BEFORE THE COLORADO WATER CONSERVATION BOARD

STATE OF COLORADO

Prehearing Statement of the United States of America, Department of the Interior, Bureau of Land Management

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IN THE MATTER OF STAFF'S RECOMMENDATIONS FOR AN INSTREAM FLOW APPROPRIATION ON TROUT CREEK BETWEEN THE CONFLUENCE WITH AN UNNAMED TRIBUTARY AND THE KOLL DITCH HEADGATE, WATER DIVISION 6

Pursuant to Rule 5n(2) of the Rules Concerning the Colorado Instream Flow and Natural Lake Level Program ("ISF Rules"), the Bureau of Land Management ("BLM") hereby submits its prehearing statement in support of the Colorado Water Conservation Board ("CWCB") staff's recommendations for an instream flow appropriation on Trout Creek between the confluence with an unnamed tributary and the Koll Ditch headgate. The BLM supports the appropriation on the reach in the locations, timing, and amounts adopted by the CWCB at its January 2019 regularly scheduled board meeting. The CWCB adopted the locations, timing, and amount set forth in the CWCB staff recommendation report made available to the CWCB and the public at the January 2019 CWCB regularly scheduled board meeting (this recommendation is available for review on the CWCB's website at www.CWCB.state.co.us.).

A. FACTUAL CLAIMS

1. There is a natural environment that can be preserved on the subject reach of Trout Creek. The finding of a natural environment is based upon fish surveys included in the Colorado Parks and Wildlife ("CPW") aquatic species database and riparian inventories conducted by the BLM.

2. The instream flow location, amount and timing originally recommended by the CWCB staff at the January 2019 board meeting:

- **a)** is based upon standard field, office, and modeling procedures that are used to identify flow rates necessary to support water-dependent natural resource values. The standard procedures include collecting hydraulic and biologic data, surveying stream channel geometry, and modeling instream hydraulic parameters.
- **b)** is based upon accurate application of R2Cross hydraulic modeling procedures, which is the standard scientific modeling methodology utilized by the CWCB for identifying the flow rates needed to support fish populations.

c) is a reasonable selection of protective flow rates, based on standard instream flow criteria used by the CWCB, and based on results from the R2Cross modeling effort that display the relationship between various flow rates and hydraulic parameters
d) is required to preserve the natural environment to a reasonable degree, given the dimensions of the Trout Creek stream channel, as well as the habitat needs, life histories, and population composition of the species found in this stream segment.

3. The natural environment on the subject reach of Trout Creek:

a) includes native and introduced fishes, aquatic macroinvertebrates, and riparian communities. The natural environment supports mottled sculpin, speckled dace, and mountain sucker, which are native species. The natural environment also supports brown trout, brook trout, hybrid cutthroat trout, and longnose dace, which are introduced species. The natural environment also supports riparian communities and species, including narrowleaf cottonwood, red-osier dogwood, and alder.
b) can be preserved with an instream flow appropriation that is based upon the flow needs of salmonid species, because those species are indicator species for other elements of the natural environment.
c) will be preserved to a reasonable degree with the proposed ISF water right.
d) can exist without material injury to existing water rights, including conditional surface water rights and conditional storage rights.

4. The water availability analysis conducted by the CWCB in support of the January 2019 instream flow appropriation:

a) is based upon scientifically accepted hydrologic analysis procedures.
b) relies upon multiple sources of data, all of which demonstrate that sufficient water is available for the proposed appropriation.
c) reflects an amount of water that is available for appropriation as an ISF right, utilizing procedures employed by the CWCB to evaluate a range of hydrologic year types.
d) includes measured flow data that reflects the operations, depletions, and return flows associated with upstream ditches and reservoirs, including Sheriff Reservoir.
e) includes measured flow data that reflects the operations and depletions associated with appropriations that may be presently undecreed, such as new junior appropriations, exchanges, and substitutions of supply between ditches.
f) demonstrates that the proposed instream flow water right will not appropriate all available water for instream use, but instead leaves a sizable volume of water available for future use and development.

5. The BLM supports the staff recommendations as set forth in the January 2019 Staff Report and Recommendation on the subject reach of the Trout Creek.

6. The BLM hereby adopts the factual claims set forth in the CWCB staff's Prehearing Statement.

B. LEGAL CLAIMS

1. The BLM is a party to these proceedings pursuant to Rule 5l(4) of the ISF Rules.

2. Because ISF water rights are non-consumptive and do not divert water from the stream, the CWCB can appropriate an ISF right that is based upon the flow of water that will be diverted downstream by a senior water right.

3. Even though the proposed ISF will be junior to existing water rights on the stream system, the CWCB can make appropriations based on water availability at the time of the proposed appropriation, without subtracting flow rates or volumes that have been adjudicated to conditional or presently undecreed appropriations.

4. The proposed instream flow water right will not deprive the people of the State of Colorado of their right to develop the volume of water allocated to the State of Colorado under the Colorado River Compact. The proposed instream flow water right leaves substantial water volumes available for new junior water rights and future water development.

5. In determining the amount of water available for an instream flow appropriation, the CWCB is not limited to the amount of water available during drought years. Instead, the CWCB may consider the amount of water available in a range of hydrologic conditions.

6. The CWCB has the exclusive authority to determine the amount and timing of water necessary to preserve the natural environment to a reasonable degree.

7. CWCB staff's ISF recommendation for the subject reach of Trout Creek meets all of the substantive and procedural requirements outlined in the ISF Rules.

8. The CWCB's appropriation of an instream flow water right on the subject reach of Trout Creek would further the express intent of Section 37-92-103(3), C.R.S. to "correlate the activities of mankind with some reasonable preservation of the natural environment."

9. The BLM hereby adopts the legal claims set forth in the CWCB staff's Prehearing Statement.

C. EXHIBITS TO BE INTRODUCED AT HEARING

1. January 2019 CWCB Executive Summary on the subject reach of Trout Creek. This report, along with its appendices, contains maps of the proposed reach, proposed ISF amounts and timing, and water availability calculations. This report and supporting appendices are available for review on the CWCB's website at https://dnrweblink.state.co.us/CWCBSearch/ElectronicFile.aspx?docid=207923&dbid=0 In the hearing, BLM will refer to this report and its appendices as **Exhibit 1.**

2. Recommendation letters from the BLM, along with supporting field data, photographs, maps, and water availability analysis. This information set includes fish sampling reports on the subject reach from the Colorado Division of Parks and Wildlife fisheries database, completed in 1993 and 2007. This data is available for review on the CWCB website at: https://dnrweblink.state.co.us/CWCBSearch/ElectronicFile.aspx?docid=207942&dbid=0I n the hearing, BLM will refer to this set of documents as **Exhibit 2.**

3. Gregory D. Espegren, Development of Instream Flow Recommendations Using R2Cross, dated January, 1996. This document is provided as an attachment to this prehearing statement. In the hearing, BLM will refer to this report and its appendices as **Exhibit 3.**

4. Development of Instream Flow Recommendations in Colorado Using R2Cross for Microsoft Excel. This document is provided as an attachment to this prehearing statement. In the hearing, BLM will refer to this report and its appendices as **Exhibit 4.**

5. The BLM may introduce demonstrative, rebuttal, or other exhibits as allowed by the CWCB or agreed upon by the Parties.

