indian Tribe, Ute Mountain Ute Indian Tribe, Animas-LA Plata Water Conservancy District, City of Durango, LA Plata West Water Authority, Lake Durango Water Authority, Colorado Water Conservation Board, LA Plata Archuleta Water District, and others that may be entitled to ALP water. The utilization could include treatment and conveyance (pumps and pipelines) of raw or treated water.	La Plata, Archuleta, Montezuma	Not Complete		Municipal water supply	Southern Ute Indian Tribe, Ute Mountain Ute Indian Tribe, Animas-LA Plata Water Conservancy District, City of Durango, LA Plata West Water Authority, Lake Durango Water Authority, Colorado Water Conservation Board, LA Plata Archuleta Water District, and others that may be entitled to ALP water		Both	Yes	Yes	Yes
2-A	Jul-13	Animas	NC	Lake Nighthorse Recreation. Provide boating, fishing, and swimming opportunities.	La Plata	Not Complete		Recreation	Animas La Plata Water Conservancy District, Bureau of Reclamation, La Plata county, City of Durango		Project	Yes	Yes	Yes
3-A	Oct-13	Animas	C	La Plata Archuleta Water District. Design and construction of a treatment plant for ALP water possibly in coordination with City of Durango. Transmission and distribution pipelines to convey treated water from the treatment plant to customers.	La Plata	Not Complete	Investigate potential partnerships, acquire land, design and construct	Municipal water supply	La Plata Archuleta Water District	Lead and Source: Ed Tolen	Project	No	Yes	Yes
4-A	SWSI 2010	Animas (Florida)	C	Florida Water Conservancy District. Need for industrial, municipal, domestic, commercial, wildlife, wetlands, exchange, augmentation, hydropower, irrigation, and fire protection water within the Florida River basin. The District has initiated institutional changes by entering into a water service contract with the BOR to use decreed 114 AF water right for augmentation purposes and has obtained a 2,500 AF water right to address the aforementioned uses. Utilization of the 2,500 AF will require another water service contract with the BOR, voluntary water turn in by users, and irrigation system efficiency improvements by the Florida Mesa Ditch Companies that would firm up agricultural delivery and provide additional water supply for those other uses in Lemon Reservoir through the reduction of losses in the delivery system.	La Plata	Not Complete	Finalize water service contract with BOR and Complete additional irrigation system improvements	Municipal, Industrial & Agricultural water supplies	Florida Water Conservancy District	Lead & Source: Florida Water Conservancy District	Project	Yes	Yes	Yes
5-A	SWSI 2010	Animas (La Plata too)	C	Rural Domestic Water Supply. Potential joint project to construct raw water pump and pipeline among Durango West Metro Districts, Lake Durango Water Company, and/or La Plata West Authority. Other options include the future Animas La-Plata/ Western La Plata rural domestic system or to purchase treated water from Lake Durango.	La Plata	Not Complete	Lake Durango Water Company was purchased by Lake Durango Water Authority; Negotiations for ALP water ongoing		Durango West Metro District #1, Durango West Metro District #2, Lake Durango, La Plata West Water Authority	Source: Steve, Janice, John	Both		Yes	Yes
6-A	SWSI 2010	Animas (Florida)	C	Edgemont Ranch Metro District. May need storage for firming.	La Plata	Not Complete			Edgemont Ranch Metro District	Source: Steve Harris	Project			
7-A	SWSI 2010	Animas (Florida)	C	El Rancho Florida Metropolitan District. System is built out but upgrading water source and treatment to meet increasing treatment standards.	La Plata	Not Complete			El Rancho Florida Metropolitan	Source: Steve Harris	Project			
8-A	SWSI 2010	Animas	NC	Recreational In-Channel Diversion. Provide a boating park that allows for rafting, kayaking, tubing and other water sports to occur. Water needs depend on the time of year. Water rights were secured in 2009. Construction of the anchored rock facility commenced in the Fall of 2013.	La Plata	Not Complete	Complete construction	Recreation	City of Durango	Source: City of Durango	Project	Yes	Yes	No
9-A	SWSI 2010	Animas	C	Purgatory Metropolitan District. District has sufficient water now, but is anticipating huge growth, especially at Durango Mountain Resort. The District is looking for more water. Water rights must be deeded to District with inclusion of property within the District. District is looking.	La Plata	Not Complete			Purgatory Metropolitan District					
10-A	SWSI 2010	Animas	C	San Juan County. San Juan County with assistance from SWCD has applied for a water right to provide for the future water needs in the Animas River basin in the County. The application is pending with negotiations with opposers. Implementation of the eventual decree will result in recommended IPPs.	San Juan	Not Complete	Water right nearly decreed; Maintain diligence		SWCD, San Juan County					

Animas River Basin Draft IPP List Continued…

PROPOSED IPPs

ID	Date	Sub Basin	NC/C/B	Description	County	Status	Remaining Steps	Need Addressed	IPP Contact Information: Sponsors	IPP Contact Information: Lead contact & Source of Info.	Project vs. Process	Project ready for implementation NOW?	Does the need exist today?	Already received some WSRA funding?
11-A	SWSI 2010 (Updated from SWSI 1)	Animas	C	Town of Silverton. Physical water supply is presently adequate, but the Town is applying for an augmentation plan to firm up supply from a potential senior call on the Animas River. The augmentation plan would utilize existing and enlarged capacity of Molas Lake as storage for augmentation water. If necessary, alternative storage sites may be reviewed to replace and/or supplement Molas Lake.	San Juan	Not Complete	Water is decreed; Maintain diligence; Develop IPPs to make use of water		Town of Silverton					
12-A	SWSI 2010	Animas	C	Cascade Village. North of Purgatory and supplies water to condominium development. Option is to develop wells. Durango proposed RICD could impact future water development.	San Juan	Not Complete		Municipal water supply	Cascade Village	Source: Steve Harris				
13-A	SWSI 2010	Animas (Florida)	C	Lemon Reservoir Ditch Companies Improvements. Currently nearly all of the irrigation system to deliver Lemon Reservoir water is old open ditch. There is the potential to upgrade these ditches (lining and piping) to conserve water in Lemon for decreed purposes. To date 3 miles of ditches has been lined.	La Plata	Ongoing	Design and construct additional improvements	Agricultural water supply	Florida Water Conservancy District, Florida Consolidated Ditch Company	Lead & Source: FWCD & FCDC	Project	Yes	Yes	Yes
14-A	Nov-13	Animas	C	La Plata Archuleta Water District. LAPLAWD's distribution system will consist of over 200 miles of pipeline, multiple storage tanks, water loading stations and other necessary infrastructure.	La Plata	Not Complete	Construction has begun	Municipal water supply (infrastructure and water quantity)	La Plata Archuleta Water District	Lead & Source: Ed Tolen, GM	Project	Yes	Yes	Yes
15-A	SWSI 2010	Animas	B	Children's Water Festival. Sponsored by the Southwestern Water Conservation District and Water Information Program.	Southwest	Ongoing		Education	Coordinated by The Water Information Program the annual program includes a varying and diverse array of stakeholders/presenters	Lead & Source: Denise Rue-Pastin	Process	Yes	Yes	No
16-A	SWSI 2010	Animas	NC	Animas River Vegetation Management. On-going annual project by SUIT to improve the riparian corridor by managing non-native vegetation. Annual program from 2002- present.	La Plata	Ongoing		Riparian health, Non-native vegetation control	SUIT	Source: SUIT Wildlife	Project			
17-A	SWSI 2010, Updated Nov 2013	Animas (Hermosa)	NC	Hermosa Creek CRCT Metapopulation Project. Collaborative effort to create an isolated meta-population of CO River cutthroat trout in the Hermosa Creek watershed. Some barriers installed; some need installation; next steps include non-native trout removal and relinkage of mainstem and tributary. CWCB minimum ISFs occur on Hermosa mainstem and tributaries; project is structural to create upstream migration barriers, cleanse existing mixed salmonic population, and subsequently link upper watershed and tributaries into genetically clean meta-population. UPDATE: Upper Hermosa Creek above the confluence, removed non-natives from 9 miles, down until Hotel Draw. Phases by segments, 1) small segment on East Fork, NNR; 2) One common barrier between steams and removed.	La Plata	Not Complete		Colorado River Cutthroat Trout	CPW, USFS, TU 5 Rivers Chapter	Lead & Source: Jim White	Project	Yes	Yes	No
19-A	Fall 2013	Animas (Florida)	B	Florida River Habitat and Water Quality Improvement Project. Install fencing along ~1mile of the Florida River to allow for management of livestock away from a riparian buffer zone and the river channel itself. Improve irrigation practices on about 25 acres of flood irrigated pastures.	La Plata	Not Complete	Complete construction	Trout, Native fish, Riparian habitat, Aquatic habitat improvements and reduction in nutrient, Sediment and bacterial loading	Animas Watershed Partnership, San Juan RC&D, Durango-La Plata Regional Airport, CO NPS, San Juan Watershed Group, Private Landowner	Lead & Source: Ann Oliver	Project	Yes	Yes	No
20-A	Jan-14	Animas	B	Microbial Source Tracking Study. A two year (2013, 2014) sampling effort to identify the genetic sources (i.e. ruminant, horse, human, dog, waterfowl, other) of E. coli and Bacteroides in the Animas Mainstem in New Mexico. One site sampled in Colorado 2 miles north of the state line. Colorado partners discussing possibility of adding sample sites in Colorado. Led by the San Juan Watershed Group in partnership with the Animas Watershed Partnership.	La Plata	Not Complete	Complete second year of sampling. Decide whether to seek funding for additional sampling locations in Colorado.	Water quality	Animas Watershed Partnership, San Juan Watershed Group, San Juan RC&D, San Juan Soil and Water Conservation District, CO NPS, Private Landowners, Citizens.	Lead & Source: Ann Oliver	Project	Yes	Yes	No
21-A	Jan-14	Animas	C	Animas Consolidated Ditch Company. The project objectives are to install control points along a specific river stream section, delineate river cross sections, collect and analyze data. The ditch's headgate has experienced head cutting impacts due to the excessively large gravel operations during the late 1900s.	La Plata	Ongoing	Evaluate data collected, Final report	Agricultural water supply	Animas Consolidated Ditch	Lead and Source: Ed Zink	Project	Yes	Yes	Yes

