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Riverine Fish-Flow Investigations

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Job Progress Report

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INTRODUCTION

Habitat loss is one of the single greatest causes of declines in populations of native fishes in North America (Williams et al. 1989). While there clearly must be some minimum flow needed to maintain a healthy, functioning river community, methods to establish minimum flows have proved controversial. Most flow studies implemented in Colorado have focused on protecting cold water habitats and use either the R2Cross method (Nehring 1979) or Instream Flow Incremental Methodology (IFIM) (Bovee 1982), which determines habitat availability based on a single target species. IFIM estimates the amount of usable habitat for fish as a function of discharge by combining habitat suitability curves with the hydraulic model. The habitat component of the model has received much criticism because of assumptions implicit with using suitability curves and assumptions of positive relationships between habitat availability and fish abundance. Validation of these assumptions have been obstacles for successfully using IFIM to model minimum flow impacts on large warm water rivers of the west slope (Rose and Hahn 1989).

Warm water fish assemblages appear to require a more intensive approach to instream flow modeling compared to cold water fish communities. Warm water stream sections tend to have higher species diversity. Also habitat suitability curves derived from microhabitat observations do not adequately describe habitat use for many warm water species. A broad community-level perspective, as opposed to an indicator species approach, may be required to protect all habitats of a functioning warm water stream ecosystem.

Instream flow techniques require integration of two processes that combine detailed knowledge of habitat requirements (by species and life stage), and the availability of necessary habitats. Both the collection and analysis of these data bases have been very labor intensive. Recent advances in surveying techniques and computer capabilities allow for collection and processing of much larger databases. Also development of new tools for instream flow and habitat availability relationships, i.e. two-dimensional flow models, may eliminate the need for microhabitat suitability curves used by IFIM.

The goal of this project is to develop and validate a methodology for determining instream flow recommendations for warm water fish communities in Colorado. The approach is to determine relationships between habitat availability and flow using a two-dimensional flow model to simulate meso-habitat diversity and abundance over a range of low flows on sections of three different rivers. Also fish population and species life history data will be collected within each of the study sites to provide habitat use and preference data.

The data collected for this study is part of a larger study addressing the need to restore depleted flows on the Yampa River. (Anderson, Modde, Miller and Ivring, in press). Minimum flows and habitat for the aquatic community were determined using an "inflection point" methodology. This approach identified regulating properties of the channel that strongly influence habitat quality and quantity. For example when stream width is plotted as a function of flow the curve indicates how width increases as flow fills the channel. Typically, stream width quickly increases up to a certain level, but as flow continues to increase, depths and velocity increase at faster rates since stream width is approaching channel width. Most of this analysis focused on riffles because they are the habitat most sensitive to low flows. Also riffles have an important ecological function since they are strongly associated with macroinvertebrate communities and other forage species.

The data and methodology used on the Yampa River provide a strong description of habitat/flow relationships and may have widespread application for minimum flow recommendations in other warm water fish communities in western Colorado. The IFIM data collected for habitat availability for Colorado squawfish is also presented. As suitability curves for other native fish are developed, habitat availability (weighted usable area) derived from IFIM sites on the Yampa will be compared to subsequent maps made from other methodologies.

Study Area

DESCRIPTION OF RIVER STRATA

The study area includes warm water reaches between the lower 59 and 135 miles of the Yampa River, from Cross Mountain to the town of Craig Colorado (Figure 1). Miller (1982) stratified the warm water portion of the Yampa River into 8 strata as a function of valley configuration. Strata one, two, three and four are located below Cross Mountain and six, seven and eight are above.

Stratum 6 begins at RM 58.5 ends at RM 88.0 and includes the communities of Sunbeam and Maybell. The Yampa River in this stratum meanders in a wide valley floor, is low gradient and has a high percentage of sandy substrates. Most of the floodplain is grazed and is adjacent to irrigated agricultural land. Only a small percentage of the river bank is stabilized by shrubby vegetation. The Maybell gage is located near the upper edge of this stratum at RM 85.8.

Stratum 7 is from RM 88.0 to 91.6, the length of Juniper Canyon. The river in Juniper Canyon is confined by narrow canyon walls and is without a flood plain. The Maybell diversion dam (a structure of large boulders across the river) and headgate are located in this reach at RM 89.2. The river below the diversion dam has reduced flows compared to above, while the river immediately above the dam in slowed and deepened because of the dam. A telemetry tower was placed near the diversion dam to monitor fish movements because it is believed fish passage at low flows could be a concern. Cross sectional profiles were not done in this stratum because this reach is very short and it is not typical of the river in general.

Stratum 8 begins at RM 91.6 and ends at the town of Craig, CO at RM 135. In this stratum the valley is more confined than in Strata 6. Between RM 91.6 and RM 105.0 the valley is wide enough for hay fields and pastures adjacent to the river. The river reach between RM 105 and RM 126 is the Little Yampa Canyon management unit. Most of the river bottom in this reach owned by the BLM is confined but the valley floor is wide enough for a flood plain. A fairly large portion of the river in Little Yampa Canyon is on private property. The Williams Fork is the only major tributary to enter the river above Cross Mountain and its confluence is at RM 129.

HISTORIC HYDROLOGY

Peak flow typically occurs in early June and minimum flows in early September (Figure 2). The hydrographs on Figure 2 represent the 90%, 80%, 50%, 20% and 10% exceedence flows for 81 years of flow records for the Maybell gage and indicate the frequency that a flow will exceed that value. For example, in one out of ten years flows have exceeded the 10% curve.