6. The BLM hereby adopts all Exhibits listed in the CWCB staff's Prehearing Statement.

7. The BLM may rely upon exhibits introduced or disclosed by any other party to this hearing.

D. WITNESSES

The following witnesses may testify at the hearing as described below, may give rebuttal testimony, and may be available at the hearing to answer questions from the CWCB.

1. Roy Smith, water rights and instream flow coordinator for the BLM (resume available upon request). Mr. Smith may testify about data collection methods, selection of data collection sites, R2Cross modeling efforts, how the BLM formulates ISF recommendations, and specifically how he worked to formulate the BLM's recommendation for the subject reach of Trout Creek.

2. Eric Scherff, BLM hydrologist for the Little Snake Field Office (resume available upon request). Mr. Scherff may testify about the hydrologic and hydraulic characteristics of the subject reach of Trout Creek. In addition, Mr. Scherff may testify regarding channel morphology, riparian characteristics, and fishery characteristics of Trout Creek.

3. Tom Fresques, BLM Colorado fisheries biologist (resume available upon request). Mr. Fresques may testify concerning the fishery composition of Trout Creek, the life history and habitat needs of the various fish species found in Trout Creek, the relationship between riparian habitat and fish habitat, and standard data collection methods for the fishery surveys.

4. The BLM may call any witness declared by any other party to this hearing.

E. WRITTEN TESTIMONY

BLM does not seek to enter any written testimony at this time. The BLM hereby adopts any written testimony listed in the CWCB staff's Prehearing Statement.

F. LEGAL MEMORANDA

BLM does not seek to enter any legal memoranda at this time. The BLM hereby adopts any legal memoranda listed in the CWCB staff's Prehearing Statement.

Respectfully submitted this 3rd day of September, 2019.

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Development of Instream Flow Recommendations In Colorado Using

R2CROSS

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Department of Natural Resources
1313 Sherman Street, Room 721
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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.O, 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.

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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.

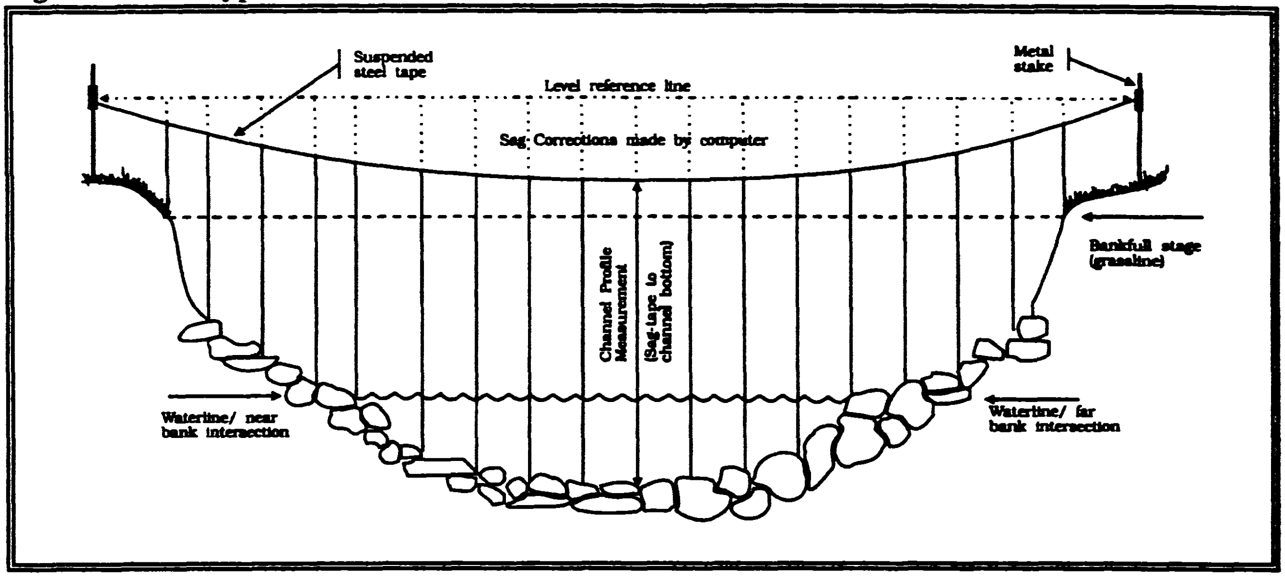
The R2CROSS program uses the standard weight of a one-foot section of the steel tape, tape tension, and the length of tape in suspension to correct horizontal distance and vertical depth measurements made from the sagging tape. The program adjusts the coordinates at each cross section vertical so that 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)

FIELD DATA FOR INSTREAM FLOW DETERMINATIONS

COLORADO WATER CONSERVATION BOARD

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

TAPE

LEGEND: Stake ⊗ Station ○ 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/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		
TOTALS											

