Development of Instream Flow Recommendations In Colorado Using

R2CROSS for Microsoft Excel

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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."

The Instream Flow statute sets forth the guidelines for the administration of Colorado's Instream Flow Program. In order to encourage other entities to participate in Colorado's Instream Flow Program, the statute directs the CWCB to request instream flow recommendations from other state and federal agencies prior to initiating an instream flow appropriation. The CWCB routinely requests instream flow recommendations from the DOW, Colorado Division of Parks and Outdoor Recreation, United States Department of Agriculture, and United States Department of Interior (the "cooperating agencies").

Prior to appropriating an instream flow water right, the statute requires the CWCB to: (1) "determine that the natural environment will be preserved to a reasonable degree by the water available for the appropriation to be made; (2) determine that there is a natural environment that can be preserved to a reasonable degree with the CWCB's water right, if granted; and (3) determine that such environment can exist without material injury to water rights" (§37-92-102(3c), C.R.S. (2002)). The CWCB makes these determinations based upon a review of the supporting technical data and a final instream flow recommendation prepared by the CWCB staff.

Standardized field and office procedures have been developed to help ensure that final instream flow recommendations meet statutory guidelines and are consistent. The standard field procedures that were established concern selection of transect sites and collection of hydraulic and biologic data. Standard office procedures have been established for determining biological instream flow recommendations using output from the R2CROSS program and for analyzing water availability.

Merriman and Janicki (2005) provide additional information on the state of Colorado’s Instream Flow Program.

Field Procedures

The R2CROSS Method is a "Standard Setting" hydraulic based instream flow assessment technique. R2CROSS instream flow recommendations are typically based on hydraulic and biologic data collected during single or multiple field visits. Hydraulic data collection consists of setting up atransect, surveying stream channel geometry, water surface elevations, and measuring stream discharge. Biologic data is gathered to document the existence of a natural environment.

Field Data Site Selection

The R2CROSS method requires that stream discharge and channel profile data be collected in a riffle stream habitat-type. A riffle is a stream segment that is controlled by channel geometry rather than a downstream flow control. Riffles are most easily visualized as the stream reaches which would dry up most quickly should streamflow cease.

Biologically, riffles are essential to the production of benthic invertebrates and the passage, spawning, egg incubation, feeding, and protective cover of fish. Riffles are also the stream habitat-type most sensitive to changes in hydraulic parameters with variation in discharge (Nehring 1979). Riffles are critical to a healthy aquatic environment because small reductions in streamflow may result in large reductions in water depth and the amount of wetted perimeter available for aquatic habitat. Maintaining adequate streamflow in riffles also preserves the natural environment in other important stream habitat-types such as pools and runs (Nehring 1979).

Hydraulic engineers have developed several mathematical models and equations to predict instream hydraulic parameters (Chow 1959). Manning's equation is one such model that is well-suited to the riffle stream habitat-type (Grant et al. 1992). In order to maximize the reliability of Manning's equation, transects are placed within a riffle so that streamflow is uniform across the transect (Grant et al. 1992). Each transect should represent the average stream width, depth, and cross-sectional area within the riffle being characterized. Transects should be located in areas that exhibit natural banks or grasslines and concentrated water flow, free from braiding. They should not be located on eroded or undercut streambanks.

Hydraulic Data Collection

Stream discharge is measured using standardized procedures established by the United States Geological Survey (USGS) (Buchanan and Somers 1969). Channel geometry can be measured using sag-tape methodology (Silvey 1976; Ray and Megahan 1979) or by the use of a land survey level and stadia rod (Benson and Dalrymple 1967). A list of recommended field equipment for completing the required streamflow measurement and channel geometry measurements is provided in Table 1.

The sag-tape methodology consists of suspending a steel tape from bank to bank across the stream channel, perpendicular to the streamflow (Figure A). Metal cross section stakes are driven into the ground above the grassline. The steel tape is suspended by attaching the zero-end of the tape to one of the metal stakes, stretching the tape across the stream, and then attaching the other end to a tape

Table 1. Recommended Field Equipment List

Equipment	Description
100' Steel Survey tape	Stretched between cross section stakes. (Obtain standard weight of a 1.0 foot section of tape from manufacturer)
Spring Tension Scale	Used to measure pounds of tension on steel tape when stretched between stakes.
Tape Clamp Handle	Holds tape in tension.
Cross Section Stakes	Two 24"-36" metal stakes used to maintain tape tension and to level steel tape. Must be strong enough to be driven into rocky stream bank.
Discharge Wading Rod (or Stadia Rod)	Used to measure vertical depths from suspended tape to stream channel.
Level, Tripod, and Stadia Rod	Used to level ends of suspended tape and to measure slope.
Current Meter	Pygmy, Price AA, Marsh-McBirney or similar devise used to measure stream velocity.
Hand Sledge Hammer	Used to drive cross section stakes into streambank.
Staging Pin	Used to detect changes in discharge during the streamflow measurement.
100' Fiberglass Tape	Used to measure horizontal distance from suspended tape to water-slope stadia rod readings.
Field Forms and Clipboard	Standardized form to ensure complete set of field data.
Miscellaneous Items	Digital camera, GPS Unit, maps, waders, stopwatch and calculator.

clamp and spring scale fastened to the metal stake on the opposite streambank. A minimum of 15 pounds of tension is applied to the tape, as the tape is drawn up and clamped. A survey level and stadia rod are used to adjust the ends of the tape up or down until they are level, thereby producing a consistent datum from which vertical distance measurements can be read.