Mean total annual runoff for the Maybell gage, from 1916 to 1997, is 1.13 million-acre feet (MAF). In both 1996 and 1997 annual runoff volumes were above average. The annual runoff for 1996 was 1.57 MAF and it was 1.88 MAF for 1997. Bankfull flow, defined as the channel forming flow, typically has a recurrence interval of about 1.5 years (Gordon et al 1992). The 1.5 year peak flow on the Yampa River at

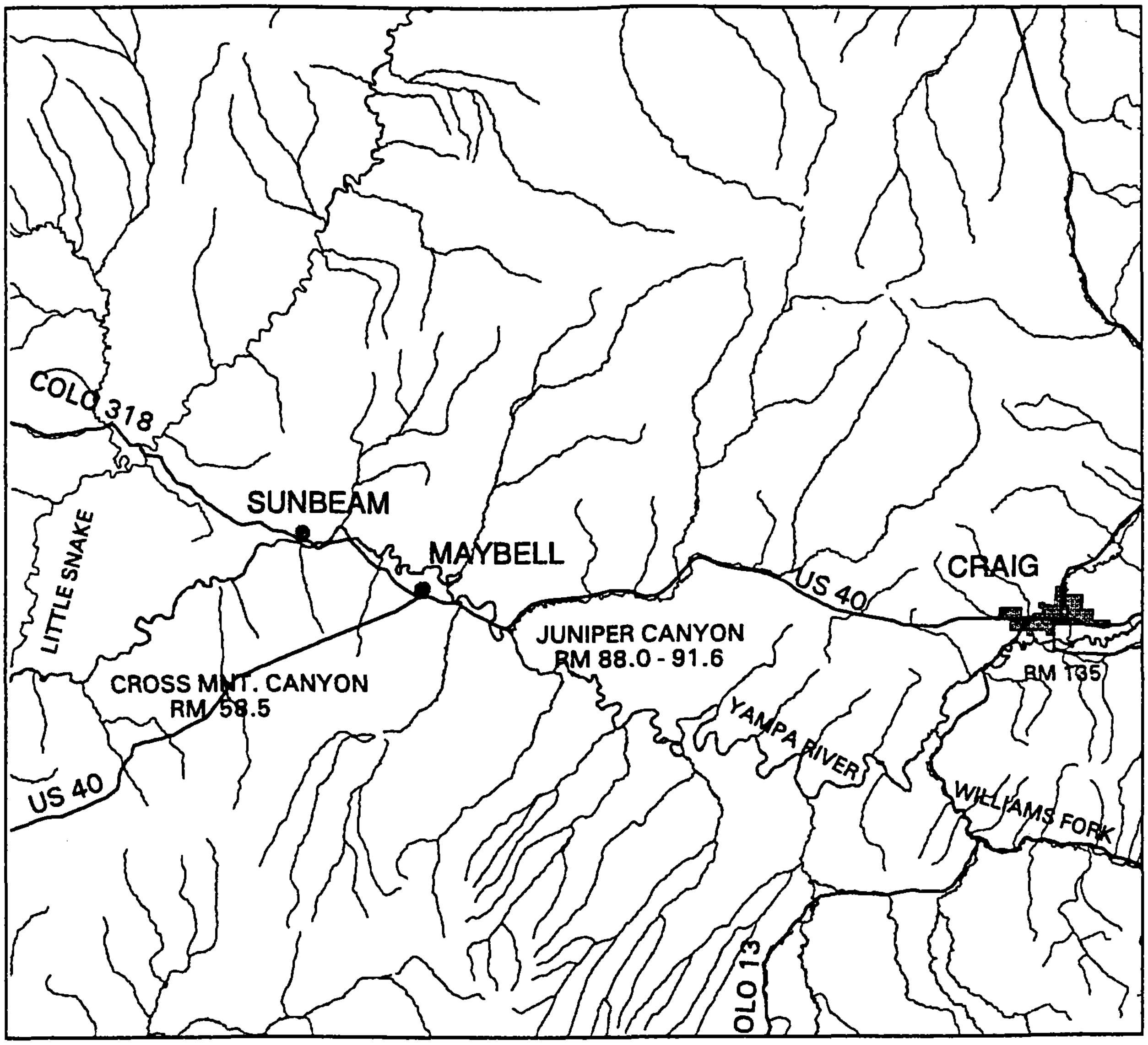


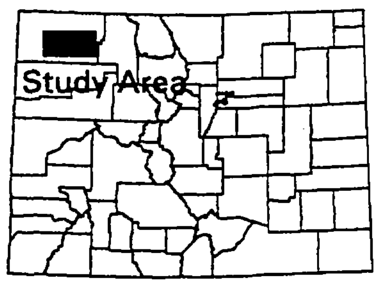
Figure 1
Study Area

3 0 3 6 Miles

6 0 6 Kilometers

N
W E
S

Highway or Interstate
River or Stream
Municipal Boundaries



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Maybell is 8,463 cfs. The median, 50% exceedence, or 2-year peak flow recorded on the Maybell gage is 10,000 cfs and the ten-year flood is 14,634 cfs. The peak flow in 1996 was 14,700 cfs, and in 1997 it 16,400 (20 year flood).

The minimum flow for the 82 years of record at Maybell was 3 cfs in 1934. The second lowest minimum flow was 7.9 cfs in 1994. Annual minimum flows have been 45 cfs or less 13 times during the last 82 years. Minimum flow exceeded 54 cfs in 80% and 74 cfs in 70% of the years since 1916. Half the years have a minimum flow exceeding 128 cfs, and minimum flow exceeded 235 cfs in 20% of the flow record (Figure 3). Ninety percent, 80 %, 70 %, 60 % and 50 % exceedence flows are given for the base flow period in Figure 4.

Currently, approximately 110,000 acre feet (AF) of water is depleted for out-of-river use per year, about 10% of the total annual yield. According to a flow model recently developed by CWCB, during the 17 year period 1975 to 1991, about 57% of total annual depletions occur in the months of April, May and June. Natural or virgin flow was reduced by an average of only 6% for those three months. The fall and winter months of October, November, December, January, February and March accounted for eight percent of the annual water diversions and natural flow was reduced by about six percent. Depletions have the greatest impact during August and September, when natural flows were reduced by 28% and 33%, respectively for the 17 year modeling period. The model determined that in six of the 17 years, natural flow was depleted by 50% or more and predicts that additional water development will likely double the number of years when total depletions exceed half the natural flow.