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

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

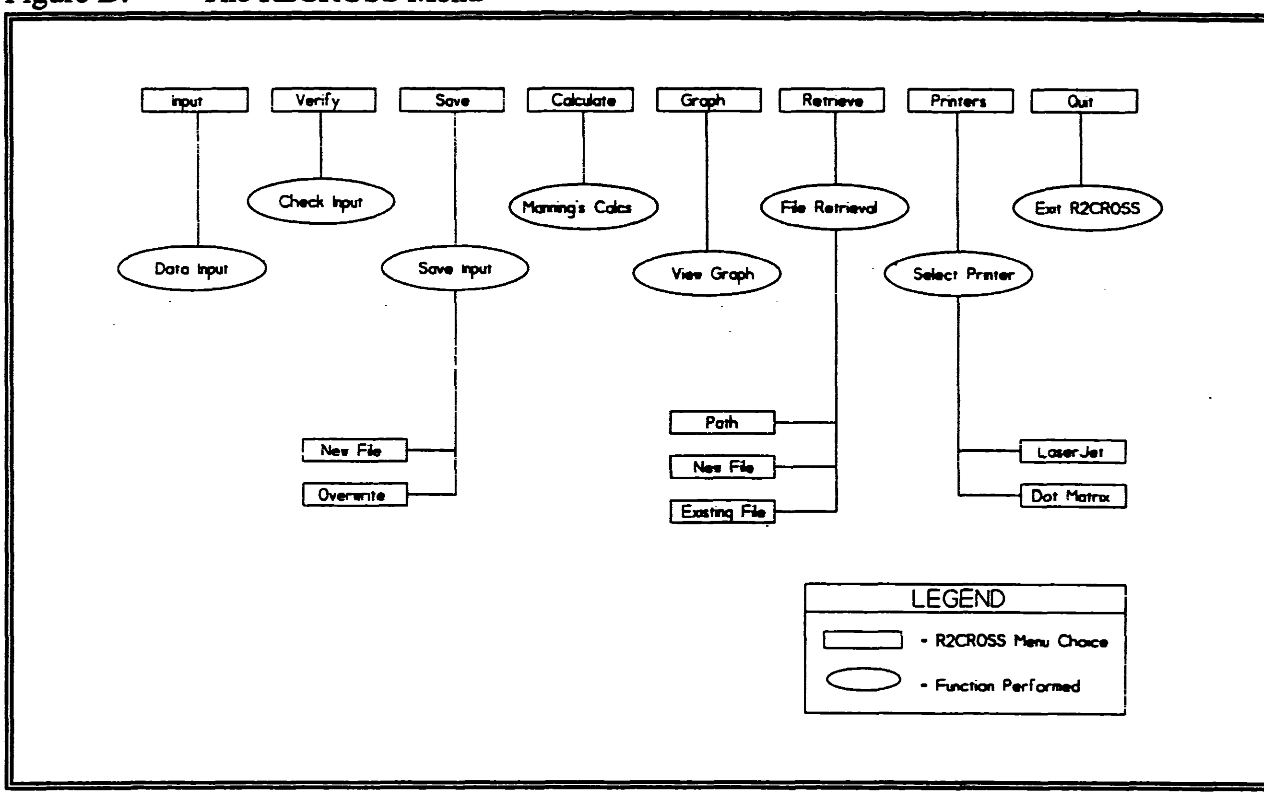


Figure E. R2CROSS proof sheet

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   MEAS   COMP   AREA
   LINE   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

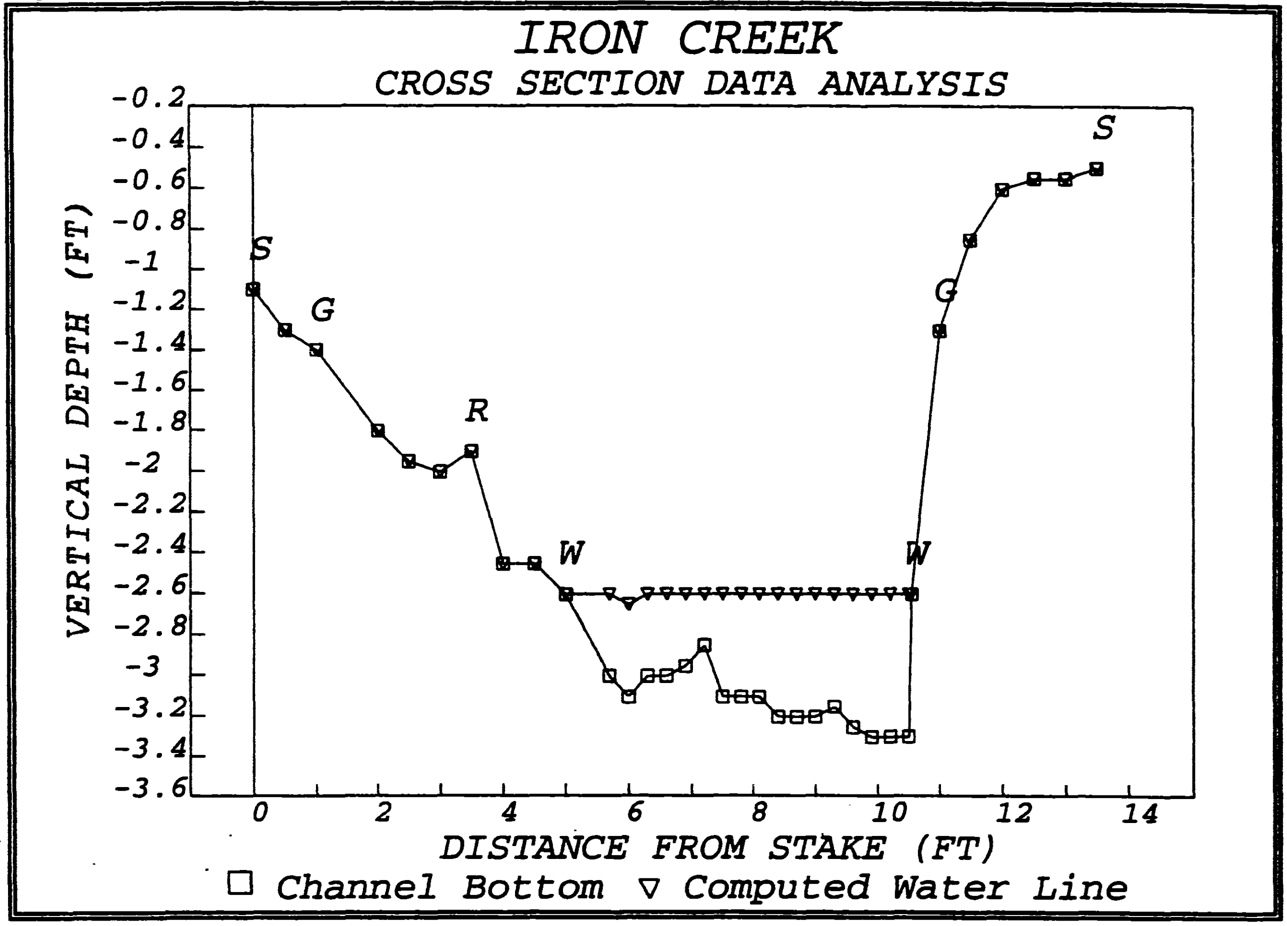
MEASURED FLOW (Qm)=	2.91 cfs		RECOMMENDED INSTREAM FLOW:	
CALCULATED FLOW (Qc)=	2.91 cfs		==========================	
(Qm-Qc)/Qm * 100 =	-0.1 %			
			FLOW (CFS)	PERIOD
MEASURED WATERLINE (WLm)=	2.61 ft		==========	======
CALCULATED WATERLINE (WLc)=	2.61 ft			
(WLm-WLc)/WLm * 100 =	-0.1 %		________	________
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:
=============================

RECOMMENDATION BY: ....AGENCY................ DATE:................

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

Figure K. Cross section plot from R2CROSS



<u>Biologic Instream Flow Recommendations</u>

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.O, 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.

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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.

<u>Sag-Tape Calculations.</u>

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.