The R2CROSS program uses the standard weight of a one-foot section of the steel tape, tape tension, and the length of tape in suspension to correct horizontal distance and vertical depth measurements made from the sagging tape. The program adjusts the coordinates at each cross section vertical so that the corrected measurements correspond to a level datum from stake to stake and not the curved datum created by the sagging tape (Figure A).

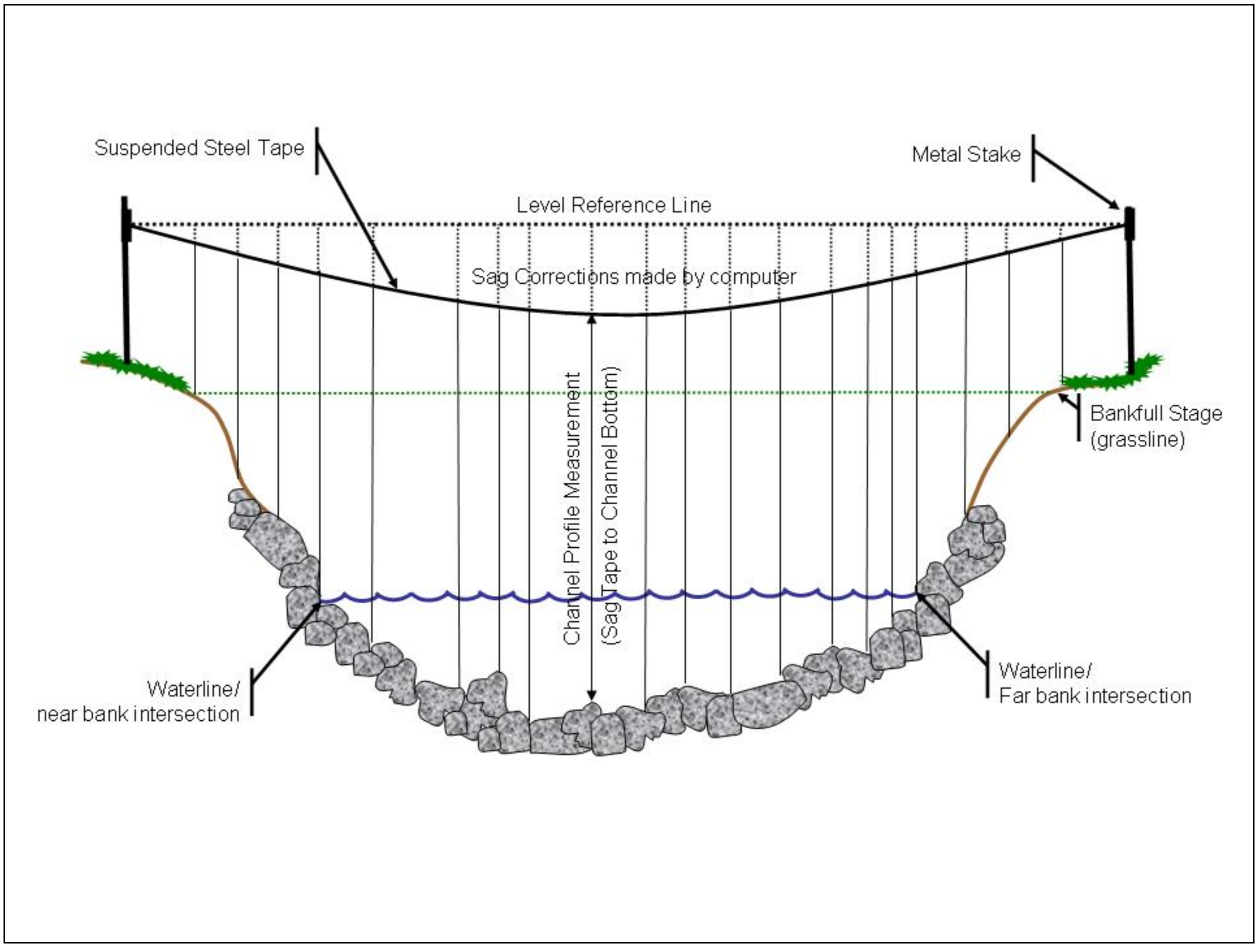

Figure A. Typical stream cross section

Vertical measurements between the suspended tape and the stream channel may be replaced with readings using a survey level and stadia rod. The suspended tape is then used to measure only the horizontal location of each cell vertical. There is no need to precisely level the ends of the suspended tape or to record the tape tension as no sag corrections are required.