Animas River Basin Draft IPP List Continued…

PROPOSED IPPs

ID	Date	Sub Basin	NC/C/B	Description	County	Status	Remaining Steps	Need Addressed	IPP Contact Information: Sponsors	IPP Contact Information: Lead contact & Source of Info.	Project vs. Process	Project ready for implementation NOW?	Does the need exist today?	Already received some WSRA funding?
22-A	Jan-14	Animas	B	Animas Watershed Partnership. The Partnership members are stewards in protecting and improving the quality of water resources in the Animas Watershed. The Partnership fosters a community based collaborative process involving all stakeholders by using available data sources and sound science.	San Juan, La Plata	Ongoing		Water quality, Recreation, Habitat quality, Drinking water	City of Durango, City of Farmington, Southern Ute Indian Tribe, Southwestern Water Conservation District, Trout Unlimited, San Juan Watershed Group, San Juan Soil and Water Conservation District, La Plata Conservation District, Bureau of Reclamation	Lead & Source: Ann Oliver	Process	Yes	Yes	No
23-A	SWSI 2010	Animas	B	Animas River Stakeholders Group. Animas River Stakeholders Group working to meet Water Quality Standards to protect aquatic species and improve aquatic habitat, Maggie Gulch to Silverton and Silverton through Durango. Remediation of 33 mine waste sites and 36 draining mines. Most of the mine waste sites have been completed. About 5 draining mines have been addressed.	San Juan, La Plata	Ongoing	Continue to address remaining draining mines	Water quality, Recreation, Habitat quality, Drinking water	SWWCD, SJCA, TU, TWS, SUIT, CDWR, CWCB, USFS, SJRC&D, Private landowners and citizens	Lead: Bill Simon and Peter Butler; Source: Ann Oliver	Process	Yes	Yes	
24-A	Dec-13	Animas	NC	Four Corners Paddle Trail Project. A study to determine if a Four Corners Paddle Trail idea is feasible under a partnership approach to management. The working group will focus on the development of a river recreation plan that addresses river access, safety hazards, conservation, education and public information. San Juan River Quality Waters will not be compromised and private property will not be affected. There will be opportunities for civic engagement throughout the planning process to listen to your concerns, ideas and opportunities.	La Plata	Not Complete	Outreach and Education around river etiquette, Trespass issues, Installation of signage	Recreation (Boating)	San Juan County, NM; City of Farmington; City of Aztec; City of Durango; City of Bloomfield; River Reach Foundation; San Juan College; Durango Trails 2000; Aztec Trails & Open Space Inc.; San Juan Watershed Group; Four Corners Economic Development; National Park Service; Bureau of Land Management; Jacks Plastic Welding; 4 Corners River Sports	Lead: Source: Kent Ford	Process	No	Yes	No
25-A	Nov-13	Animas	NC	Florida River Habitat Assessment. Florida River Habitat Assessment for Native Warmwater Fish.	La Plata	Not Complete	Conduct field assessment	Habitat quality, Native fish species	CPW, private landowners	Lead: Jim White	Project	No	Yes	No
26-A	Jan-13	Animas	NC	Salmonid Habitat Improvements. Salmonid Habitat Improvement above Howardsville.	San Juan	Not Complete		Aquatic habitat quality, Trout fishery	BLM, CPW	Source: Jim White	Project	No	Yes	No
27-A	Sep-12	Animas	C	Animas Airpark Water Distribution System. The POA applied for WSRA funds to design the pipe distribution system to utilize water available from the City of Durango pipeline.	La Plata	Not Complete	Obtain City approval of design, Construction and Connection to water source	Municipal water supply	Animas Airpark POA	Lead & Source: Bob Wolf	Project	Yes	Yes	Yes
28-A	Jan-14	Animas	C	Hess Ditch Lateral Replacement. Sunnyside school location…Incorporated ditch. Put 1.5 miles in a pipe. Irrigates 600acres.	La Plata	Not Complete	Engineering design, funding and implementation	Agricultural water supply	CDOT, NRCS, Florida Canal Enlargement Company	Lead: Florida Canal Enlargement Company Source: Sterling Moss	Project			
29-A	Jan-14	Animas (Florida)	B	Florida River Water Quality Initiative. Targeted EQIP funds for work on agricultural lands in the watershed, including salt creek.	La Plata	Not Complete	Continue to develop landowner partners, Design fund implement	Water quality, Riparian habitat, Aquatic habitat quality, Agriculture infrastructure for irrigation	NRCS, LPCD, landowners	Lead & Source: Sterling Moss	Project			
30-A	Jan-14	Animas (Florida)	NC	El Rancho Florida, Florida River Riparian and Aquatic Habitat Improvement. Improve riparian buffer vegetation and instream habitat.	La Plata	Not Complete	Final design, Fund implement	Water quality, Riparian, Aquatic habitat	NRCS, RMBO, La Plata Open Space, El Rancho Florida MD, private landowner	Lead & Source: Sterling Moss	Project	No	Yes	No
31-A	Dec-13	Animas	C	La Posta Road Water Distribution System. The La Posta Road Property Owners Association is interested pursuing the formation of a special district. The special district will conduct a mill levy election which is needed to finance a water distribution system for La Posta Road and surrounding parcels. The POA will receive treated water from the City of Durango.	La Plata	Not Complete	Formation of District, Mill levy election, Secure funding, Construct distribution system	Municipal water supply, Infrastructure	La Posta Road property owners	Lead & Source: Bob Wolf	Process & Project	No	Yes	No
32-A	Jan-13	Animas	C	Reinforcement of the Boulder Head Gate. The headgate is the source of water for the Town of Silverton. The Town has been working on the headgate upgrades since 2005. They shotcreted the headgate area in 2005 and again in 2011. The area still needs one more application of shotcrete. If the third application is not applied, there is a chance for an avalanche to destroy the	San Juan	Not Complete	Secure funding, Complete application of shotcrete	Municipal water supply, Infrastructure	Town of Silverton	Lead: Gilbert Archuleta, Source: Anthony Edwards	Project	Yes	Yes	No

Animas River Basin Draft IPP List Continued…

PROPOSED IPPs

ID	Date	Sub Basin	NC/C/B	Description	County	Status	Remaining Steps	Need Addressed	IPP Contact Information: Sponsors	IPP Contact Information: Lead contact & Source of Info.	Project vs. Process	Project ready for implementation NOW?	Does the need exist today?	Already received some WSRA funding?
33-A	Jul-14	Animas, Hermosa	B	River Protection Workgroup Regional Process. The workgroups of 5 rivers from the San Juan to Animas and Hermosa lead a local process involving the public in protecting natural values while allowing water development to continue. Watershed values were defined and a final report was generated. The process continues today in the form of regional discussions with potential project outcomes. The process may convene the subbasin workgroups in the future.	Archuleta, Hinsdale, Mineral, La Plata, San Juan	Ongoing			SWCD, SJCA, TU, TWS, SUIT, DWR, CWCB, USFS, SJPL, 4 Corners Backcountry Horseman, Private landowners and citizens	Lead: River Protection Workgroup Source: Ann Oliver	Both	N/A	N/A	No
34-A	SWSI 2010	Animas (Elbert)	C	Elbert Creek Augmentation Plans. The Elbert Creek tributary of the Animas River North of Durango is over developed. Electra Lake is available as a source of augmentation. Other augmentation sources are not developed.		Not Complete		Water supply		Source: Steve Harris	Project			
35-A	SWSI 2010	Animas	C	Animas River Water Supply Upstream of RICD. Once the RICD at Smelter Rapids is constructed Animas River Basin north of Durango will become water critical. SWCD and LA Plata County obtained a decree to provide water senior to the RICD to meet this need. Portions of this decree are being distributed to water users.		Ongoing		Water supply	Unincorporated Northern La Plata County not covered by a water system	Source: Steve, Janice, John	Project			