<u>Use of Manning's Equation.</u>

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

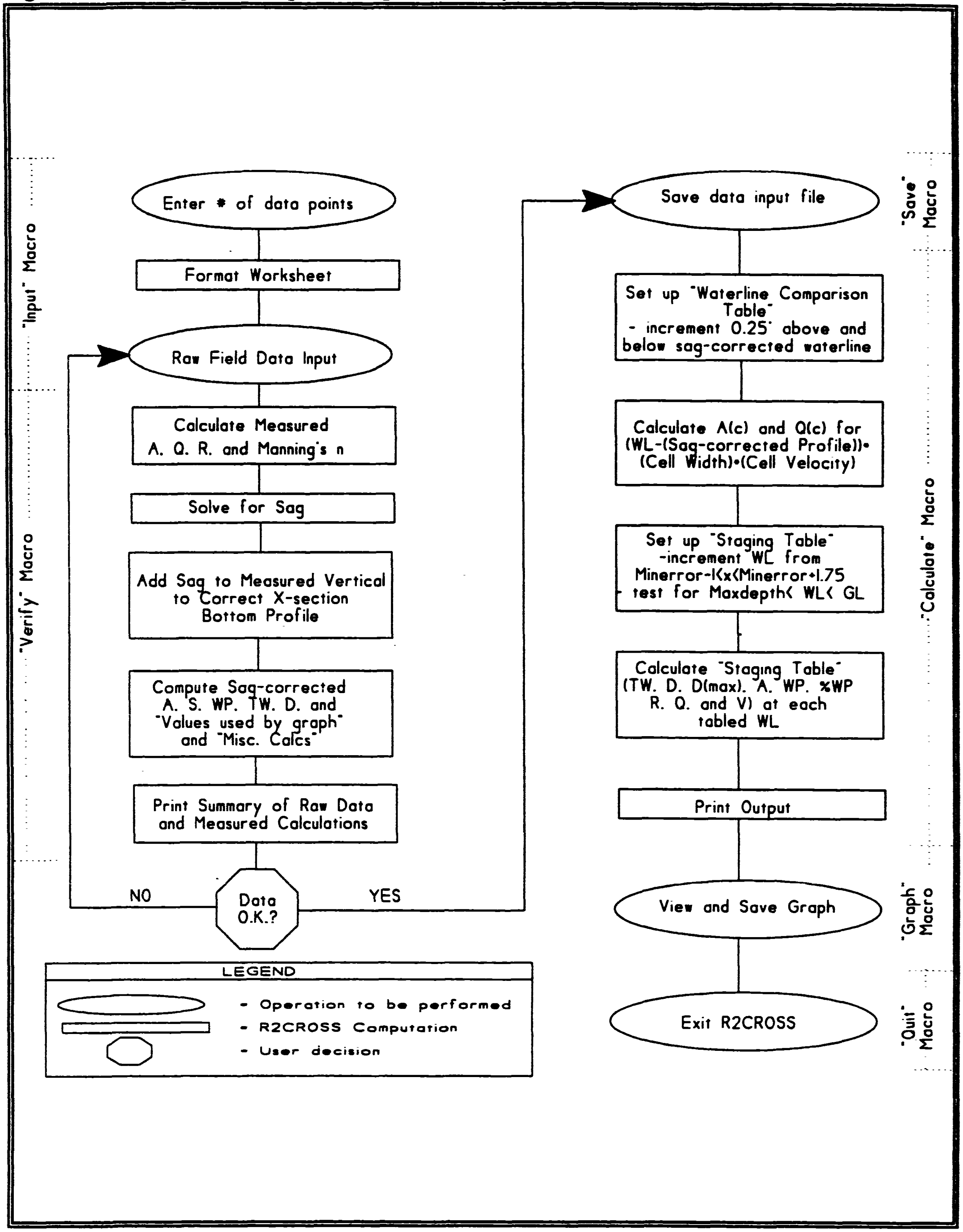

Figure M. Lotus 1-2-3 worksheet layout for R2CROSS macro

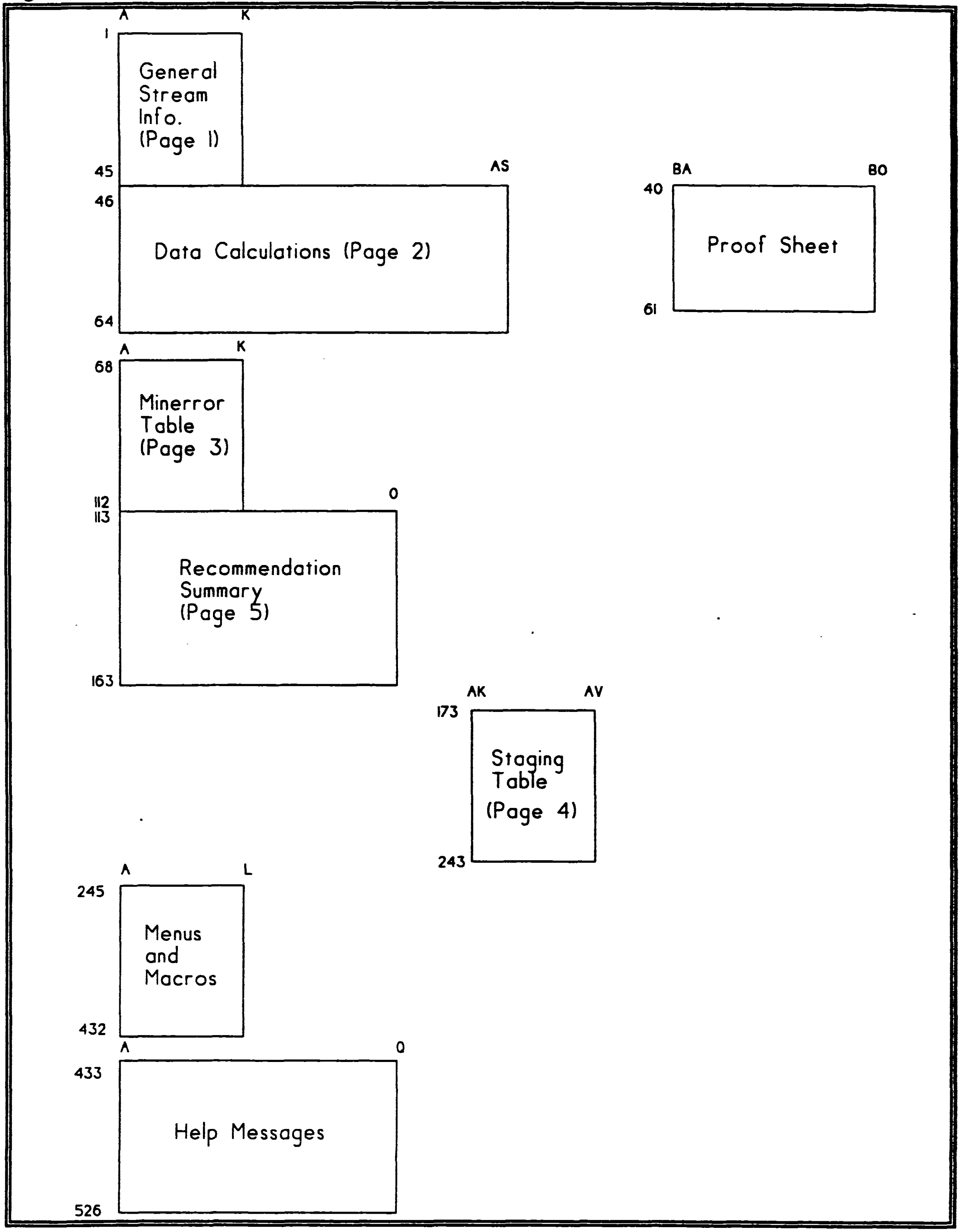

Table 4. Hydraulic Formulas used in R2CROSS staging table

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 ($\bar{x}_v$)	$\frac{Q}{A}$

Development of
Instream Flow Recommendations
In Colorado Using

R2CROSS for Microsoft Excel

For additional copies
Write or call:

:

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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.