Biologic Data Collection

Biologic sampling is conducted to document the existence of a natural environment. Coldwater fish species, particularly salmonids, have been used to indicate the existence of such a natural environment in the majority of the CWCB's instream flow appropriations to date. Warmwater fish species and other aquatic life forms may be used to document the existence of a natural environment in more downstream, low-elevation stream segments. In addition to salmonids, the CWCB has used amphibians, such as frogs and salamanders, and warmwater fish species, including the endangered fishes of the Colorado River basin, as the biologic basis for instream flow appropriations.

Biologic data typically consists of a fish sample, collected by electrofishing, and an aquatic invertebrate sample. Captured fish are identified and measured and a length-frequency distribution is constructed for each species. The fish sample is not tied directly to the R2CROSS hydraulic modeling but it may be used to refine the biologic instream flow recommendation to meet the specific habitat requirements of unique populations.

Digital Camera and GPS Unit

Digital cameras should be used to record the field data collection effort. A photographic record of the hydraulic data collection process may include pictures of the transect location (upstream, downstream and across stream views) and the stream flow measurement process. These photos can serve as valuable visual evidence that cross sections were properly located in riffles and that standard data collection protocols were met. In addition, photographs may help relocate a transect in the future should additional data be required.

Photos of the biologic data collection effort may also assist the CWCB in making its natural environment findings. Photographs of the biologic sampling process and captured organisms (fish, aquatic insects, etc.) may be used in combination with a statistical summary of the results of biologic sampling to document the existence of a natural environment.

Handheld GPS Units should be used to record field data collection site locations. Geographic coordinate information helps relocate transect locations in the future should additional data be required.

Digital cameras and handheld GPS Units are small in size and light in weight. Digital photos can easily be transferred into written reports and they provide valuable visual evidence. A digital camera and a handheld GPS Unit should be considered standard equipment on any field data collection effort.

The Field Form

The CWCB and DOW use a standardized field form to record all field data. The use of this form helps to ensure that all instream flow recommendations are based upon a uniform set of field data. The front page of the form provides space for cross section "Location Information", "Supplemental Data", "Channel Profile Data", an "Aquatic Sampling Summary", and "Comments" (Figure B). The back page is dedicated to "Discharge/Cross Section Notes" (Figure C).

The "Location Information" section of the field form is used to describe the location of the cross section as well as the date and names of the members of the field crew. Geographic information can be obtained from USGS maps, United States Forest Service (USFS) maps, or handheld GPS Units. Water divisions and DOW water codes can be obtained from the State Engineers' Office, the CWCB, or the DOW.

The "Supplemental Data" section is used to provide supporting documentation of the field data collection effort. Most importantly, this section is used to record the tape manufacturer's standard weight (lbs/ft) and tape tension (lbs). The R2CROSS program uses this information, together with the length of tape in suspension, to adjust vertical distances measured from the sagging tape to a level reference datum.

The "Channel Profile Data" section of the form is used to establish the relationship between the sag-tape cross section and the stream. Stadia rod readings are taken at each end of the suspended tape and at the water surface on the right and left streambanks. These readings are recorded within the "Rod Reading (ft)" column. They are used to assure that the ends of the tape are level and to quantify the vertical distance between the suspended tape and the water surface. Water surface readings and horizontal distances are also recorded upstream and downstream of the suspended tape. These observations are used to establish the water surface slope for input into Manning's equation.

COLORADO WATER CONSERVATION BOARD

FIELD DATA FOR INSTREAM FLOW DETERMINATIONS

COLORADO DIVISION OF WILDLIFE

LOCATION INFORMATION

STREAM NAME:					CROSS-SECTION NO.:
CROSS-SECTION LOCATION					
DATE	OBSERVERS.				
LEGAL DESCRIPTION	¼ SECTION·	SECTION	TOWNSHIP N/S	RANGE: E/W	PM:
COUNTY.	WATERSHED	WATER DIVISION·	DOW WATER CODE.		
MAP(S)	USGS:				
	USFS:				

SUPPLEMENTAL DATA

SAG TAPE SECTION SAME AS DISCHARGE SECTION· YES / NO	METER TYPE.			
METER NUMBER.	DATE RATED.	CALIB/SPIN ______ sec	TAPE WEIGHT ______ lbs/foot	TAPE TENSION ______ lbs
CHANNEL BED MATERIAL SIZE RANGE	PHOTOGRAPHS TAKEN YES/NO	NUMBER OF PHOTOGRAPHS.		