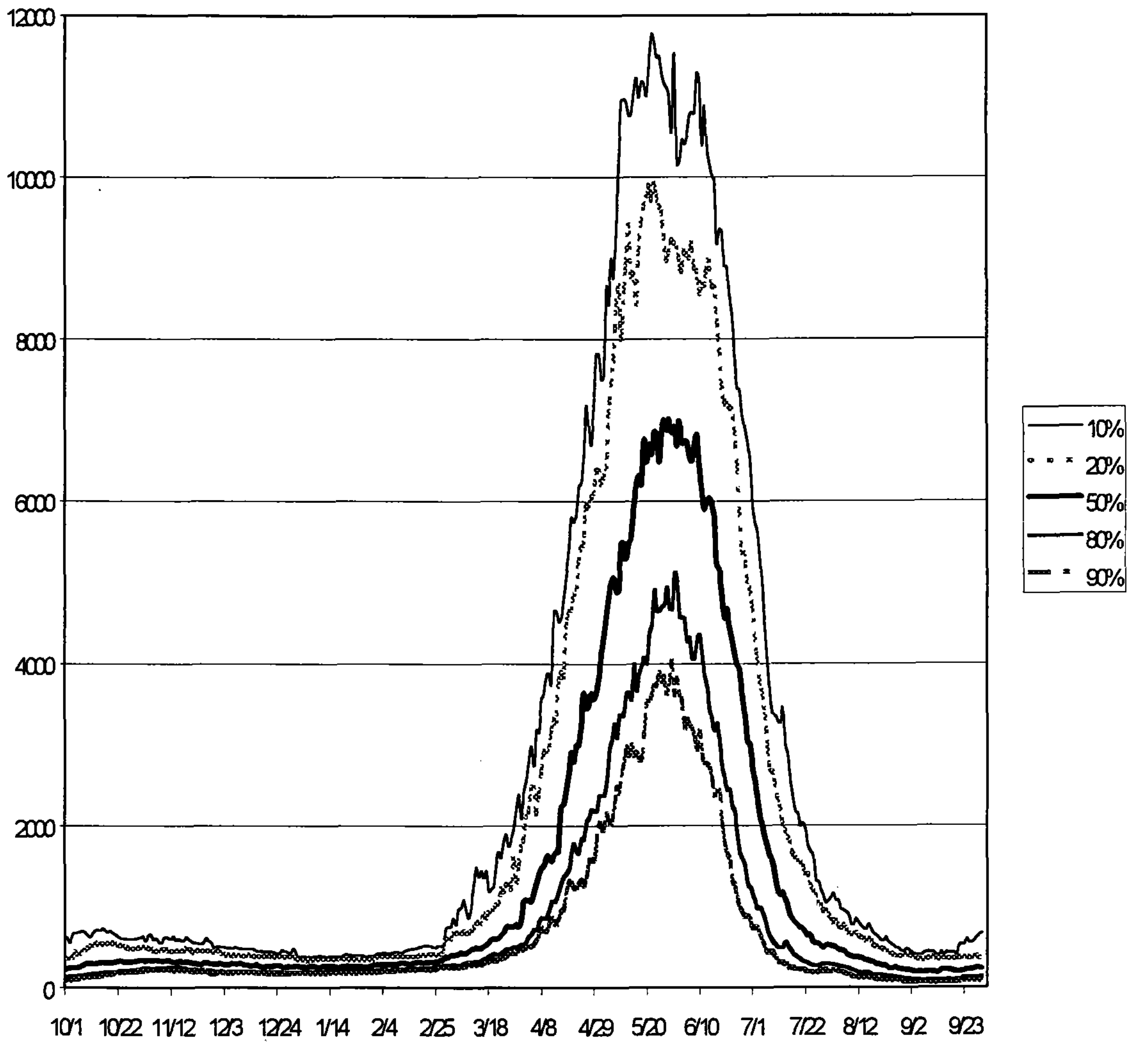

Figure 2. .Annual hydrograph for the Yampa River, Maybell gage for 10%, 20%, 50%, 80% and 90% exceedence flows

FLOWS DURING THE STUDY PERIOD

Flows during the study period in 1996 (August to November) ranged between the 50% to 80% exceedence hydrographs (Figure 3). In 1996 flow was under 100 cfs for two days. The minimum flow of 79 cfs was on September 6, and the next lowest daily mean flow was 88 cfs on September 5. Flow was under 128 cfs (50% exceedence minimum) for 12 days.

In 1997, flows during August, September and October were exceptionally high (Figure 5). Flows were above the 10% exceedence for most of the summer and fall, except between September 1 to 18, when flows were near the 20% exceedence level. On September 21 the mean daily flow rose to 6,770 cfs, which is not much below the