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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." SB 97 was amended by Senate Bill 414 in 1981, Senate Bill 91 in 1986, Senate Bill 212 in 1987, Senate Bill 54 in 1994, SB ___ 1996, SB 200?. These changes and amendments are consolidated within §37-92-102(3), C.R.S. (2002), the Instream Flow statute.

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).

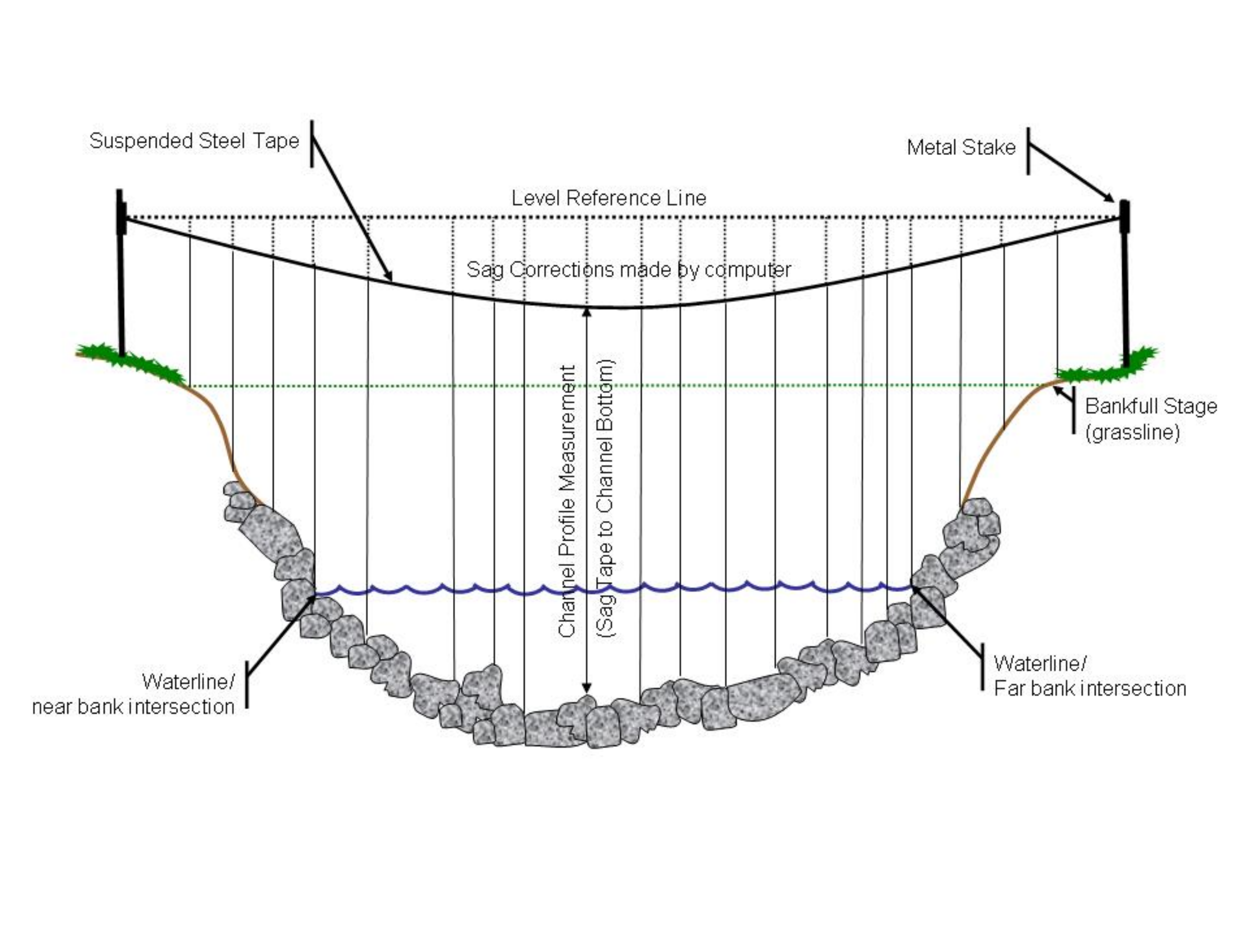

Figure A. Typical stream cross section

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

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

TAPE

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 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) At Point	Velocity (ft/sec) Mean in Vertical	Area (ft^2)	Discharge (cfs)
TOTALS											

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

Figure C. Field data input sheet (Back Page)

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.