CHANNEL PROFILE DATA

STATION	DISTANCE FROM TAPE (ft)	ROD READING (ft)
Tape @ Stake LB	0.0	
Tape @ Stake RB	0.0	
(1) WS @ Tape LB/RB	0.0	
(2) WS Upstream		
(3) WS Downstream		
SLOPE		

SKETCH

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 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.

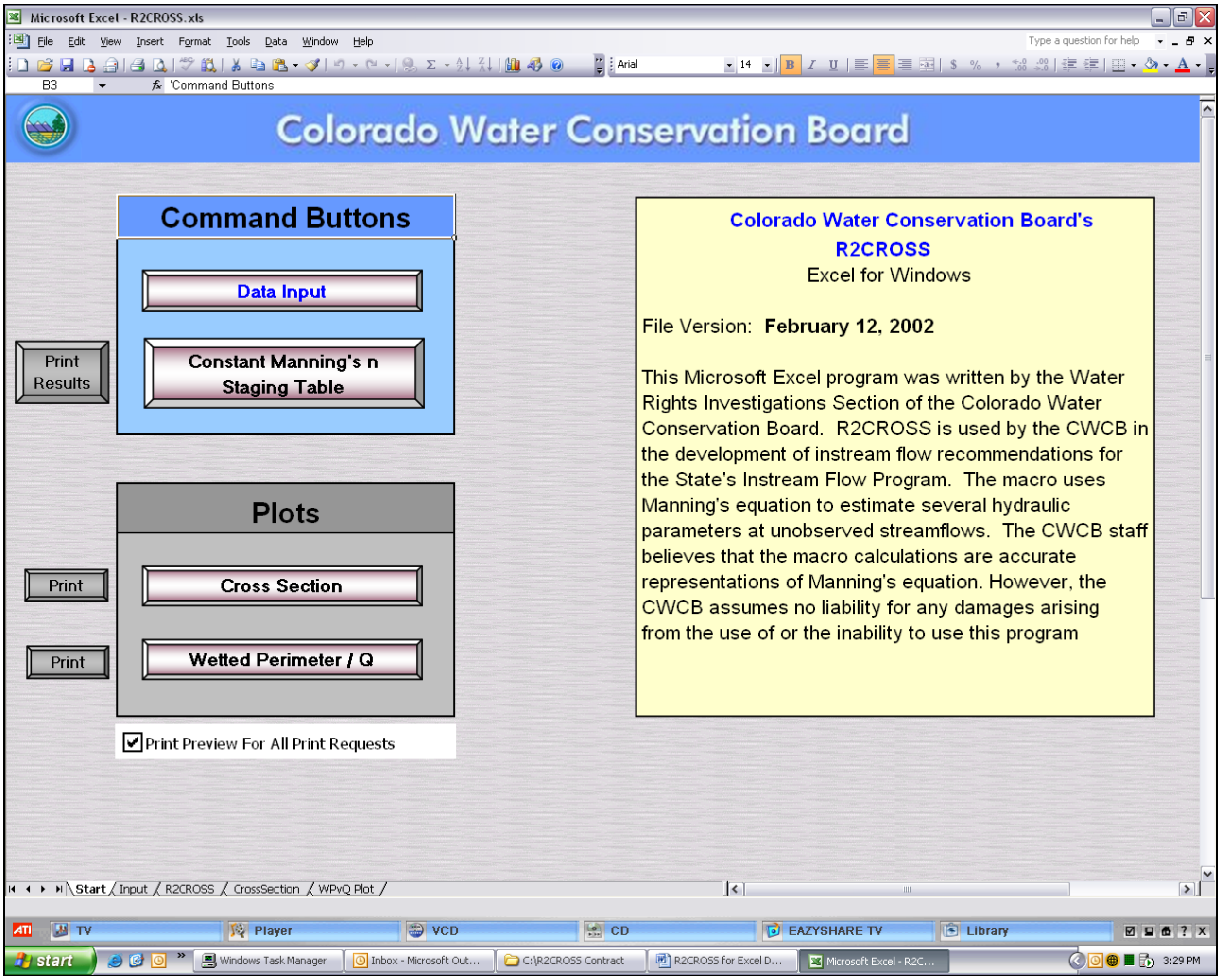