Updated: 3/20/2015

La Plata River Basin Draft IPP List

PROPOSED IPPs

ID	Date	Sub Basin	NC/C/B	Description	County	Status	Remaining Steps	Need Addressed	IPP Contact Information: Sponsors	IPP Contact Information: Lead contact & Source of Info.	Project vs. Process	Project ready for implementation NOW?	Does the need exist today?	Already received some WSRA funding?
1-LaP	SWSI 2010	La Plata	C	La Plata West Water Authority. Provide Western La Plata County with a rural domestic water system to provide a safe, dependable source of domestic water in an area with minimal groundwater availability and diminishing amounts of water from La Plata River.	La Plata	Not Complete		Municipal water supply	La Plata West Water Authority, UMUT, SUIT, Lake Durango	Lead & Source: Roy Horvath		N/A	Yes	Yes
2-LaP	SWSI 2010	La Plata	C	Long Hollow Dam Project (aka Bobby K Taylor Reservoir). LPWCD developed a reservoir site with 5,309 AF storage in Long Hollow. Water will be used for Compact compliance and irrigation supply by exchange. There is also potential use for augmentation and exchange for domestic wells.	La Plata	Construction Completed	Annual Reservoir Operations	Agricultural water supply, Compact compliance	La Plata Water Conservancy District	Lead & Source: Eric Bikis	Project	Yes	Yes	Yes
3-LaP	Mar-14	La Plata	C	Long Hollow Reservoir Compact Water Delivery Study. La Plata Water Conservancy District is performing a study to understand stream characteristics of the La Plata River along the 4.5 mile reach between Low Hollow and the New Mexico stateline stream gage. This work will help administer Compact compliance and develop a plan for reservoir releases and stream administration.	La Plata	Not Complete	Secure funding, Conduct study	Compact compliance	La Plata Water Conservancy District	Source: Brice Lee; Lead: Eric Bikis	Project	Yes	Yes	Yes
4-LaP	SWSI 2010	La Plata	C	Red Mesa Ward Reservoir. Existing storage and rights for 1,176 AF storage owned by Red Mesa Reservoir Company, primary use irrigation with other uses including industrial and existing domestic augmentation plans. Needs include spillway and/or outlet updates to maintain existing capacity and compile with Division of Water Reservoirs regulations. Enlargement-refill water rights of 4,074 AF held by LPWCD to meet existing and future demands including domestic, augmentation, irrigation, etc. Studies of enlargement potential in place and feasibility ongoing.	La Plata	Not Complete	Secure funding. Construct project.	Agricultural, Industrial, Municipal water supplies	La Plata Water Conservancy District	Source: Trent Taylor	Project	Yes	Yes	Yes
5-LaP	SWSI 2010	La Plata	NC	In-channel Habitat Enhancement. La Plata River (Doughty), 450 feet of channel and riparian habitat improvements.	La Plata	Not Complete			SUIT, NRCS, BOR		Project	Yes	Yes	No
6-LaP	SWSI 2010	La Plata	C	Augmentation Plans in La Plata River Basin. The La Plata River basin is water critical and new uses require augmentation plans to change existing water rights to new uses.	La Plata	Not Complete					Project			
7-LaP	SWSI 2010	La Plata	NC	Management of Invasive Riparian Species. Management of weeds, tamarisk, and Russian olive control. Ecosystem enhancement/non-native vegetation control. Work has been ongoing since 2002.	La Plata	Not Complete		Riparian habitat	SUIT, DWR		Project	Yes	Yes	No
8-LaP	Jan-14	La Plata	C	Rehabilitation of the "Old Fort Lewis" Water System. The current water system was built over 50 years ago to serve the student and employee populations. Once the college moved to Durango, the property became a resource for community activities including research and education. The water system is need of major upgrades and rehabilitation. The water source is the Lory Spring and is considered Groundwater Under the Direct Influence of Surface Water which requires direct filtration and disinfection. The project proposes to rehabilitate the old system by upgrading electrical system, replacing the current pressure tank, installing up to date chlorination system, cartridge filtration equipment and upgrading safety issues in the building.	La Plata	Not Complete	Secure funding and construct	Municipal water supply	Fort Lewis	Lead & Source: Beth LaShell	Project	Yes	Yes	No
9-LaP	Jan-14	La Plata, Mancos, McElmo	C	Water Conservation and Management Plan. The plan is a process to discuss development of the UMUT allocation in A-LP (including but not limited to: development into western La Plata County and eastern Montezuma County (dry side development)).	La Plata, Montezuma	Not Complete	Complete planning process	Future municipal, Industrial water supply	Ute Mountain Ute Tribe	Lead & Source: Celene Hawkins	Process	Yes	Yes	Yes
10-LaP	Jan-14	La Plata	C	Lake Durango Water Authority. Development of infrastructure and water sources to deliver water within the Lake Durango service area.	La Plata	Not Complete	Design and Construction	Municipal water supply	Lake Durango Water Authority	Source: Tom Brossia & Charlie Smith	Project	Yes	Yes	Yes
11-LaP	Jul-14	La Plata & Animas	C	Agricultural Water Supply. Southwestern Water Conservation District holds water rights in the Animas River that are decreed and available to meet irrigation demands within the La Plata basin. This water supply could potentially provide water for supplemental supplies on existing irrigate lands and to provide a supply for full service lands.	La Plata	Not Complete		Agricultural water supply	Southwestern Water Conservation District	Lead & Source: Bruce Whitehead	Project	No	Yes	No

La Plata River Basin Draft IPP List Continued…

PROPOSED IPPs

ID	Date	Sub Basin	NC/C/B	Description	County	Status	Remaining Steps	Need Addressed	IPP Contact Information: Sponsors	IPP Contact Information: Lead contact & Source of Info.	Project vs. Process	Project ready for implementation NOW?	Does the need exist today?	Already received some WSRA funding?
12-LaP	Jul-14	La Plata	C	Big Stick Ditch. Improvements to be made to existing diversion structure and ditch. Mancos shale slide areas exist around the ditch, the project proposes to pipe the ditch within these areas. Complete improvements to the diversion structure.	La Plata	Not Complete	Secure funding, Construct	Agricultural water supply		Lead & Source: Guy Stees	Project	Yes	Yes	No
13-LaP	Nov-14	La Plata	C	Soldiers Draw. A feasibility study was conducted in the La Plata River basin to define additional water storage in the area. La Plata water Conservancy District received a decree for water storage rights in Soldiers Draw for construction of a reservoir allowing 1,000 acre-feet of storage. Water would be used for Compact compliance purpose as well as domestic and agricultural use by downstream users.	La Plata	Not Complete	Secure funding, Construct project	Compact compliance, Agricultural water supply	La Plata Water Conservancy District	Source: Eric Bikis	Project	Yes	Yes	Yes
14-LaP	Mar-15	La Plata	C	La Plata River Ditch Capacity Enlargement. Numerous La Plata River ditches are feeder ditches decreed to divert and convey water to the Long Hollow Project and associated recharge pits. These ditches do not have sufficient capacity to convey this volume of water during some portions of the year. Funding is needed to increase the size of one or more of these ditches.	La Plata	Not Complete	Secure funding, Construct project	Compact compliance, Agricultural water supply	La Plata Water Conservancy District	Source: Eric Bikis	Project	Yes	Yes	Yes
15-LaP	Mar-15	La Plata	C	La Plata River Ditch Lining and/or Sealing. Several of the La Plata River Ditches that may be used as an alternative conveyance of water to meet Colorado's obligation to New Mexico under that La Plata River Compact would benefit from lining or sealing. This would increase efficiency of Compact deliveries and would thereby benefit both Colorado and water users within the La Plata River Basin. Ditch losses would be assessed and a proposed ling/sealing plan would be developed prior to implementation of the plan.	La Plata	Not Complete	Secure funding, Construct project	Compact compliance, Agricultural water supply	La Plata Water Conservancy District	Source: Eric Bikis	Project	Yes	Yes	Yes
16-LaP	Mar-15	La Plata	C	BKT Diversion Ditch Study. A study is needed to determine if a ditch dedicated to convey water from the La Plata River to the Long Hollow Project is feasible. Such a ditch would benefit storage in the BKT Reservoir and improve Compact deliveries to New Mexico.	La Plata	Not Complete	Secure funding, Conduct study	Compact compliance, Agricultural water supply.	La Plata Water Conservancy District	Source: Eric Bikis	Project	Yes	Yes	Yes

Updated: 7/31/2014

Mancos River Basin Draft IPP List

PROPOSED IPPs

ID	Date	Sub Basin	NC/C/B	Description	County	Status	Remaining Steps	Need Addressed	IPP Contact Information: Sponsors	IPP Contact Information: Lead contact & Source of Info.	Project vs. Process	Project ready for implementation NOW?	Does the need exist today?	Already received some WSRA funding?
1-M	SWSI 2010	Mancos	B	Salinity Control Project. Mancos Valley Salinity Control Project Plan and Environmental Assessment.	Montezuma	Ongoing	Continue to work with private landowners to install irrigation pipelines	Agriculture, Water quantity, Water quality, Aquatic habitat	NRCS, MCD, Ute Mtn Ute Tribe, private landowners	Lead: NRCS; Source: Ann Oliver	Project	Yes	Yes	No
2-M	Dec-13	Mancos	B	Mancos River Watershed Stakeholders Group. Mancos River Watershed Stakeholders implementing recommendations of completed Watershed Based Plan. Plan identifies goals, sources and practices to implement to protect and improve water resources in the Mancos River watershed.	Montezuma	Ongoing	Continue to foster awareness and dialogue; Develop funding for implementing recommendations and other projects	Water quality, Aquatic habitat, Channel function, Riparian function, Fisheries, Agriculture, Municipal	MCD, CWCB, CO NPS, UMUT, Mesa Verde National Park, private landowners and interested citizens	Lead: Mancos Conservation District Source: Ann Oliver	Process	No	Yes	Yes
3-M	Dec-13	Mancos	B	Mancos River Habitat and Diversion Project - Phase II. To restore aquatic habitat and efficiency of 4 irrigation diversions along a 2.4 mile reach downstream of Mancos (ditches: Veits, Bolen, Sheek, and Exon). To allow fish and sediment passage and promote channel stability.	Montezuma	Not Complete	Construct 4 diversion structures; Complete RSRA surveys; Final Report	Agriculture; Trout and native fish, Aquatic habitat, Healthy channel, Riparian habitat	Landowners, ditch companies, MCD, TU, CWCB, Peter Stacey	Lead: MCD; Source: Ann Oliver	Project	Yes	Yes	Yes
4-M	Dec-13	Mancos	NC	Mancos Fishing Habitat Improvements. Potential project to improve aquatic habitat and fishing opportunity through Mancos. Potential to design and install habitat improvement measures in channel.	Montezuma	Not Complete	ID partners and funding source(s)	Trout fisheries, Native fish, Aquatic habitat	CPW, MCD, TU	Source: Ann Oliver and Jim White	Project	No	Yes	No
5-M	Nov-13	Mancos	NC	Habitat Assessment of the Mancos River. Identify opportunities to enhance or protect habitat in water limited streams. The Mancos River, together with the La Plata River, hosts the most genetically intact native fish community on the West slope of Colorado, due largely to the lack of invasion by non-native fish species.	Montezuma	Not Complete	Conduct study; Report results and recommendations	Native fish, Aquatic habitat	CPW, Ute Mountain Ute Tribe	Lead: Paul Jones Source: Paul Jones	Project	Yes	Yes	No
6-M	Jan-14	Mancos	C	Jackson Gulch Reservoir Enlargement. Reservoir enlargement of 5 feet added to the dam height which equates to 1,000 AF of new storage.	Montezuma	Not Complete	Feasibility, Design, and Construction; Secure funding	Agricultural water supply, Municipal water supply	Mancos Water Conservancy District	Lead & Source: Gary Kennedy	Project	No, Planning stage	No	Yes
7-M	Jan-14	Mancos	C	Lake Mancos Reservoir. New reservoir with a dam height of 10 feet and 80 AF of new storage.	Montezuma	Not Complete	Phase 1 Completed; Feasibility, Design, and Construction; NEPA compliance	Agricultural water supply, Municipal water supply	Mancos Water Conservancy District	Lead & Source: Gary Kennedy	Project	No, Planning stage	Yes	Yes
8-M	Jan-14	Mancos	C	Weber Reservoir Diversion. Inlet rehabilitation is needed. Improvements to the structure and line or pipe the inlet canal.	Montezuma	Not Complete	Secure funding; Design and Construction	Agricultural water supply	Mancos Water Conservancy District	Lead & Source: Gary Kennedy	Project	No	No	No
9-M	Jan-14	Mancos	C	Bauer Lake Diversion. Inlet rehabilitation is needed. Improvements to the structure and line or pipe the inlet canal.	Montezuma	Not Complete	Secure funding; Feasibility, Design, and Construction	Agricultural water supply	Mancos Water Conservancy District	Lead & Source: Gary Kennedy	Project	No	No	No
10-M	Jan-14	Mancos	C	Joe More Reservoir Diversion. Inlet rehabilitation is needed. Improvements to the structure and line or pipe the inlet canal.	Montezuma	Not Complete	Secure funding; Feasibility, Design, and Construction	Agricultural water supply	Mancos Water Conservancy District	Lead & Source: Gary Kennedy	Project	No	No	No
11-M	Jan-14	Mancos	C	River Measuring Stations. Mancos River contributories need measurement. Needed for water management with an addition of 3 to 4 measuring flumes.	Montezuma	Not Complete	Secure funding; Currently undergoing Placement Study; Next steps design and construction	Agricultural water supply management, Environmental	Mancos Water Conservancy District	Lead & Source: Gary Kennedy	Project	No, Planning stage	Yes	No
12-M	Jan-14	Mancos	C	Weber Ditch Piping. Piping of the ditch in areas that are compromised by the Weber fire and areas that have issues of safety and seepage.	Montezuma	Not Complete	Secure funding; Feasibility completed; Design and Construction	Agricultural water supply; Fire mitigation	Mancos Water Conservancy District	Lead & Source: Gary Kennedy	Project	No, Planning stage	Yes	No
13-M	Jan-14	Mancos	C	Root & Ratliff Ditch Piping. Ditch piping needed for better water conservation and control.	Montezuma	Not Complete	Secure funding; Feasibility completed; Design and Construction	Agricultural water supply management	Mancos Water Conservancy District	Lead & Source: Gary Kennedy	Project	No, Planning stage	Yes	No