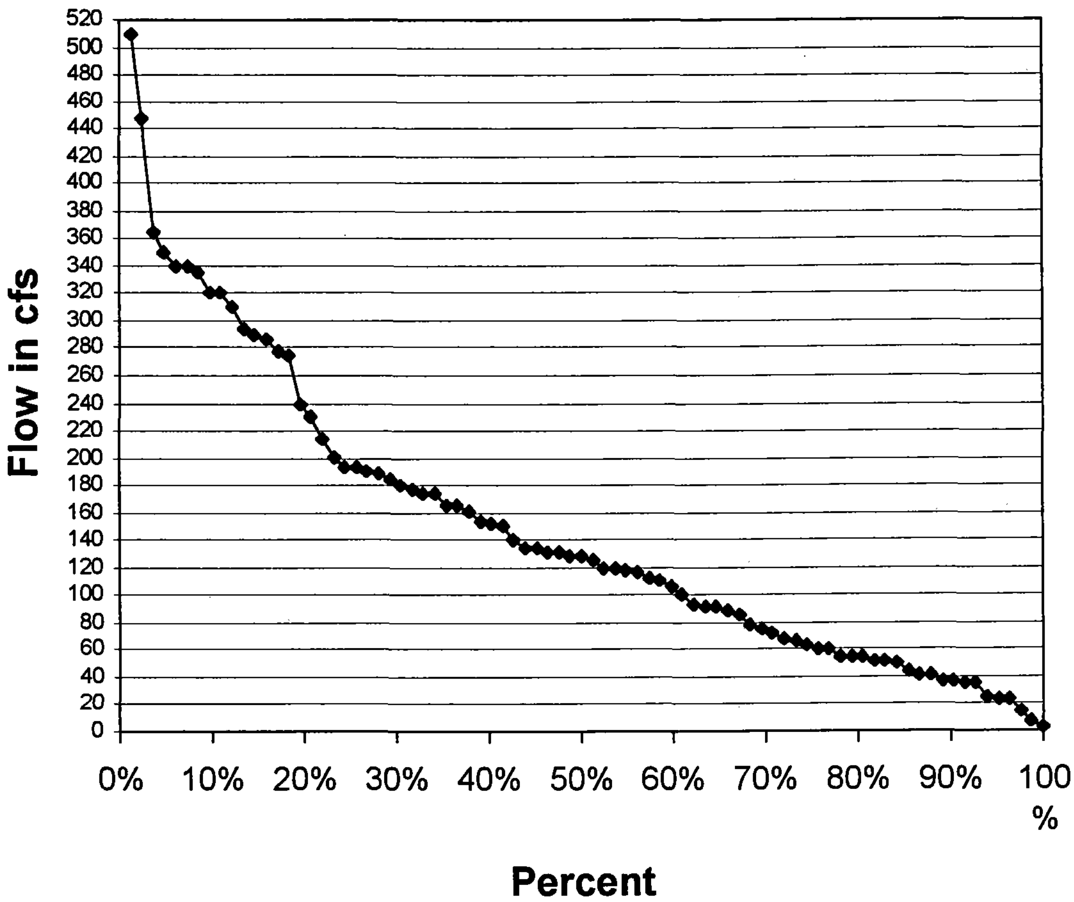

Figure 3. Duration curve for minimum flow for 82 years for the Maybell gage.

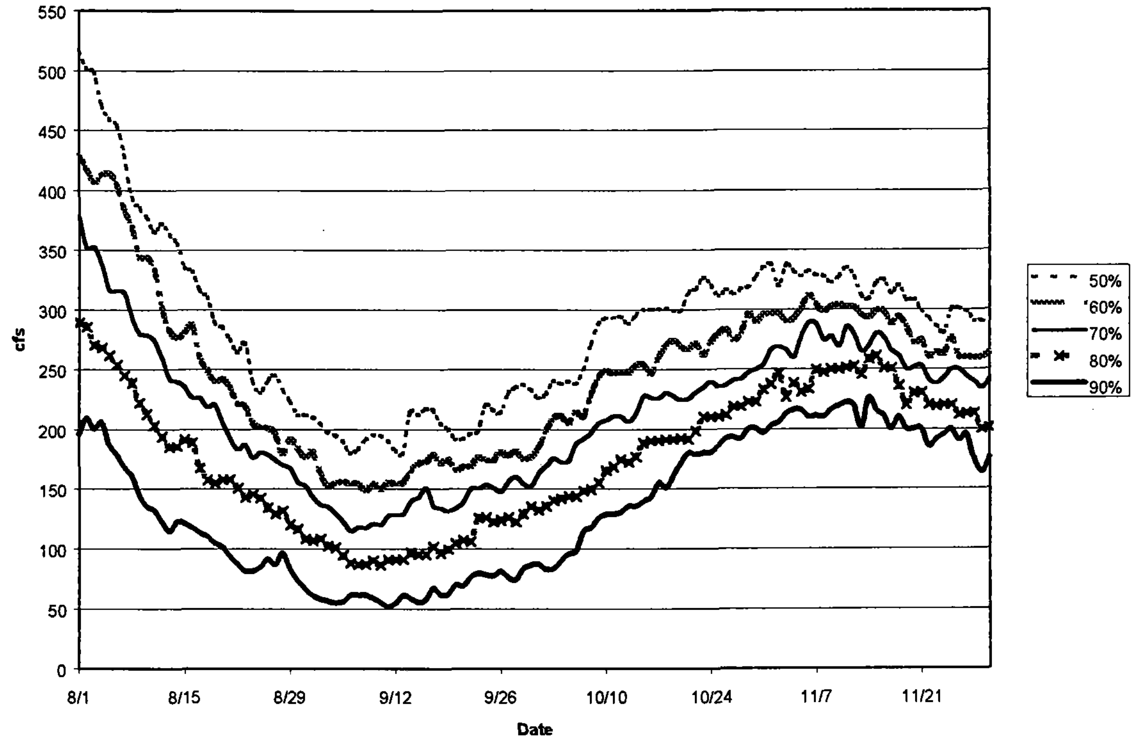

Figure 4. Fall Hydrograph for the Yampa River Maybell Gage.