Figure D. R2CROSS menu in Microsoft Excel for Windows

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

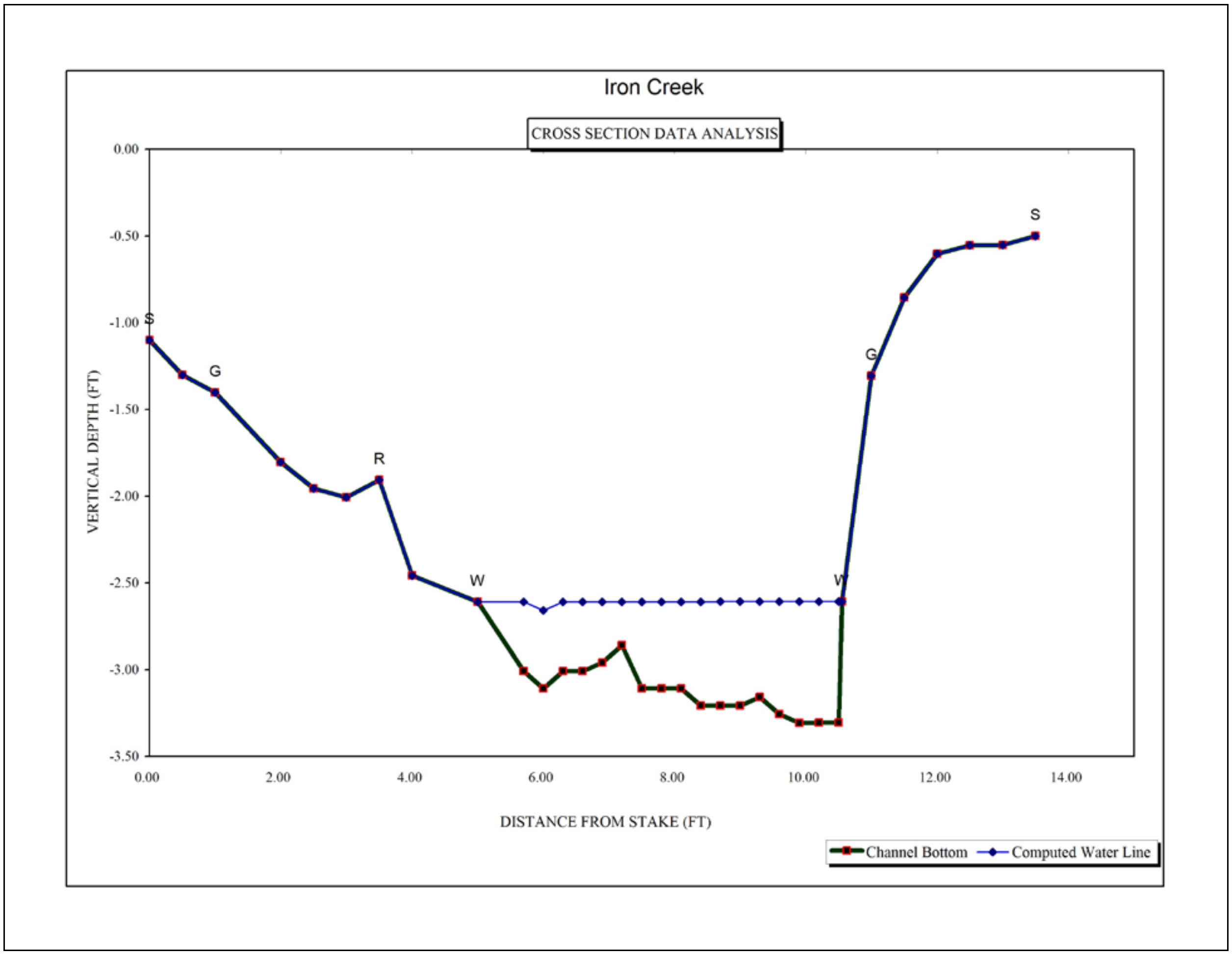

Figure K. Cross Section Plot from R2CROSS – Iron Creek Example

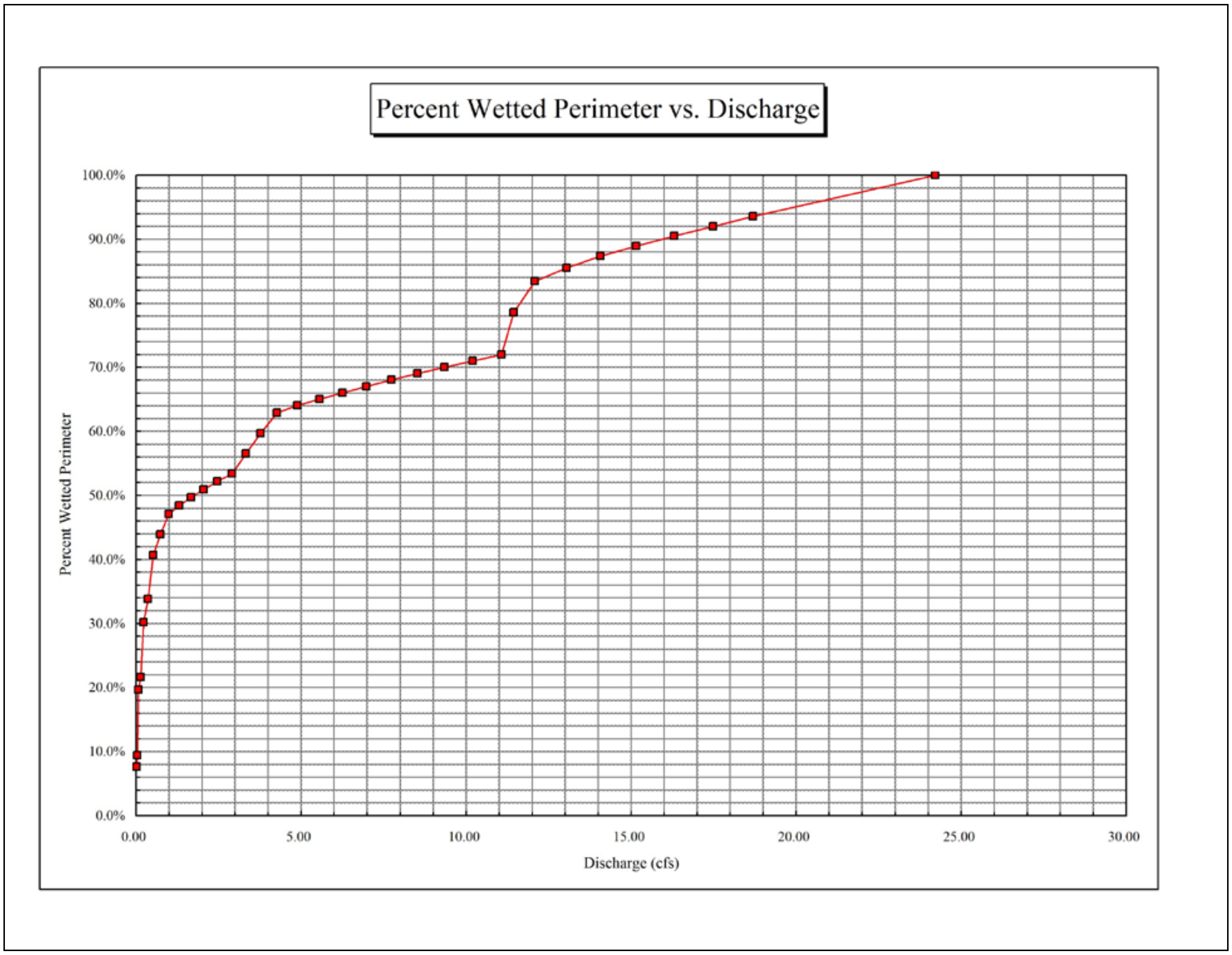

Figure L. Wetted Perimeter Plot from R2CROSS – Iron Creek Example

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.