Mancos River Basin Draft IPP List Continued…

PROPOSED IPPs

ID	Date	Sub Basin	NC/C/B	Description	County	Status	Remaining Steps	Need Addressed	IPP Contact Information: Sponsors	IPP Contact Information: Lead contact & Source of Info.	Project vs. Process	Project ready for implementation NOW?	Does the need exist today?	Already received some WSRA funding?
14-M	Jan-14	Mancos	C	Town of Mancos. Increase portable water storage; larger storage facilities for portable water, public health and fire suppression.	Montezuma	Not Complete	Secure funding; Feasibility completed; Design and Construction	Municipal water supply, Water quality	Mancos Water Conservancy District	Lead & Source: Gary Kennedy	Project	No, Planning stage	Yes	No
15-M	Jan-14	Mancos	C	Mancos Rural Water Company. Increase portable water storage; larger storage facilities for portable water and public health.	Montezuma	Not Complete	secure funding; Feasibility completed; Design and Construction	Municipal water supply, Water quality	Mancos Water Conservancy District	Lead & Source: Gary Kennedy	Project	No, Planning stage	Yes	No
16-M	Jan-14	Mancos	NC	Hydropower Potential. Potential for hydropower facilities within the canals and ditches within the Mancos Valley. As technologies progress potential hydropower production progresses.	Montezuma	Not Complete	Conduct study; Report Results and recommendations	Renewable energy	Mancos Water Conservancy District	Lead & Source: Gary Kennedy	Project	No	No	No
17-M	Feb-14	Mancos	C	Jackson Gulch Drop Chute Pipe. Need piping to secure water source for the reservoir; provide protection of private property and safety.	Montezuma	Not Complete	Secure funding; Currently in planning sages; Design and Construction	Agricultural water supply	Mancos Water Conservancy District	Lead & Source: Gary Kennedy	Project	No, Planning stage	Yes	No
18-M	Jan-14	Mancos	B	Natural Disaster Planning. Conduct planning for natural disaster such as fire, flood, etc...	Montezuma	Not Complete	Planning stages	Protection of water supply, Water quality for all values	Mancos Water Conservancy District	Lead & Source: Gary Kennedy	Process	No, Planning stage	Yes	No
19-M	Jan-14	Mancos	C	Water Conservation and Management Plan. The plan is a process to discuss development of the UMUT allocations in the Mancos River drainage (including, but not limited to: development with non-tribal partners in the Mancos River Valley).	Montezuma	Not Complete	Complete planning process	Agricultural/irrigation and livestock needs	Ute Mountain Ute Tribe, non-tribal partners within Mancos River Valley	Lead & Source: Celene Hawkins	Process	Yes	Yes	Yes
20-M	Jan-14	Mancos	NC	Mancos Watershed Enhancement Projects. An environmental project describing the UMUT's work in the Mancos River watershed to remove invasive species (tamarisk, Russian olive) and to regenerate and farm native species (cottonwood and willow).	Montezuma	Ongoing	Design, Fund, and Implement projects	Habitat quality and quantity	Ute Mountain Ute Tribe	Lead & Source: Celene Hawkins	Project	Yes	Yes	No
21-M	Jan-14	Mancos	B	Additional Storage. Development of additional storage within the Mancos River drainage (expansion of Jackson Reservoir, off-reservation and/or on-reservation sites possible).	Montezuma	Not Complete	Investigate, Develop, Design and Construct reservoirs	Agricultural water supply, Habitat quality and quantity	Ute Mountain Ute Tribe	Lead & Source: Celene Hawkins	Project	No	Yes	No

Updated: 3/19/2015

Dolores and McElmo River Basins Draft IPP List

PROPOSED IPPs

ID	Date	Sub Basin	NC/C/B	Description	County	Status	Remaining Steps	Need Addressed	IPP Contact Information: Sponsors	IPP Contact Information: Lead contact & Source of Info.	Project vs. Process	Project ready for implementation NOW?	Does the need exist today?	Already received some WSRA funding?
1-DM	Jul-13	Dolores	C	Summit Reservoir & Irrigation Company. Summit and Lost Canyon for irrigation system improvements.	Dolores, Montezuma	Not Complete		Agricultural	Summit Reservoir & Irrigation Company		Project		Yes	Yes
2-DM	SWSI 2010	Dolores	C	Montezuma Water Company. Supplies potable water to rural Dolores and Montezuma Counties. Continually expanding to serve new areas presently on wells or hauling.	Montezuma, Dolores	Not Complete		Municipal water supply	Montezuma Water Company					
3-DM	Jan-14	Dolores, McElmo	C	Water Conservation and Management Plan. The plan is a process to discuss the UMUT's additional needs from the Dolores Project (including the 4,000 AF acquisition request and ongoing projects in water conservation and additional storage).	Montezuma	Not Complete	Complete planning process	Agricultural, Municipal, Industrial water supply	Ute Mountain Ute Tribe	Lead & Source: Celene Hawkins	Process	Yes	Yes	Yes
4-DM	Jan-14	Dolores, McElmo	NC	Energy Dissipating Structure Hydropower Development. The EDS site is located on the Towaoc Highline Canal at the transition from Reach 2 into Reach 3. A preliminary hydropower feasibility study was completed in December of 2010. DWCD and UMUT are jointly pursuing this development.	Montezuma	Not Complete	Joint development of entity to operate power plant, RFQ for design and construction	Renewable Energy	Ute Mountain Ute Tribe, DWCD	Lead & Source: Celene Hawkins		Yes	Yes	No
5-DM	SWSI 1, SWSI 2010	Dolores	C	Augmentation upstream of McPhee Reservoir. CWCB ISF may limit the ability to provide augmentation above McPhee Reservoir in the future. Alternatives include small storage (10 to 20 AF) or alluvial storage.	Dolores	Not Complete		Municipal water supply, Agricultural water supply	DWCD	Source & Lead: DWCD	Project	No	Yes	No
6-DM	SWSI 2010	Dolores	B	Upper Plateau Storage Reservoir. This is a new, up to 20,000 AF reservoir proposed by DWCD as a method to increase the water supply from the Dolores River. The water could be used for fishery flows below McPhee and/or M&I.	Dolores	Ongoing		Municipal, Environmental water supplies	DWCD	Lead: DWCD Source: Steve Harris	Project	No	Yes	No
7-DM	Jul-14	Dolores	C	Plateau Pumpback Project. Water is released from an upper reservoir through a penstock to generate hydropower and pumped back up to the upper reservoir during off-peak demand. This project would operate as a giant battery to fill green power gaps when the sun is not shining and the wind is not blowing.	Dolores	Investigating	DWCD exercising FERC feasibility license; Investment Information Memo response will determine if the need exists today	Hydropower production	DWCD	Lead: DWCD Source: Ken Curtis	Project	No	No, unknown	No
8-DM	SWSI 2010	Dolores	C	Groundhog Reservoir Expansion. The reservoir could potentially be expanded by decreasing the freeboard in the spillway, thus, raising the water level by about 1,000 AF. Studies have not been completed to fully evaluate this option.	Dolores	Not Complete	DWCD and MVIC are investigating options to maximize the use of Groundhog	Municipal water supply (well augmentation)	DWCD	Lead and Source: DWCD	Process then project	No, need further evaluation	No	No
9-DM	SWSI 2011	Dolores	B	Dolores River Dialogue. Formed in 2004 to explore management opportunities to improve the ecological conditions downstream of McPhee Reservoir while honoring water rights, protecting agricultural and municipal water supplies, and the continued enjoyment of rafting and fishing. Meets twice a year, guided by a Steering Committee, which oversaw the development of a watershed plan in 2013. A Legislative Subcommittee has also been formed from this effort, which lead to an Implementation Team developing an Implementation Monitoring and Evaluation Plan. The IM&E Plan is part of the foundation for NCA Legislation to protect native fish, downstream values, water rights and Dolores Project allocations.	Dolores, Montezuma, San Miguel, Montrose	Ongoing	Continue to provide a forum for initiatives related to DRD Purpose Statement, Adopt Implementation Plan and introduce NCA Legislation	Native fish, Agricultural water supply, Municipal water supply, Boating, Fishing	USBR *; CDWR; CDNR; CPW*; CWCB; Dolores County; Dolores Public Lands Office (USFS/BLM); Dolores River Action Group (local private boaters); Dolores River Coalition* (represents 20 groups) ; DWCD*; Army Corps of Engineers; Montezuma County; MVI*; public at large; SJCA*; SJPLC; San Miguel County; TNC*; USFWS; and the Ute Mountain Ute Tribe*; Dolores River Boating Advocates (* = Steering Committee Representation)	Source: Mike Preston	Process & Project	Yes	Yes	No