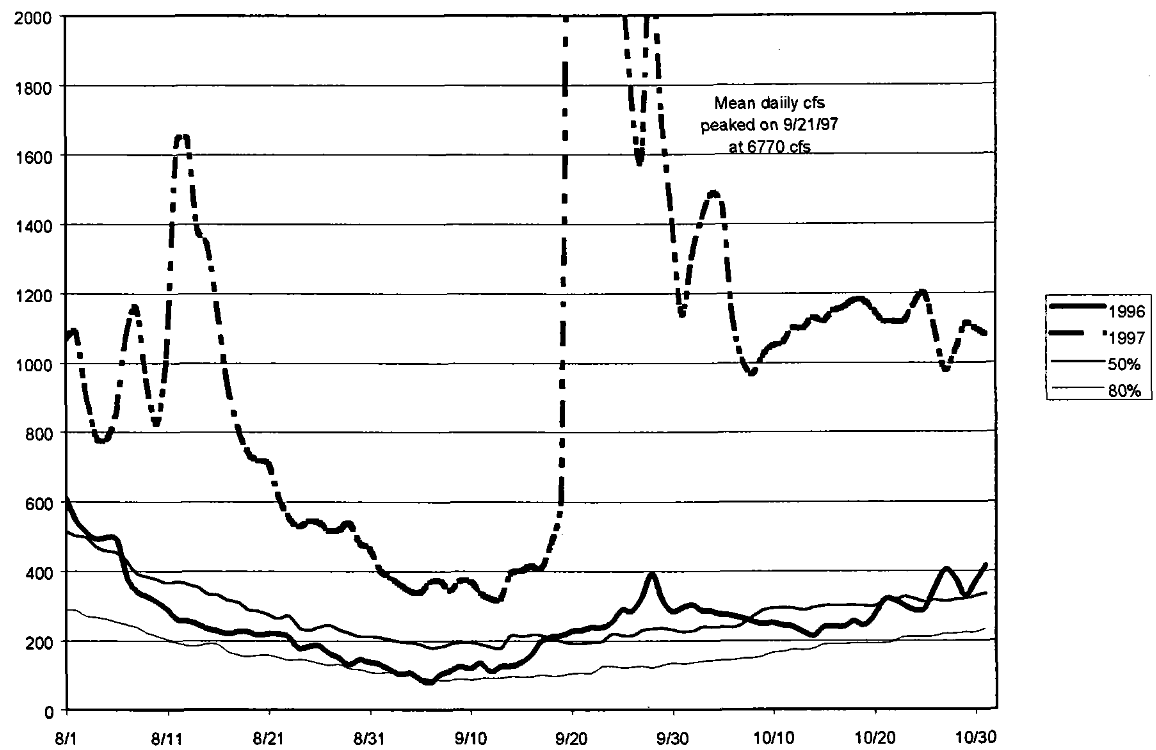

Figure 5. Fall flows for 1996 and 1997 with reference flows for 50 and 80 % exceedence.

calculated bankfull flow. The very high flows of September and October 1997 were an obstacle for cross section work, and because of the short window when flows were below 600 cfs some of the field work was modified or abandoned.

METHODS

Cross Section Profiles

Cross section methods are frequently used to determine minimal flows for maintaining habitats required by members of the aquatic community. These methods operate by determining a stage-discharge relationship, usually across a riffle, and using that relationship to find a flow that provides adequate depths and velocities for fish habitat maintenance. This study used a total of 110 cross sectional profiles spread over a distance of 64 river miles. Sample sites were selected in strata 6 and 8, described above (Miller et al.1982), and their river mile location is given in Table 1. Sampling sites were randomly selected by dividing the strata into 0.5 mile segments (called clusters), which were meant to include two run/riffle sequences. Twelve clusters were randomly selected from Strata 6 and 13 clusters were randomly selected from Strata 8.

Only one stage-discharge measurement was taken at each cross section. The concern was for habitat availability during the base flow period, when flow typically ranges from 100 to 300 cfs. Since a few cross sections were done at flows of about 600 cfs, model runs were compared using the calculated and a higher roughness value to determine if calculated mannings n values were suitable for extrapolating beyond 40% of the measured flow.

Cross sectional measurements were made during the base flow period in August and September in 1996 and in September and October 1997. The bed profile was surveyed between head pins set at or above the grassline on both sides of the channel.

Bank slopes and water surface elevations were measured using a standard surveying level. Depth and velocity measurements were taken at 25 to 30 points along the profile. The first cross section was placed at the most suitable hydraulic control point in the cluster. Cross sections upstream of the control were positioned in the lower, middle and upper parts of the run, and through a pool, if present. Also in each cluster at least one cross-section was positioned across the shallowest part of the riffle upstream of the hydraulic control. Because of extraordinarily high base flows in 1997, priority was assigned to sampling riffles, and because of that in some clusters only the riffles were surveyed. Between one and three cross sections were done in the clusters where only riffles were sampled.

HYDRAULIC SIMULATION

The hydraulic equation was used to simulate flows from a range of 1 to 500 cfs. The conveyance channel module of RHABSIM (Payne 1995) was used to model stage-discharge relationships for cross sections on riffles. When multiple cross sections were taken to determine habitat in a cluster, the step-backwater option was used.

This study was designed to determine habitat availability during the base flow period, when flow typically ranges from 100 to 300 cfs. The plan was to do cross section work at flows in this range because a single measurement could be accurately extrapolated down to near zero. However base flows were high in 1997 and cross sections were made at flows as high as 600 cfs. Concerns about only one stage-discharge measurement were addressed by increasing the manning n at low flow since roughness increases as flow decreases. Increasing mannings n at flows of 40% and less of the measured flow did not change results compared to using the original mannings value.

DEFINITIONS OF HABITAT VARIABLES

Seven flow and/or channel parameters were computed by the hydraulic equation for each riffle cross section. Each strata was characterized by determining the mean and variance of the seven parameters for all its riffle cross sections. Strata were compared to each other by statistically testing for difference between the means of the seven parameters to identify and group strata with similar attributes. The seven parameters and bankfull flow are defined as:

a) Top width: width of the stream at the water surface.

b) Percent wetted perimeter: The distance along the stream bed in contact with the water divided by the distance along the stream bed between the grassline of each bank.

c) Depth: The vertical distance between the water surface and some point on the streambed.

d) Rise in stage: The difference in the vertical distance from the water surface elevation at a flow of 1 cfs to the water surface elevation at a higher flow.

e) Width/depth ratio: A unitless index of cross-sectional shape, where top width is divided by average depth.

f) Cross Sectional Area: Wetted area in square feet determined by multiplying stream width times average depth.

g) Velocity: Distance water moves per second.

h) Bankfull stage: Discharge at which channel maintenance is the most effective, that is, the discharge at which moving sediment, forming or removing bars, forming or changing bends and meanders, and generally doing work that results in the average morphologic characteristics of a channel (Dunne and Leopold (1978).