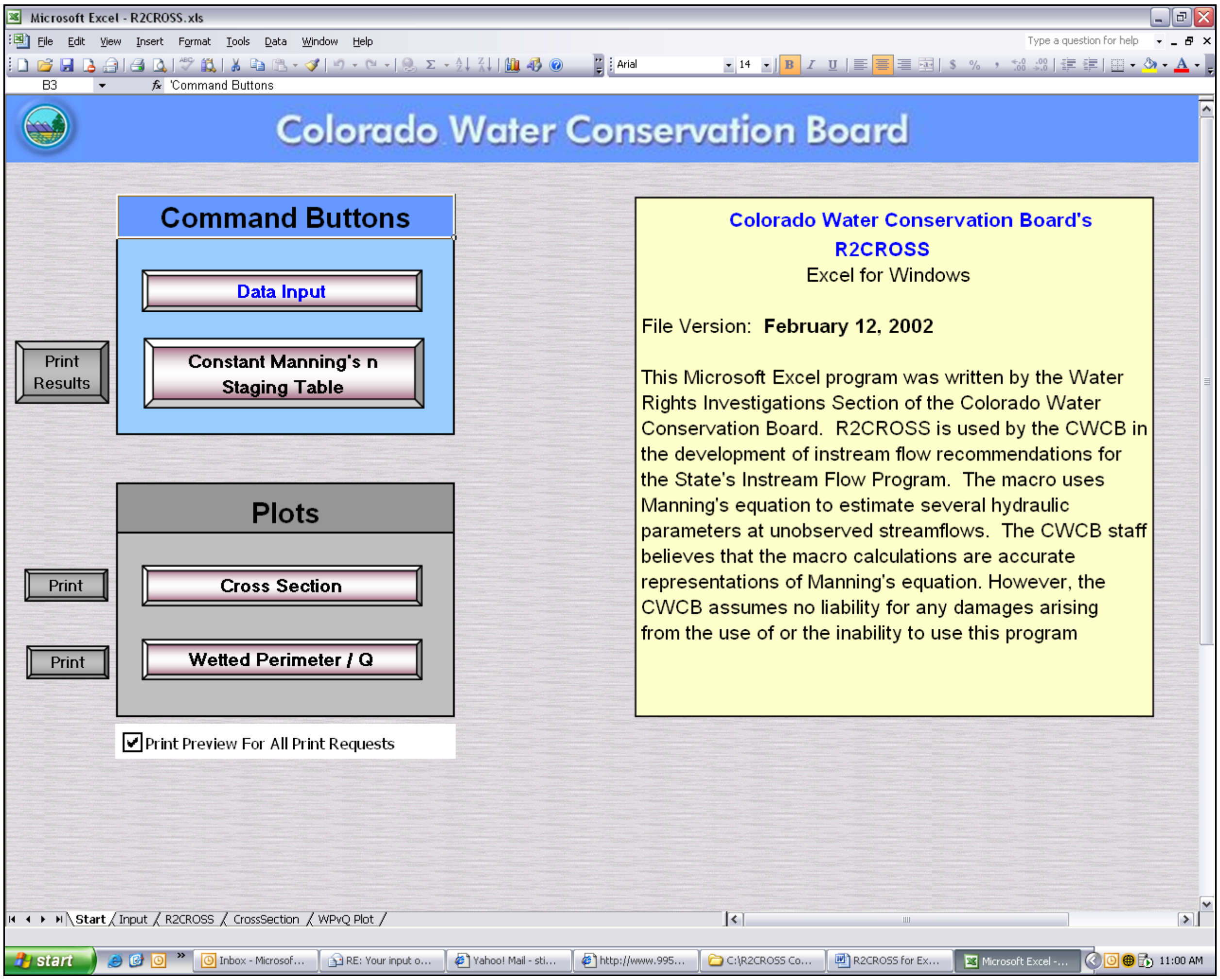

Figure M. R2CROSS Menu

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.