Dolores and McElmo River Basins Draft IPP List Continued…

PROPOSED IPPs

ID	Date	Sub Basin	NC/C/B	Description	County	Status	Remaining Steps	Need Addressed	IPP Contact Information: Sponsors	IPP Contact Information: Lead contact & Source of Info.	Project vs. Process	Project ready for implementation NOW?	Does the need exist today?	Already received some WSRA funding?
10-DM	Jul-13	Dolores	NC	Proposed Instream Flow on the Dolores River . BLM is beginning to collect preliminary data for an instream flow water right downstream of the San Miguel River, within the Uncompahgre Field Office to protect habitat for 3 sensitive fish species. Section discussed during Wild and Scenic Process and stakeholders identified it as eligible.	Montrose, Mesa	Ongoing		Habitat for 3 sensitive fish species	BLM, CWCB, CPW	Source: Roy Smith; Linda Bassi	Process	Yes	Yes	No
11-DM	SWSI 2010	Dolores	B	Paradox Valley Salinity Control. BOR Desalination Plant intercepts and collects saline water flowing toward Dolores River within the Paradox Valley and stores that water in deep wells. Losses to the Dolores surface flows are mitigated with 700 AF/year out of McPhee Reservoir. Managed as part of the downstream fishery water, and does not share shortages.	Dolores	Ongoing		Water quality	BOR, DWCD, CPW		Project	Yes	Yes	No
12-DM	SWSI 2010	McElmo	C	Totten Reservoir. The existing 3,300 AF reservoir was acquired by DWCD. With no new facilities the reservoir can be used for direct service and augmentation in the McElmo Creek basin. With a pump and pipeline to Towaoc-Highline Canal can provide additional water for use within Dolores Project area. There are several potential water sources. The yield is variable based on type of use (M&I or irrigation) and sources.	Montezuma	Not Complete		Municipal water supply, Agricultural water supply	DWCD	Lead and Source: DWCD	Project	Yes	Yes	Yes?
13-DM	Jul-13	McElmo	C	McElmo Irrigators. Completed pilot phase of project. Pilot phase was to initiate a 1 time lease of water from Totten to McElmo irrigators during the early irrigations season. Improvements will need to be made to Totten before this can become a permanent lease.	Montezuma	Not Complete	Improvements to Totten	Agricultural water supply	DWCD	Lead and Source: DWCD	Project	Ongoing	Yes	No
14-DM	Jan-14	Dolores	B	Optimization Study. A study to review the available water supplies to evaluate whether the water is being used as effectively as possible using the existing facilities. Then determined if there are additional management methods and/or facilities that may improve the effectiveness.	Montezuma, Dolores	Not Complete	Develop a RFP; hire a consultant; conduct work	All needs within the basin could be possible addressed	DWCD	Lead and Source: DWCD	Process	Yes	Yes	No
15-DM	Jan-14	Dolores	C	DWCD Water Management and Conservation Plan. The 2002 Plan will be updated through 2013 with new data and candidate programs and measures. The programs and measures range from water management, water supply, budget, infrastructure, and conservation. The Plan describes actions for each program and measure with priorities of implementation of measures by the Board.	Montezuma, Dolores	Not Complete	Drafting a WMCP	Agricultural water supply, Municipal water supply	DWCD, MVIC, UMUT, CPW, CSU Extensions, USBR, Full Service Farmers, DCD, other stakeholders	Lead and Source: DWCD	Process & Project	Yes	Yes	No
16-DM	Jan-14	McElmo	B	Rehabilitation of the McElmo Creek Flume. The McElmo Flume was designated one of Colorado's Most Endangered Places in 2011. Its is a most fitting recognition for reasons beyond just being endangered. The Flume represents the heritage of the culture that developed with the advent of water being trans-basin diversion from the Dolores during the mid-1880s. This is a water education project that will provide a new opportunity for the public to learn about the water history of the Montezuma Valley.	Montezuma	Not Complete	Construct highway access point, rehabilitate flume	Public Education	Montezuma County	Lead: James Dietrich	Project	Yes	Yes	No
17-DM	Mar-14	Dolores	NC	Upper Dolores River Recreation Access. The Upper Dolores lacks safe, adequate and appropriate access for recreational opportunities including boating and fishing. The San Juan Skyway runs along the Dolores River and offers highway accessibility, but an official access site has not been established, resulting in user created access and riparian damage. An established site with day use accessibility would be ideal for enabling recreation in a manner that is safe and appropriate.	Dolores	Not Complete		Public Education, Recreation access	Dolores River Boating Advocates, Forest Service	Lead & Source: Lee-Ann Hill	Project	Yes	Yes	No
18-DM	Mar-14	Dolores	B	Future River Stewards. Program to involve local youth in water quality sampling at Bradford Bridge, river stewardship and mindful use.	Dolores	Not Complete		Public Education, Water quality	Dolores River Boating Advocates, local schools, Riverwatch Program	Lead & Source: Lee-Ann Hill	Project	Yes	Yes	No
19-DM	Mar-14	Dolores, McElmo	B	Dolores Project McPhee Reservoir Aquatic Nuisance Species (ANS) Protection. With the recent infestation of Lake Powell by invasive mussels, McPhee remains vulnerable to traveling ANS from other waters open to boating. The impacts of an infestation would destroy biological, recreational, ecological and consumptive uses provided by the Dolores Project. An infestation would damage the fishery and hurt boating and fishing opportunities. Infrastructure impacts would increase costs and hinder operations at McPhee with unknown impacts extending beyond the reservoir. Prevention remains the only successful strategy to prevent these negative impacts. DWCD is working with CPW and USFS to bolster the current efforts led by CPW to prevent an infestation of Zebra and Quagga mussels to the Dolores Project.	Montezuma	Ongoing		Municipal supply, Agricultural supply, Boating, Aquatic habitat	DWCD, CPW, USFS	Lead & Sources: Ken Curtis & Jim White	Project	Yes	Yes	No

Dolores and McElmo River Basins Draft IPP List Continued…

PROPOSED IPPs

ID	Date	Sub Basin	NC/C/B	Description	County	Status	Remaining Steps	Need Addressed	IPP Contact Information: Sponsors	IPP Contact Information: Lead contact & Source of Info.	Project vs. Process	Project ready for implementation NOW?	Does the need exist today?	Already received some WSRA funding?
20-DM	Apr-14	Dolores	NC	Dolores River Restoration Partnership, 170 miles of riparian restoration on the Dolores River between Dove Creek Pump Station and the Dolores's confluence with the Colorado River.	Dolores, Mesa	Ongoing		Habitat	TNC, Tamarisk Coalition, Conservation Corps groups and three offices of BLM: Uncompahgre, Tres Rios & Grand Junction		Project	Yes	Yes	No
21-DM	2014	Dolores	B	Trout Unlimited and Montezuma Land Conservancy. Upper Dolores River Assessment. This is an assessment of fisheries and riparian conditions of the Upper Dolores Watershed aimed at applying the best science to help strategic planning for targeted restoration activities. Identify possible restoration and irrigation infrastructure improvement partnerships in the Dolores Watershed. Identify reaches of the Dolores main stem for restoration work. Identify and implement monitoring and restoration projects on critical and important streams containing conservation populations of native trout. Identify and prepare critical and important streams for reconnection / isolation and reintroduction of native trout.	Montezuma and Dolores	Ongoing		Water quality, Aquatic habitat, Channel function, Riparian function, Fisheries, Recreation, Agriculture	Trout Unlimited and Montezuma Land Conservancy	Matt Clark, TU	Project	Yes	Yes	No
22-DM	May-14	San Miguel	B	Wines Diversion Structure Renovation. Dolores River, near the State line, renovate the Wines diversion structure and adjacent riparian area 8 miles northwest of Gateway. This passage currently impedes safe recreational boaters and provides a barrier to fish passage into the upper Dolores River.	Mesa	Not Complete		Recreational, fish passage, Agricultural water supply (delivery)	TNC, John Hendricks, Grand Junction BLM, CPW	Lead: Pete Foster & Source: Peter Mueller	Project	Yes	Yes	No
23-DM	Mar-15	Dolores	C	Gateway Community Water System. The Gateway Community would greatly benefit from the development of a potable water system, to increase the quantity as well as construction of a drinking water distribution system within the town of Gateway Colorado.	Mesa	Not Complete		Municipal water supply, Municipal infrastructure	Gateway Canyons Resort, Mesa County	Source: Carrie Gudorf	Project	No	Yes	No