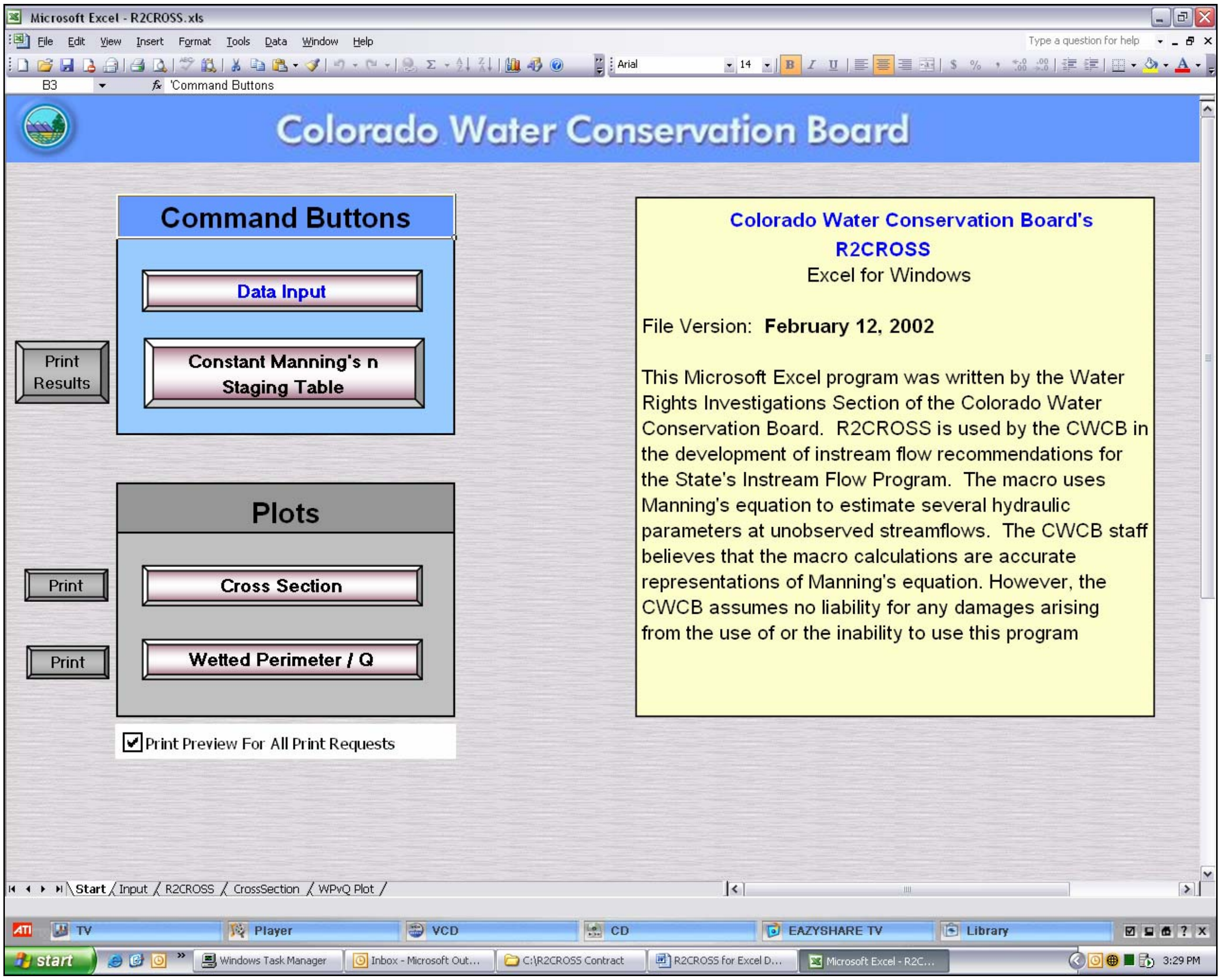

Figure D. R2CROSS menu in Microsoft Excel for Windows

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
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
		4.00	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
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 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

STAGING TABLE

GL = lowest Grassline elevation corrected for sag
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