STATISTICAL TESTING

Tests for significant differences between means of the seven parameters were used to indicate if physical properties of aquatic habitats varied between strata. These tests would be used as justification on whether or not to combine similar strata into larger groups or management units or not. Each variable was tested at three flow levels; 80, 150 and 300 cfs. Eighty cfs represented minimum flows that infrequently have occurred (<25%), 150 cfs represent the minimum flow that commonly occurs (<50%), and 300 cfs represents median flows that typically occur during the base flow period. A heteroscedatic t-test was used to compare means of each of the seven variables between strata. The null hypothesis was that the means of adjacent strata were equal and the test also assumed unequal variances. This test was performed by the excel spreadsheet.

INFLECTION POINT DETERMINATION

To understand how channel morphology influences habitat characteristics, the values for each of the seven variables were plotted for a range of flows between 1 to 300 cfs (300 cfs representing the median flow during the base flow period). The "inflection point" of each curve was identified for seven variables at all cross sections by fitting a line to the x and y coordinates and then selecting the largest residual (greatest difference between the curve and the line). Inflection points were grouped by habitat type, riffle, run or pool and by parameter. Inflection point means were compared between variables and between habitats for differences.

HABITAT AVAILABILITY

Weighted usable area (WUA) was calculated for sites with multiple cross sections using the step-back module of RHABSIM. This model is equivalent to IFIM described by Bovee (1982). The most downstream cross section in a cluster was located on a hydraulic control point. Upstream cross sections were used to represent available habitats in a run/riffle sequence.

Depth and velocity criteria used in the biological component of the model was developed for adult Colorado squawfish using radio telemetry (Miller 1997). Five Colorado squawfish were implanted with radio transmitters in both 1996 and 1997. These fish were located biweekly between July and October and habitat descriptions were made based on 24 hour observations. Daytime Colorado squawfish habitat is primarily restricted to pools over 2 ft deep, while nighttime habitat is more general and includes shallower swifter areas (Miller 1992).

Results

Cluster Locations

Data for all cross sections are summarized and presented in Appendix Tables 1 to 6. Data for strata 6 and 8, are in Appendix 1 and 2, respectively. The data in appendices 1 and 2 are grouped by riffles (A), runs (B), and pools (C). Within each habitat group are the results of inflection point identification (1), and the data and curves for the relationships between flow and the six variables of interest, i.e. percent wetted perimeter (2); wetted stream width (3); average depth (4); stage (5); width/depth ratio (6); and velocity (7).

Table 1 presents the strata, clusters, the date and number of cross sections for this study. In general, the flows determined in the field were somewhat higher than reported for the Maybell gage in Strata 6.

Table 1. Cross-section Dates, Locations and Flow Measurements for the Study Period.

Strata	River Mile	No. of Cross-Sections	Date of Survey	Field measured Flow (cfs)	Maybell Flow (cfs)	Craig Flow (cfs)
6	59.8	6	9/10/97	358	370	
6	62.8	9	9/10/96	132	119	
6	69.8	6	9/11/97	407	337	
6	70.8	3	9/15/97	474	400	
6	73.3	6	9/26/96	286	284	
6	74.5	6	9/10/97	450	370	
6	75.3	1	9/10/97	406	370	
6	76.3	3	9/16/97	465	415	
6	77.8	6	9/12/96	136	110	
8	92	3	9/17/97	459	407	438
8	94	8	9/25/96	330	288	341
8	99	2	9/17/97	485	407	438
8	102.5	2	9/12/97	399	320	319
8	104.5	5	8/20/97	719	719	637
8	105.5	1	9/2/97	515	384	376
8	108	1	9/2/97	431	384	376
8	109.8	1	9/2/97	510	384	376
8	111.3	1	9/2/97	470	384	376
8	115.5	6	9/24/96	332	253	284
8	117.5	4	8/31/97	424	464	409
8	117.5	3	9/1/97	424	405	384
8	119	5	8/31/97	440	464	409
8	120.4	1	8/31/97	464	464	409
8	120.8	3	8/30/97	513	483	426
8	121.5	5	8/29/97	420	538	417
8	124	5	8/28/97	485	519	460

Riffle Locations and Variable Testing

Twenty cross sections on 12 different riffles were surveyed in Strata 6, and 28 cross sections on 19 riffles in Strata 8 (Appendix V.A., Table 1 and Appendix VI. A., Table 1). Strata 6 and strata 8 had non-significant t-test results for all seven parameters for all three flows (Table 2). These test results strongly indicate that strata 6 and 8 have similar channel characteristics despite the fact that strata 6 is primarily located in a wide valley compared to strata 8 which is mostly within Little Yampa Canyon.

Table 2. Mean width, depth, percent wetted perimeter, stage, velocity, area, and width-depth ratio for strata 6 and 8 at simulated flows of 80, 150 and 300 cfs (n in parenthesis) and results of t-tests for significant differences.

Strata	Wetted Width			Average Depth		
	80	**150**	**300**	**80**	**150**	**300**
6 (11)	144	171	224	0.47	0.60	0.77
8 (19)	155	188	226	0.44	0.57	0.77
6 to 8	ns	ns	Ns	Ns	Ns	Ns
Strata	**% Wetted Perimeter**			**Stage**		
	80	**150**	**300**	**80**	**150**	**300**
6 (11)	44.9%	53.0%	69.3%	0.83	1.08	1.43
8 (19)	42.3%	51.0%	60.8%	0.77	1.01	1.33
6 to 8	ns	ns	Ns	Ns	Ns	Ns
Strata	**Velocity**			**Area**		
	80	150	300	80	150	300
6 (11)	1.49	1.71	1.98	59.0	92.2	157.2
8 (19)	1.30	1.55	1.89	64.9	102.7	167.7
6 to 8	Ns	ns	Ns	Ns	Ns	Ns
Strata	**Width Depth Ratio**					
	80	**150**	**300**			
6 (11)	357.6	322.5	333.5			
8 (19)	404.8	366.4	321.9			
6 to 8	Ns	ns	Ns			

*P(T<=t) two-tail; significance for alpha <=0.1 is 90%, alpha <=0.05 is 95%, alpha <=0.01 is 99%, alpha <= 0.001 is 99.9%.