Updated: 1/20/2015

San Miguel River Basin Draft IPP List

PROPOSED IPPs

ID	Date	Sub Basin	NC/C/B	Description	County	Status	Remaining Steps	Need Addressed	IPP Contact Information: Sponsors	IPP Contact Information: Lead contact & Source of Info.	Project vs. Process	Project ready for implementation NOW?	Does the need exist today?	Already received some WSRA funding?
1-SM	SWSI 2010	San Miguel	C	Enlargement of Gurley Reservoir. Designs have been prepared to enlarge the existing Gurley Reservoir.	San Miguel	Not Complete		Agricultural water supply	Farmers Reservoir and Ditch Company	Source: Steve Harris	Project			
2-SM	SWSI 2010	San Miguel	C	Lone Cone Reservoir. Enlargement of Lone Cone Reservoir.	San Miguel	Not Complete		Agricultural water supply	Lone Cone Reservoir and Ditch Company	Source: April Montgomery	Project			
3-SM	Dec-13	San Miguel	B	Montrose County Firming Project Phase 1. The purpose of the Project is to provide a reliable source of water for municipal and industrial demands in Montrose County over the next 50 years, including future growth in the Towns of Nucla and Naturita. The first phase of the Project, to be completed by 2018, is to complete feasibility-level engineering studies of the Upper Maverick Draw, Lower Maverick Draw, Big Bucktail, Tuttle Draw, and Nucla Town Reservoir Enlargement storage sites and the Nucla Pump Site and Pipeline, Highline Canal, Paradox Valley Pipeline diversion points pursuant to the 2012 Water Court decree in Case #10CW164 et seq.	Montrose	Not Complete	Secure funding, Conduct feasibility study	Municipal water supply, Industrial water supply, Environmental water supply, Recreation	Montrose County	Source: Jon Waschbusch; Lead: M. Catlin	Process	Yes	Yes	No
4-SM	Dec-13	San Miguel	B	Montrose County Firming Project Phase 2. The second phase of the Project will be to construct one or two reservoirs, in addition to the Nucla Town Reservoir Enlargement, and the direct flow points of the diversion. The Project will address the 3,200 acre-feet gap between existing water supplies and demands projected to occur by the year 2060 in the west on of Montrose County, and will also allow for reservoir releases to provide non-consumptive piscatorial use and water quality improvements.	Montrose	Not Complete	complete Phase 1, Start Phase 2	Municipal water supply, Industrial water supply, Environmental water supply, Recreation	Montrose County	Source: Jon Waschbusch; Lead: M. Catlin	Project	Yes	Yes	No
5-SM	SWSI 2010	San Miguel	B	San Miguel Project. The project was authorized as a participating project in the Colorado River Storage Project (CRSP) and includes a large storage and diversion water right on the San Miguel River. Though the project as authorized is not likely to be constructed, the water right could be changed to meet future water needs in the San Miguel Basin. As a participant in CRSP, power revenues are being accumulated in the name of the project and legislation might allow funds to construct a locally approved alternative to the authorized project.	San Miguel	Not Complete		Potentially all needs possible	SMWCD	Source: Steve Harris	Process & Project			
6-SM		San Miguel	NC	Suitability - Wild and Scenic Rivers Act. Protect outstandingly remarkable values through consideration of suitability under Wild and Scenic Rivers Act and the Uncompahrge BLM Resource Management Plan Revision. Determine what segments of the 21 found eligible should be identified as suitable.	San Miguel	Not Complete		Native Fish, Recreation	BLM, Counties, citizens and other organizations	BLM, Counties, citizens and other organizations	Process			
7-SM	SWSI 2010	San Miguel	B	Rehabilitation of Priest Lake. The Priest Lake dam owned by USFS was breeched under order of DWR. The lake is an important facility for fishing and augmentation of USFS facilities.	San Miguel	Not Complete		Augmentation, Fishing recreation	EXCEL Energy	Source: April Montgomery	Project			
8-SM	SWSI 2010	San Miguel	NC	CCC Ditch Fish Passage. Provide fish passage at CCC-Ditch diversion. A fish ladder was constructed that abuts CCC-Ditch, add electronic gauges to assist in diversion. No additional water associated with this project.	Montrose	Not Complete		Fish passage	CCC-Ditch, CWT, BLM, CPW, TNC, SWCD, CWCB, Telluride Foundation	Source: Peter Mueller	Project		Yes	
30-SM	Sep-14	San Miguel	NC	Reed Chatfield Diversion Structure Renovation. This passage currently impedes safe recreational boaters and creates a barrier to fish passage into the upper San Miguel River.	Dolores	Not completed		Fish passage, Recreation	TNC, San Miguel Watershed Council	Source & Lead: Peter Mueller	Project	Yes, begin planning stage	Yes	No
31-SM	Sep-14	San Miguel	NC	Parkway Diversion Structure Renovation. This passage currently impedes safe recreational boaters and creates a barrier to fish passage into the upper San Miguel River.	Dolores	Not completed		Fish passage, Recreation	TNC, San Miguel Watershed Council	Source & Lead: Peter Mueller	Project	Yes, begin planning stage	Yes	No
9-SM	Fall 2013	San Miguel	NC	Woods Lake Colorado River Cutthroat Trout Refuge. CPW with partners is continuing implementation of a cutthroat refuge concept at Woods Lake, and has completed 2 (of 3) infrastructure improvement projects designed to isolate this fishery from exposure to non-native trout (mainly brook trout). CPW has obtained internal funding and is working in partnership with the Hughes Ditch Co to modify the diversion structure to facilitate cutthroat isolation and allow diversion of existing water rights.	San Miguel	Not Complete		Native Fish, Cutthroat Trout	CPW, USFS, Hughes Ditch Company, San Miguel County	Source: David Garf	Project			
10-SM	Fall 2013	San Miguel (Howard's Fork)	B	Carbenaro Mine Adit Reclamation. Reduce or treat the contaminated water - heavy metals, principal contributor to Howard's Fork. Investigating what options exist to mitigate heavy metal loading.	San Miguel	Not Complete		Water Quality	EPA, Division of Water Safety, CDPHE, DRMS, private landowner	Source: Peter Mueller, Pat Willits	Project			
11-SM	Fall 2013	San Miguel (Naturita Creek)	NC	Naturita Creek Proposed ISF. Spawning habitat for flannelmouth sucker, bluehead sucker, and roundtail chub. BLM has collected preliminary data for an instream flow right. Could also protect agricultural lands and water rights to preserve existing flows. Current conservation easements and supportive landowners. ISF data collected and CWCB Appropriation; possible purchase/lease of ISF.	San Miguel	Not Complete		Native Warmwater Fish, Aquatic Habitat	BLM, CWCB, CPW, private landowners, San Miguel Co Open Space	Source: Roy Smith, BLM, Dave Foley, private landowners	Process			
12-SM	SWSI 2010	San Miguel (Howard's Fork)	B	Carribou Mine Tailings and Adit. Investigate how best to reclaim. Improvement of water quality.	San Miguel	Not Complete		Water quality	USFS, private landowner, DRMS, EPA, CDHPE	Source: Peter Mueller	Project			
13-SM	SWSI 2010	San Miguel	NC	Flow Protection for Area of Critical Environmental Concern. Flows to protect already designated ACEC values. Portion of section determined as wild suitability under Wild and Scenic.	San Miguel, Montrose	Not Complete			BLM, Wild and Scenic stakeholders, TNC, San Miguel County	Source: BLM, Jenny Russell				
14-SM	SWSI 2010	San Miguel	NC	Valley Floor River Channel Restoration. Valley floor restoration of historic river channel. Riparian habitat restoration. Flows to protect wetlands. Existing flows may be sufficient.	San Miguel	Not Complete		Riparian habitat, Aquatic habitat	Town of Telluride	Source: Telluride, Lance McDonald	Project			

San Miguel River Basin Draft IPP List Continued…

PROPOSED IPPs

ID	Date	Sub Basin	NC/C/B	Description	County	Status	Remaining Steps	Need Addressed	IPP Contact Information: Sponsors	IPP Contact Information: Lead contact & Source of Info.	Project vs. Process	Project ready for implementation NOW?	Does the need exist today?	Already received some WSRA funding?
15-SM	SWSI 2010		NC	San Miguel Instream Flow. Identify non-consumptive need to support fisheries from CCC-ditch downstream to Calamity Creek in times when CCC-Ditch diverts most or all of the water. Identify willing lessor for 3 to 10 year paid lease of water.		Not Complete		Native Warmwater Fish, Aquatic Habitat	CPW, TNC, CWT, and others ass needed	Source: Peter Mueller				
16-SM	SWSI 2010	San Miguel	C	Tri-State Power Facility. Have adequate water rights for future demands but would need storage to firm the yield if plant is expanded. Need storage options.	Montrose	Not Complete		Industrial water supply	Tri-State Power Facility					
17-SM	SWSI 2010	San Miguel	C	Straw Dam. The dam is located immediately downstream of the existing Gurley Reservoir and could provide additional storage for M&I uses on Wrights Mesa. Designs have been prepared.	San Miguel	Not Complete			San Miguel Water Conservancy District (SMWCD)	Source: Steve Harris	Project			
18-SM	SWSI 2010	San Miguel	C	Town of Ophir. The Town of Ophir is investigating methods to provide for the long term water supply possibly including diversion and storage facilities.	San Miguel	Not Complete		Municipal water supply	Town of Ophir	Source: April Montgomery	Project			
19-SM	SWSI 2010	San Miguel	C	Town of Norwood. The Town of Norwood holds water rights on the San Miguel River to provide for future municipal water needs. Use of the water rights would involve a diversion from the river and a small storage facility.	San Miguel	Not Complete		Municipal water supply	Town of Norwood	Lead & Source: Patti Grafmyer	Project			
20-SM	SWSI 2010	San Miguel	C	Aldarosa Ranch & Homeowners Company. Have water rights and groundwater.	San Miguel	Not Complete		Municipal water supply	Aldarosa Ranch & Homeowners Co	Source: Helton & Williamsen				
21-SM	SWSI 2010	San Miguel	C	Norwood Water Commission. This project would be for municipal needs when growth takes place and infrastructure would be updated and the water system expanded to enable Norwood Water Commission to serve unincorporated Montrose County (Phase III, as called out by the NWC Master Plan). This would provide additional back-up to the existing 10 inch mainline from the water treatment plant to Norwood.	San Miguel, Montrose	Not Complete		Municipal water supply	Norwood Water Commission	Source: Patti Grafmyer Lead: Tim Lippert	Project			
22-SM	SWSI 2010	San Miguel	NC	Potential RICD. Important rafting/boating area. No protection of recreation flows currently exists. Area identified by BLM as suitable for recreation under Wild and Scenic process. Potential recreation in channel diversion, kayak park or protection of rafting flows.	San Miguel, Montrose	Not Complete		Recreational boating	San Miguel Whitewater Alliance, Telluride Outside, Jagged Edge, San Miguel County, BLM	Source: San Miguel Whitewater Alliance	Project			
23-SM	Apr-14	San Miguel	C	Norwood Lawn and Garden. The installation of a raw water irrigation system within Norwood for residents to use for outside watering. Norwood Water Commission would be able to utilize their 119 shares of water for this project and residents would use less treated water for outside use.	San Miguel	Not Complete		Municipal water supply (infrastructure)	Norwood Water Commission	Lead: Tim Lippert Source: Patti Grafmyer	Project			
24-SM	Apr-14	San Miguel	C	Town of Mountain Village. This project includes two components: 1) Installation of a connection waterline between two tanks to better supply water for fire protection; 2) Installation of 2 micro hydro generators in the systems.	San Miguel	Not Complete	Permitting has started, Construction	Municipal water supply	Mountain Village	Source & Lead: Finn Kjome	Project	Yes	Yes	No
25-SM	Apr-14	San Miguel	B	San Miguel Watershed Coalition. The Coalition works to "advance the ecological health and promote the economic vitality of the watershed through the collaborative efforts of the entire community. Our ultimate goal is to realize a watershed that is healthy in every respect while offering a sustainable and quality lifestyle for all who live in it. "The coalition periodically compiles and issues a watershed health assessment entitled the San Miguel Watershed Report Card.	San Miguel, Montrose	Ongoing		Water Quality, Riparian habitat, Aquatic habitat		Source & Lead: Linda Luther-Broderick	Process			
26-SM	May-14	San Miguel	NC	Tabeguache Creek Native Fish Barrier Removal Project. The project will remove existing barrier on the Tabeguache Creek in order to create passage for the native fish to move upstream, which will help protect and enhance habitat and restore populations of these native fish. The need for action is outlined in the Range-Wide Conservation Agreement and Strategy for three warmwater fish.	Montrose	Not Complete		Native warmwater fish	BLM, TNC, San Miguel Watershed Coalition	Source & Lead: Linda Luther-Broderick	Project	Yes	Yes	No
27-SM	Jun-14	San Miguel	NC	CCC-Ditch Fish Ladder Repair. This project will repair the scour hole below the CCC Ditch diversion dam and place boulders in a reverse shingled manner in order to improve and repair the fish ladder and to improve the passage over the dam for whitewater boaters.	San Miguel	Not Complete		Native fish, Recreation	BLM, Colorado Water Trust, San Miguel Watershed Coalition	Source & Lead: Linda Luther-Broderick	Project	Yes	Yes	No
28-SM	Jun-14	San Miguel	C	Alternate Main Line to Norwood. Additional 14 inch main line from the Water Treatment Plant to the 200,000 gallon tank south of Norwood (Phase I, as called out by the NWC Master Plan).	San Miguel	Not Complete		Municipal water supply	Norwood Water Commission	Source: Patti Grafmyer Lead: Tim Lippert	Project			
29-SM	Jun-14	San Miguel	C	Up-grade and Loop Water Lines. Up-grade the undersized water lines, add a 100,000 gallon portable water tank and loop the water line on the north east of Norwood (Phase II, as called out by the NWC Master Plan).	San Miguel	Not Complete		Municipal water supply	Norwood Water Commission	Source: Patti Grafmyer Lead: Tim Lippert	Project			