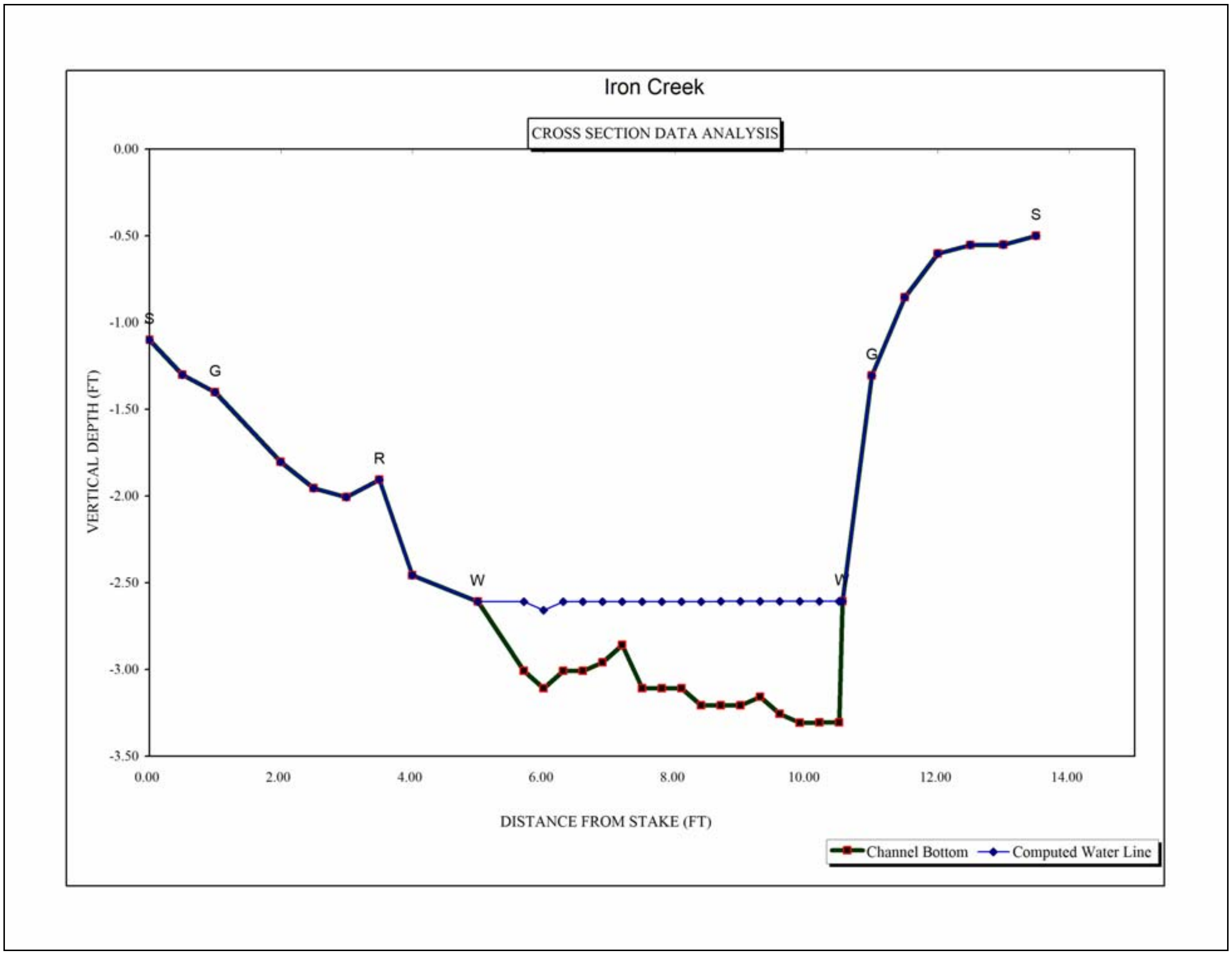

Figure K. Cross Section Plot from R2CROSS – Iron Creek Example

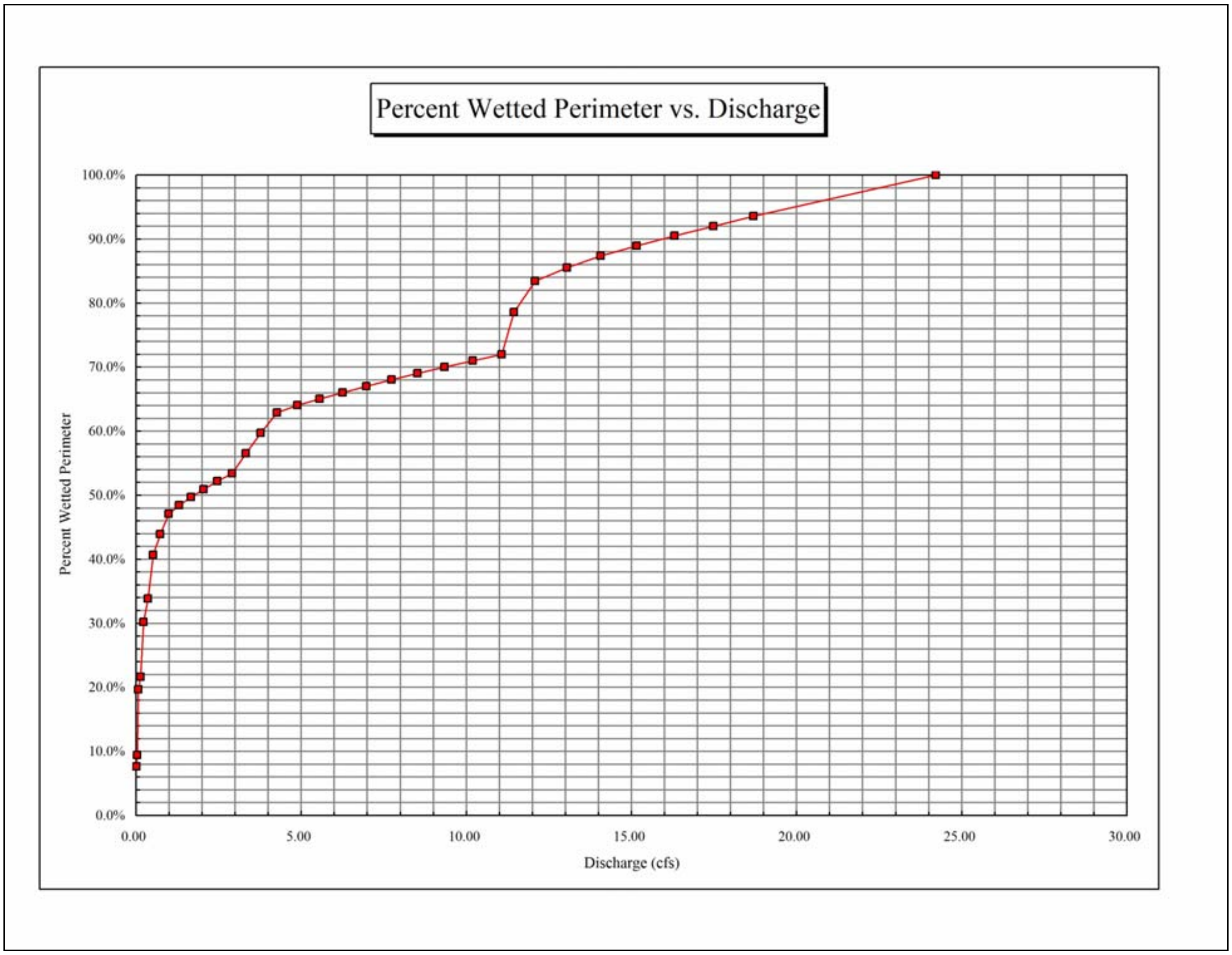

Figure L. Wetted Perimeter Plot from R2CROSS – Iron Creek Example

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.

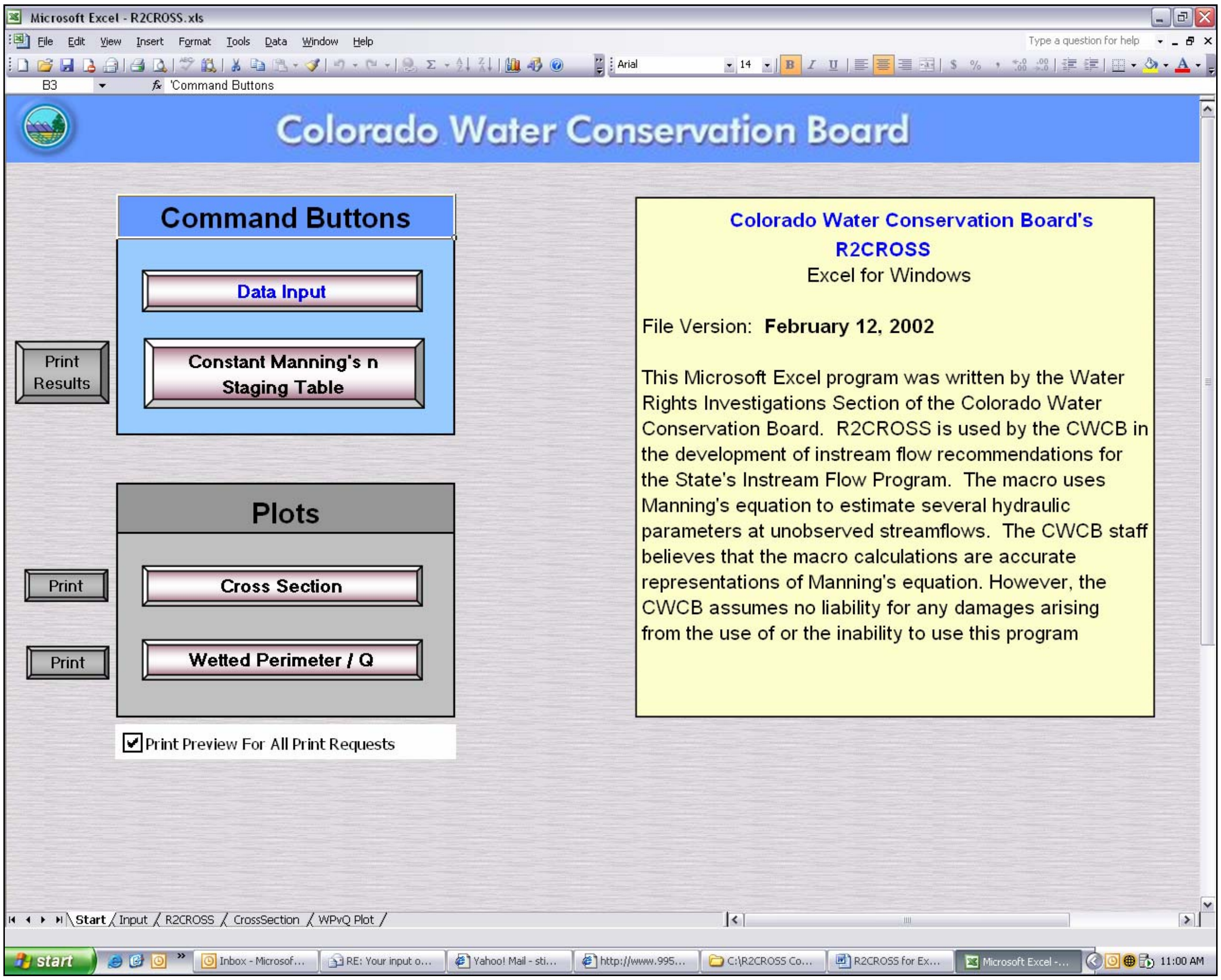

Figure M. R2CROSS Menu

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.