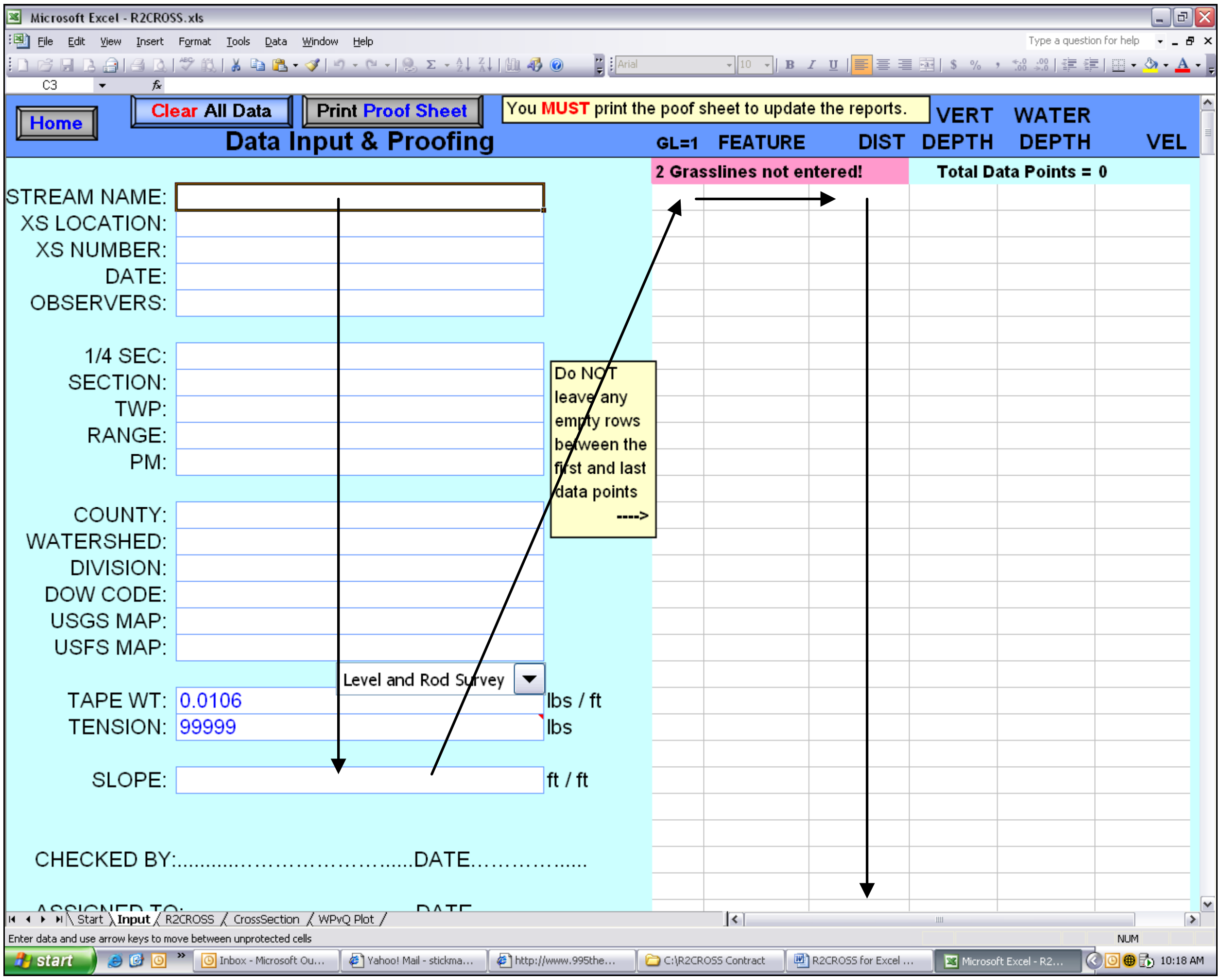

Figure N. R2CROSS Data Input and Proofing Screen

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.