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1	**COMPLETED IPPs**							**Remaining Steps**	**Need Addressed**	**IPP Contact Information**		**Project vs. Process**
2	**ID**	**Date**	**Sub Basin**	**NC/C/B**	**Description**	**County**	**Status**			**Sponsors**	**Lead contact & Source of Info.**	
3	1	SWSI 2010	San Juan	NC	Upper Colorado and San Juan Endangered Fish Recovery Programs. Federal program affecting water management throughout Upper Colorado and San Juan River Basins; both basins operated under Programmatic Biological Opinion (PBO) allowing depletions under a cumulative cap without individual consultation on each project. San Juan program extended through 2023. A process to provide certainty for meeting consumptive needs.	Western Slope	Completed				Source: DG (CPW)	
4	2	SWSI 2010	San Juan	NC	Rio Blanco River Project. The Project is an environmental enhancement. The project is completed; the entire planned reaches have been restored, reports submitted to all grant agencies and ended when the LBPOA and SJWCD published "A River Once More" by Val Valentine in 2010.	Archuleta	Completed		water quality, habitat restoration	LBPOA, SJWCD		Project
5	3	SWSI 2010	San Juan	NC	San Juan River. River Protection Workgroup leading local process to involve the public in protecting natural values while allowing water development to continue. It is a stakeholders process to address Wild & Scenic suitability and determine appropriate protection tools. Consensus that the following tools could be acceptable as alternatives to Wild and Scenic Suitability/Eligibility: Planning and Zoning Districts, Deed Restrictions in Exchange for Release of WSR, Local Community Council, Mineral Withdrawal, and County Planning.	Archuleta, Hinsdale, Mineral	Completed		Habitat quality, water quality, recreation	SWCD, SJCA, TU, TWS, SUIT, DWR, CWCB, CPW, 4 Corners Backcountry Horseman, Private landowners and citizens	Source: Ann Oliver	Process
6	4	SWSI 2010	Piedra	NC	Stolsteimer Creek #1. 3 miles of channel and riparian habitat improvements	La Plata	Completed 2005			SUIT, USEPA		Project
7	5	SWSI 2010	Piedra	NC	Stolsteimer Creek #2. 0.3 miles of channel and riparian habitat improvements	La Plata	Completed 2008			SUIT, USFWS		Project
8	6	SWSI 2010	Piedra	NC	ME&M Ditch. 400 ft. of bank stabilization and habitat enhancement including 5 J-hooks	La Plata	Completed 2004-2006			SUIT, BOR		Project
9	7	SWSI 2010	Piedra	NC	Piedra River Restoration. Piedra River Phase I and Phase II, 2.25 miles of channel and riparian habitat improvements	La Plata	Completed 2000			SUIT, BOR		Project
10	8	SWSI 2010	Piedra	NC	Piedra River Restoration. Piedra River Phase III, 0.5 miles of channel and riparian habitat improvements	La Plata	Completed 2007			SWWCD, SJCA, TU, TWS, SUIT, CDWR, CWCB, USFS, Private landowners and citizens		Project
11	9	SWSI 2010	Piedra	C	Aspen Springs Water Depot. The Metro District needs a water hauling station to reduce the travel time for existing residents.	Archuleta	Completed Fall 2013		Municipal water supply (infrastructure and water quantity)	Aspen Springs Metro District	Lead & Source: Carrie Lile	Project
12	10	SWSI 2010	Piedra	NC	Stolsteimer Creek #3.Channel and riparian habitat improvements between Aspen Springs and confluence with the Piedra River.	La Plata	Completed		Habitat quality (riparian and channel)	SUIT, NRCS, San Juan Conservation District	Lead & Source: Jerry R. Archuleta	Project
13	11	SWSI 2010	Piedra	B	River Protection Workgroup. The Workgroup is leading local process to involve the pubic in protecting natural values while allowing water development to continue. Watershed values are defined by the collaborative workgroup and include outstandingly remarkable values: scenery, fish, geology, archeology, and recreation.	Archuleta & Hinsdale & Mineral	Completed			SWCD, SJCA, TU, TWS, SUIT, DWR, CWCB, USFS, SJPL, 4 Corners Backcountry Horseman, Private landowners and citizens	Lead: River Protection Work group Source: Ann Oliver	Process
14	12		Pine	C	Town of Bayfield. Need storage to firm existing water rights. Only other option is to lease water from Vallecito Reservoir.	La Plata	Completed		Municipal water supply (water quantity)	Town of Bayfield	Source: Steve Harris, Janice Sheftel, John Porter	Both
15												

	B	C	D	E	F	G	H	I	J	K	L	M
16		**COMPLETED IPPs Continued…**										
17	**ID**	**Date**	**Sub Basin**	**NC/C/B**	**Description**	**County**	**Status**	**Remaining Steps**	**Need Addressed**	**IPP Contact Information**		**Project vs. Process**
										Sponsors	**Lead contact & Source of Info.**	
18	13	SWSI 2010	Pine	C	Municipal Users upstream of Vallecito Reservoir. There is a large number of homes upstream of Vallecito Reservoir that are currently served by wells. LAPLAWD will not serve this area. Augmentation water, primarily from Vallecito is necessary for these wells to utilize water in priority.	La Plata	Completed			Unincorporated La Plata County upstream of Vallecito Dam; Happy Scenes Water System	Source: Steve Harris	Project
19	14	SWSI 2010	Pine, Florida, Animas, Piedra	C	La Plata Archuleta Water District was formed in August of 2008. A Board of Directors is currently seated and making plans for a mill levy election needed to finance a water distribution system for southeast La Plata County. A Master Plan has been prepared to describe the facilitates and water sources.	La Plata	Completed. Mill levy to fund facilities has been approved by voters. Pipelines to serve customers are under construction.			La Plata Archuleta Water District	Lead & Source: Ed Tolen, GM	
20	15	SWSI 2010	Pine	NC	Beaver Creek Bank Stabilization and Habitat Enhancement. 200 ft. of bank stabilization and habitat enhancement including 2 arm vane weirs, 3 J'hooks, and construction of a backwater.	La Plata	Completed 2010			SUIT, BOR		
21	16	SWSI 2010	Pine	NC	Beaver Creek, 2000 feet of channel work and riparian restoration	La Plata	Completed Spring 2010			SUIT, USEPA		
22	17	SWSI 2010	Pine	NC	Dry Creek, 3000 feet of channel work and riparian restoration	La Plata	Completed Fall 1999			SUIT, USEPA		
23	18	SWSI 2010	Pine	NC	Ignacio Creek, 2500 feet of channel work and riparian restoration	La Plata	Completed Spring 2008			SUIT, USEPA		
24	19	SWSI 2010	Pine	NC	Rock Creek I, 4000 feet of channel work and riparian restoration	La Plata	Completed Spring 2001			SWWCD, SJCA, TU, TWS, SUIT, CDWR, CWCB, USFS, Private landowners and citizens		
25	20	SWSI 2010	Pine	NC	Rock Creek II, 2500 feet of channel work and riparian restoration	La Plata	Completed Spring 2003			SWWCD, SJCA, TU, TWS, SUIT, CDWR, CWCB, USFS, Private landowners and citizens		
26	21	SWSI 2010	Pine	NC	Rock Creek IV, 3500 feet of channel work and riparian restoration	La Plata	Completed Spring 2006			SWWCD, SJCA, TU, TWS, SUIT, CDWR, CWCB, USFS, Private landowners and citizens		
27	22	SWSI 2010	Pine	NC	Naranjo, 1100 ft. of bank stabilization and habitat enhancement including 6 J-hooks, construction of an earthen berm and backwater	La Plata	Completed 2008			SWWCD, SJCA, TU, TWS, SUIT, CDWR, CWCB, USFS, Private landowners and citizens		
28	23	SWSI 2010	Pine	NC	Pine River #1, 1 mile of channel and riparian habitat improvements	La Plata	Completed 2005			SUIT, BOR		
29	24	SWSI 2010	Pine	NC	Pine River #2, 0.5 miles of channel and riparian habitat improvements	La Plata	Completed 2006			SUIT, BOR		
30	25	SWSI 2010	Pine	NC	Pine River #3, 0.5 miles of channel and riparian habitat improvements	La Plata	Completed 2009			SWWCD, SJCA, TU, TWS, SUIT, CDWR, CWCB, USFS, Private landowners and citizens		
31	26	SWSI 2010	Pine	NC	Watts, 850 ft. of bank stabilization and habitat enhancement including 8 bendway weirs, 1 J-hook, and 1400 ft. of livestock exclusion fence	La Plata	Completed 2010			SUIT, BOR		
32	27	SWSI 2010	Pine	NC	Pine River Protection Workgroup. River Protection Workgroup leading local process to involve the public in protecting natural values while allowing water development to continue. Watershed values are defined by the collaborative workgroup and include the outstandingly remarkable values of scenery and recreation.	Hinsdale & La Plata	Completed			SWWCD, SJCA, TU, TWS, SUIT, CDWR, CWCB Private landowners and citizens	Source: Ann Oliver	Process
33	28		Animas	C	Purchase of ALP Available Water Supply. CWCB had an option to obtain approximately 10,400 AF of water from the Animas La Plata Project. SWCD sent a letter to CWCB recommending the water be purchased and maintained for use in Colorado. CWCB is currently studying the potential needs for the water. CWCB studied the potential needs for the water and completed the purchase.	La Plata	Completed	None			Colorado Water Conservation Board, supported by Southwestern Water Conservation District (SWCD)	Lead contact & Source: SWCD