Inflection point means for strata 6 and strata 8 were also not-significantly different based on results of t-tests (Table 3). Because of this it is reasonable to combine all data into a single reach and treat the entire river between Cross Mountain and Craig as a single strata.

Table 3. Means of inflection points (cfs) for the seven variables (n in parenthesis), and results of t-test for differences. P(T<=t) for two-tail is given if alpha is <=0.1 is 90%. Higher significance is indicated when alpha <=0.05 (95%), alpha <=0.01 (99%), or alpha <= 0.001 (99.9%).

Strata	**WIDE Cfs**	**DPTH cfs**	**VEL Cfs**	**WETP cfs**	**STG cfs**	**WDR Cfs**	**AREA Cfs**
6 (11)	80	123	109	80	97	93	105
8 (19)	93	83	82	93	87	66	111
6 to 8	Ns	0.001	0.003	Ns	Ns	Ns	Ns
Strata	**WIDE (ft)**	**DPTH (ft)**	**VEL (ft/sec)**	**WETP %**	**STG (ft)**	**W/D Ratio**	**AREA (sq ft)**
6 (11)	154	0.54	1.7	47%	0.86	414	70
8 (19)	172	0.47	1.3	47%	0.82	488	83
6 to 8	Ns	Ns	Ns	Ns	Ns	Ns	Ns

Inflection Point Analysis

A single cross section was selected for those riffles with more than one cross section so that an individual riffle would not be over represented. A total of 48 cross sections were done on 30 different riffles. Appendix Tables 1 and 2 give the inflection point data for all 48 riffles.

The riffle variable with the lowest mean inflection point was width/depth ratio (79 cfs) while the variable with the highest mean (111 cfs) was wetted area (Table 4-A). The mean of the inflection points for width, depth, velocity and stage were similar at 83, 101, 93 and 92 cfs, respectively. The grand mean for the inflection points for riffles was 93.1 cfs. It was felt that the grand mean was the most unbiased estimator of the minimum flow required to maintain riffle habitats. This flow is used as a standard for comparisons with other habitats.

The mean of the inflection points was greater than the median (50% percentile) for width, stage, width/depth ratio and area, but less than the median for depth and velocity. Flows of 125 cfs would equal or surpass the inflection points for all variables for 80% of the riffles surveyed while 100 cfs would equal or surpass the inflection points for 50% of the riffles.

Table 4-A. The mean and standard deviation of the inflection point flows (cfs) and the inflection point flow for the 50, 70, 80 and 90 percentile riffle for seven variables at 30 riffles.

Variable	Mean	Std. Dev.	50%	70%	80%	90%
Wetted Width (ft)	82.8	49.6	80	100	125	150
Average Depth (ft)	100.8	35.2	100	100	125	125
Change in Stage (ft)	92.2	49.6	80	80	100	125
Width/Depth Ratio	78.8	50.8	60	117.5	125	150
Wetted Area (sq ft)	111.0	34.9	100	117.5	125	125
Average Velocity (ft/s)	92.7	31.0	100	100	100	125
Grand Mean	93.1	40.0				

Eighteen run cross sections were done in 8 clusters and 22 cross sections in 9 clusters in Strata 6 (Appendix Tables 3 and 4). Unlike riffles, it was felt that all run cross sections should be included. All runs sampled had multiple cross sections and were selected to represent different habitat qualities of that run. For example, the tail of a run had characteristics similar to riffles while upper reaches may have had characteristics similar to pools.

The mean of the inflection points for runs ranged from 76 cfs (width/depth ratio) to 92 cfs (velocity) (Table 4-B). The mean of the inflection points for width, depth, area and stage were very similar at 87, 86, 90 and 84 cfs, respectively. The grand mean for the inflection points for runs at 86 cfs, was somewhat less than identified for riffles. A flow of 100 cfs would equal or surpass inflection points for 70% of the runs.

Table 4-B. The mean and standard deviation of the inflection point flows (cfs) and the inflection point flow for the 50, 70, 80 and 90 percentile runs for seven variables at 40 runs.

Variable	Mean	Std. Dv.	50%	70%	80%	90%
Wetted Width (ft)	86.5	53.7	60	100	125	150
Average Depth (ft)	86.3	45.9	80	100	120	125
Change in Stage (ft)	84.0	24.4	80	80	80	100
Width/Depth Ratio	76.1	53.7	60	100	125	150
Wetted Area (sq ft)	90.0	25.8	80	100	100	125
Average Velocity (ft/s)	91.8	36.0	100	100	100	125
Grand Mean	85.8	41.6				

There were a total of 13 pools with cross sections, of which eight were in Strata 6 and five in Strata 8. The grand mean for inflection points on pools was 89 cfs. For most variables the mean of inflection points for pools were generally somewhat less than for riffles and runs. The main exception was for velocity, which was 127 cfs (Table 4-C) and the higher flow for velocity caused the grand mean for pools to be higher than runs. The higher inflection points for velocity is explained by the fact that velocity is very low in pools and therefore, the curve for the velocity/flow relationship does not have a dramatic rate break as flows decrease to zero.

Flows of 80 cfs would achieve inflection points on 50% of the pools measured and 110 cfs would maintain 80% of the pools. Flows that equal or exceed the mean of inflection points for riffles and runs, will also encompass those identified for pools.

Table 4-C. The mean and standard deviation of the inflection point flows (cfs) and the inflection point flow for the 50, 70, 80 and 90 percentile runs for seven variables at 13 pools.