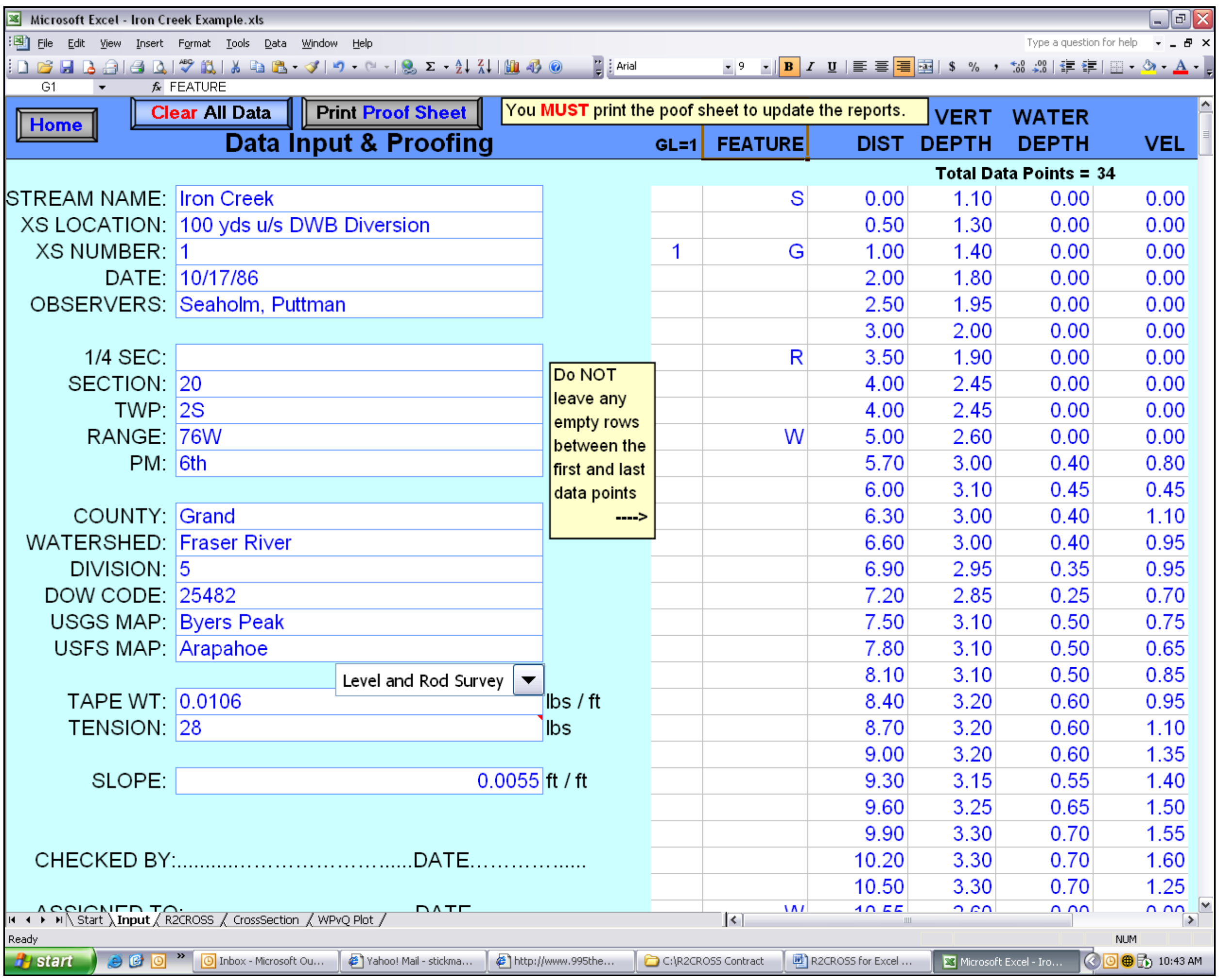

Figure O. Iron Creek Data Entry and Proofing Screen

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