	B	C	D	E	F	G	H	I	J	K	L	M
34	**COMPLETED IPPs Continued…**											
35	**ID**	**Date**	**Sub Basin**	**NC/C/B**	**Description**	**County**	**Status**	**Remaining Steps**	**Need Addressed**	**IPP Contact Information**		**Project vs. Process**
										Sponsors	**Lead contact & Source of Info.**	
36	29		Animas (Hermosa)	NC	Hermosa Creek River Protection Workgroup. The Workgroup is leading local process to involve the public in protecting natural values while allowing water development to continue. Watershed values are defined by the collaborative workgroup and outstandingly remarkable values include recreation and Cutthroat Trout.		Completed	**Completed process, and identified additional IPPs**		SWWCD, SJCA, TU, TWS, SUIT, CDWR, CWCB Private landowners and citizens	Source: Ann Oliver	Process
37	30	SWSI 2010	Animas	NC	Animas Watershed Partnership. Animas Watershed Partnership contracting preparation of Animas Watershed Based Plan for entire river - CO and NM, with focus on identifying sources of and reducing non-point source pollutants. Water quality protection and/or improvement for all uses, including aquatic habitat and recreation.	La Plata	Plan completed and priorities identified			City of Durango, SJCA, SUIT, SWCD, TU 5 Rivers Chapter, Citizens	**Lead & Source: Ann update!**	Process
38	31	SWSI 2010	Animas	NC	Animas River Basin Creek In-Channel Habitat Restoration. Right name? Animas River Basin Creek, 0.5 miles of channel and riparian habitat improvements		Completed 2004			SWWCD, SJCA, TU, TWS, SUIT, CDWR, CWCB, USFS, Private landowners and citizens	Source: SUIT Wildlife	
39	32	SWSI 2010	Animas	NC	Animas In-Channel Habitat Enhancement. Animas River High Flume, 1.4 miles of channel and riparian habitat improvements		Completed 2004,2006			SWWCD, SJCA, TU, TWS, SUIT, CDWR, CWCB, USFS, Private landowners and citizens	Source: SUIT Wildlife	
40	33	SWSI 2010	Animas	NC	Silverton to Baker's Bridge Animas River Protection Work Group. River Protection Workgroup leading local process to involve the public in protecting natural values while allowing water development to continue. Watershed values are defined by the collaborative workgroup and include outstandingly remarkable values scenery, geology, recreation, cultural/historical, wildlife, and ecological.	San Juan, La Plata	Completed (June 2013)		Scenery, recreation, ecology, and cultural/historical values	SWCD, SJCA, TU, TWS, SUIT, CDWR, CWCB, DWR, San Juan County, Four Corners River Sports, Animas River Stakeholders, Private landowners and citizens	Source: Ann Oliver	Process
41	34	SWSI 2010	Animas	C	City of Durango. Have adequate water rights and negotiating for Animas-La Plata Project Water to increase overall storage.		**Completed. ALP water purchase completed**			City of Durango	Durango	Process
42	35	SWSI 2010	Animas	C	La Plata Archuleta Water District. LAPLAWD has sent a letter to CWCB requesting a portion of the ALP water. Obtaining a portion of this water is critical to serving LAPLAWD.	La Plata	Completed		Municipal water supply (water quantity)	La Plata Archuleta Water District	Lead & Source: Ed Tolen, GM	Process?
43	36	SWSI 2010	Animas (Lightner Creek)	NC	Animas Watershed Partnership (Lightner Creek Workgroup). Heavy sediment loading degrading channel health and causing impacts to private property owners and aesthetic water quality. Priority sediment loading sites have been identified - funding was sought in FY 2011.	La Plata	Completed			Animas Watershed Partnership, San Juan RC&D, CO NPS, San Juan Watershed Group, SUIT, CWCB	Lead & Source: Ann Oliver	Project
44	37	SWSI 2010	Animas (Florida)	NC	Florida Source Water Protection Plan.	La Plata	Completed			City of Durango, Edgemont Ranch Metro District, Forest Groves Home Owners, El Rancho Florida Homeowners, Durango-La Plata Regional Airport, La Plata County, SJPL, CRWA, COWQCC	Source: Edd Balch, CRWA	Process?
45	38	SWSI 2010	Animas (Cascade Creek)	NC	Cascade Creek Mitigation. Mitigate impacts to flows incurred on Cascade Creek by Tacoma Power Plant. FERC relicensing process is completed and mitigation measures are being implemented.	La Plata	Completed			Xcel, SWCD, SJPL, SJCA, TU, DWCD, MVIC	Source: Bruce Whitehead	
46	39	SWSI 2010	Animas	C	Town of Silverton. The Town of Silverton with assistance from SWCD has applied for a water right to provide for the future water needs of the Town. The application is pending with negotiations with opposers. Implementation of the eventual decree will result in recommended IPPs.	San Juan	Completed, water right has been decreed.	Water is decreed; maintain diligence; develop IPPs to make use of water		SWCD and Town of Silverton	Source: SWCD	
47	40	Jul-13	Animas	NC	Animas River Stakeholders Group. Currently, no water needed, although water rights have been purchased in the past. MAYBE MAKE THE DESCRIPTION MORE ABOUT THE GROUP?	San Juan	**Complete!**			SWWCD, SJCA, TU, TWS, SUIT, CDWR, CWCB, USFS, Private landowners and citizens		Process?
48	41	Dec-13	Dolores	C	DWCD and UMUT Joint Study. DWCD and the UMUT are conducting a reconnaissance water study, with partial CWCB funding, to evaluate potential water supplies and alternative facilities to serve the water needs of DWCD and UMUT now and into the future. The study is approximately half completed and will recommend IPPs to be implemented.	Montezuma	Completed	Pursue Study's recommendations	Water Supply	DWCD, UMUT	Lead & Source: Carrie Lile	Process

	B	C	D	E	F	G	H	I	J	K	L	M
49	**COMPLETED IPPs Continued…**							**Remaining Steps**	**Need Addressed**	**IPP Contact Information**		**Project vs. Process**
50	**ID**	**Date**	**Sub Basin**	**NC/C/B**	**Description**	**County**	**Status**			**Sponsors**	**Lead contact & Source of Info.**	
51	42	SWSI 1, SWSI 2010	Dolores	C	Rico Alluvial Pipeline Water Supply Project. The project would provide a new more reliable water source for Rico. A Preliminary Engineering Report has been prepared describing the new well and 2 mile pipeline. An agreement with CWCB to address Instream flow right is imminent. Rico is now within the DWCD. The Project may provide adequate water through 2050 depending on growth in Rico.	Dolores	Completed			Rico	Source: Steve Harris	
52	43	SWSI 2010	Dolores	C	Dove Creek Lawn and Garden. Dove Creek purchases water from Dolores Water Conservancy District. A lawn and garden raw water system has been completed in Dove Creek.	Dolores	Completed		Municipal water supply	Town of Dove Creek, DWCD	Source & Lead: DWCD	Project
53	44	SWSI 2010	McElmo	C	Lawn and Garden Water. There is a demand for lawn and garden water within DWCD for small tracts of land that do not currently have a water source. Raw water distribution facilities have been constructed in some locations but additional facilities are needed.	Montezuma, Dolores	Completed	Ongoing	Municipal water supply	DWCD	Lead and Source: DWCD	Project
54	45	Jul-13	Dolores	NC	Taylor Creek Project and Tenderfoot Ranch Project. Erosion control, breeding habitat, channel stabilization, and habitat enhancement for trout. Tenderfoot Ranch is the small restoration completed in 2012. Taylor Creek was an erosion control project completed in 2013.	Dolores, Montezuma	Completed		River health, fisheries	TU, USFS, private landowners	Source: Ann Oliver (check with Matt Clark)	
55	46	2014	Dolores	B	Trout Unlimited and Redburn Ranch Diversion. Replace a cobble push-up diversion dam and associated irrigation infrastructure to improve operation and to allow fish and sediment passage and promote channel stability.	Montezuma	Completed		agriculture, aquatic habitat, channel function, riparian function, fisheries	Trout Unlimited and Redburn Ranch	Matt Clark, TU	Project
56	47		San Miguel	NC	CWCB declared intent to appropriate 1/2011. Montrose County has provided additional information on flow/ habitat relationships that is being reviewed by CWCB staff.		Completed, ISF in place			CWCB, BLM, CPW, Montrose County		
57	48	SWSI 2010	San Miguel	C	UMETCO Water Rights Transfer. Joint study in 2008 by SWCD and CWCB to determine best use of UMETCO (Uravan) water rights. Uravan water trust 1987, MOU CWCB local governments 1991, historic use (Armbuster Report) 2005.	Montrose	Completed		Water supply	SWCD, CWCB, Montrose County, Naturita, Nucla	Source: BRT feedback	Process
58	49	SWSI 2010	San Miguel	B	Future San Miguel County Demands. San Miguel County, with assistance from SWCD is evaluating the future water needs in the San Miguel basin in the County and the IPP's to meet the needs. A report and water rights application are planned. IPP's will be identified and recommended as part of a future water right.	San Miguel	Completed		Potentially all needs possible	SWCD, San Miguel County	Source: SWCD	Process
59	50		San Miguel (Howard's Fork)	NC	Mine Tailings Reclamation. USFS imitating tailings removal from riparian area east of Ophir.	San Miguel	Completed			USFS, SMWC, Town of Ophir, TLR, San Miguel Conservation Foundation, GOCO	Source: Peter Mueller, Pat Willits	
60	51	SWSI 2010	San Miguel	C	Mustang Water Authority. Mustang Water Authority formed to provide water to Nucla and Naturita.	Montrose, San Miguel	Completed		Municipal water supply	Nucla, Naturita	Source: Buckhorn Geotech Report on Mustang Water Authority	Process