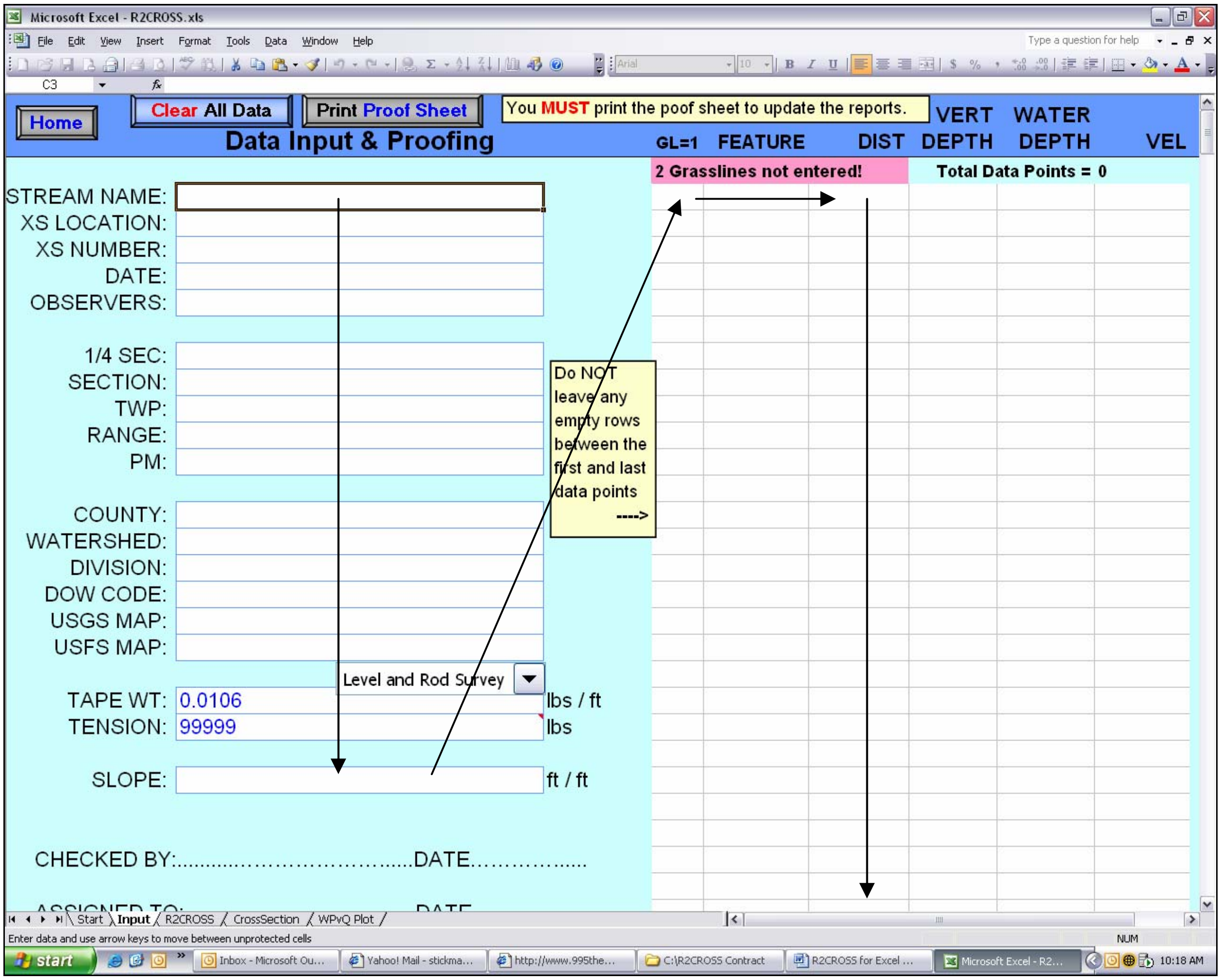

Figure N. R2CROSS Data Input and Proofing Screen

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.

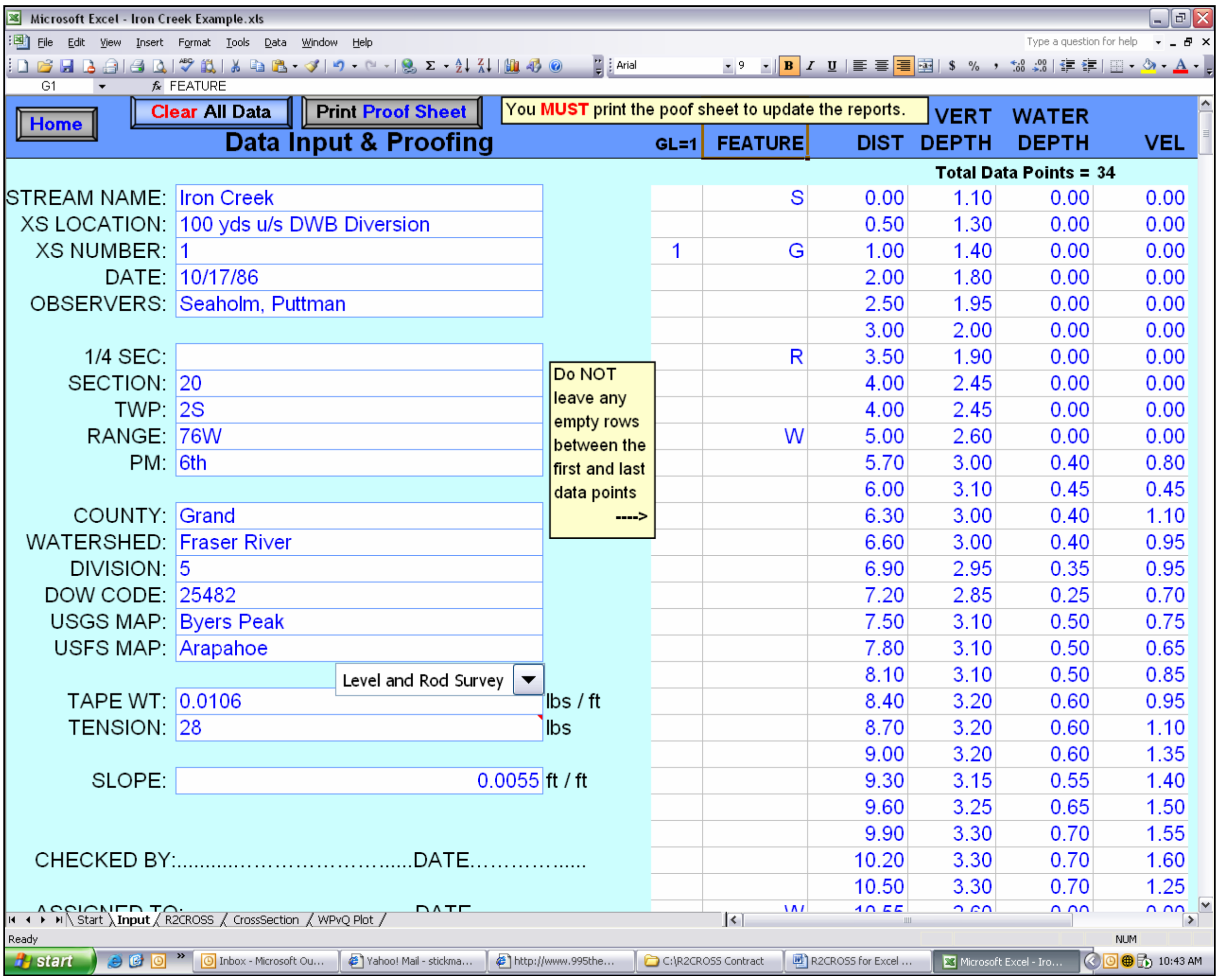

Figure O. Iron Creek Data Entry and Proofing Screen

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.

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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})	$\overset{n}{\underset{i=1}{MAX}}(D_i)$
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 ($\bar{x}_v$)	$\frac{Q}{A}$