Variable	Mean	Std.Dev.	50%	70%	80%	90%
Wetted Width (ft)	80.0	38.1	60	100	100	135
Average Depth (ft)	84.6	37.7	80	82	100	100
Change in Stage (ft)	85.0	26.6	80	100	100	100
Width/Depth Ratio	73.8	45.6	70	82	110	142
Wetted Area (sq ft)	83.1	24.3	80	100	100	100
Average Velocity (ft/s)	126.9	23.9	125	125	135	150
Grand Mean	88.9	37.0				

Habitat Characteristics of Inflection Point Flows

Tables 5-A, 5-B and 5-C give the values for the variables for mean of the inflection points for riffles, runs and pools, respectively. The mean of the inflection point for stream width was the variable that was most similar between habitat types, and was 164 ft (at 83 cfs), 170 ft (at 87cfs) and 166 ft (at 80cfs), for riffles, runs and pools, respectively. At flows of around 100 cfs, stream width for the three habitat types is similar at 165 ft (Appendix Figure 1). However, the width/flow relationship is much different between habitat types as flow drops below 100 cfs. Stream width decreases rapidly on riffles and typically approaches zero at zero flow (Appendix I, Figure 1). On the runs, stream width decreases to 80 ft at 1 cfs and stream width is maintained at nearly 150 ft on pools at 1 cfs (Appendix I, Figures 1).

Even though inflection points for stream widths were similar for the three habitat types, the percent of the channel that is wetted (wetted perimeter) at those widths differed. For riffles the mean inflection point width of 164 ft is only a 47% wetted perimeter. The wetted perimeter variable was 52% (170 ft) for runs, and was 72% for pools (166 ft). The larger percent wetted perimeter for pools is a result of a smaller channel width compared to riffles and runs.

Figure 2 in Appendix I plots the variability of stream width within habitats (the coefficient of variation (C.V.)) versus flow. Pools were the most uniform habitat in regard to variability of stream width between 1 and 500 cfs and the pool C.V. never exceeded 18%. For both runs and riffle, C.V. dramatically increased as flow is lowered, but at flows over 200 cfs, stream width becomes more uniform. The maximum C.V. on runs was 65% at 1 cfs and 77% for riffles at 1 cfs. The C.V. for runs dropped below 30% at 60 cfs and was fairly stable at flows above that level. The C.V. for riffles did not drop below 30% until flow exceeded about 180 cfs.

Table 5-A. The mean and standard deviation for each of the seven variables that correspond to the inflection point flows presented in Table 3-A, riffles, n=30.

Variable	Mean	Std.Dev.	50%	70%	80%	90%
Wetted Perimeter (%)	46.6	12.4	49.5	52.9	54.7	59.8
Wetted Width (ft)	164	52.0	162	192	208	222
Average Depth (ft)	0.50	0.15	0.46	0.51	.057	.067
Change in Stage (ft)	0.84	0.29	0.76	0.91	0.97	1.19
Width/Depth Ratio	453	301	389	521	678	762
Wetted Area (sq ft)	79.5	22.9	71.6	83.6	91.5	106.6
Average Velocity (ft/s)	1.47	0.49	1.26	1.60	1.67	2.0

Table 5-B. The mean and standard deviation for each of the seven variables that correspond to the inflection point flows presented in Table 3-A, runs, n=40.

Variable	Mean	Std.Dev.	50%	70%	80%	90%
Wetted Perimeter (%)	51.6	17.7	48.9	62.3	70.0	78.2
Wetted Width (ft)	170	55.0	170	198	214	221
Average Depth (ft)	1.20	0.45	1.03	1.39	1.52	1.87
Change in Stage (ft)	1.14	0.38	1.02	1.15	1.29	1.65
Width/Depth Ratio	195	148	140	196	289	450
Wetted Area (sq ft)	202	96.3	191	238	261	319
Average Velocity (ft/s)	0.61	0.32	0.52	0.69	0.80	1.00

Table 5-C. The mean and standard deviation for each of the seven variables that correspond to the inflection point flows presented in Table 3-A, pools, n = 13.

Variable	Mean	Std.Dev.	50%	70%	80%	90%
Wetted Perimeter (%)	72.2	17.0	77.0	80.6	84.4	88.8
Wetted Width (ft)	166	28.3	166	176	180	189
Average Depth (ft)	3.2	0.76	3.17	3.74	3.86	4.13
Change in Stage (ft)	0.97	0.28	0.91	1.04	1.08	1.18
Width/Depth Ratio	57	21.7	49	59	80	83
Wetted Area (sq ft)	522	125	507	584	622	661
Average Velocity (ft/s)	0.24	0.078	0.22	0.26	0.29	0.33

For the depth/flow relationship, the mean of the inflection points for riffles, runs and pools was 0.5 ft, 1.2 ft, and 3.2 ft, respectively (Tables 5A-5B-5C).

The inflection points for the stage/flow relationship were fairly similar between the three habitat types. The increase in stage (rise in water surface elevation from stage at one cfs) was 0.84 ft on riffles (92 cfs), 1.14 ft on runs (84 cfs) and 0.97 ft on pools (85 cfs) (Tables 5-A-B-C). The stage/flow relationship is related to stream width. Stage increases quicker in parts of the channel where stream width increases slower. Stage is an expression in water depth. In riffles, the stage of zero flow is the deepest part of the channel (thalweg) and therefore stage is equivalent to maximum depth. On runs and pools the stage of zero flow is dependent on a downstream control point. The inflection points for stage and average depth were very similar for the three habitat types, but stage was higher than average depth on riffles, stage and average depth was similar on runs, and stage was less than average depth on pools.

Width/depth ratio can be a useful expression of habitat quality. High width/depth ratios result from wide/shallow habitats and river sections with high ratios are likely to have limited fish potential and are very likely to become passage barriers for larger fish. Riffles should have the highest width/depth values, and pools the lowest. The inflection points for the relationship between width/depth ratio and flow were at the lowest flows (79 cfs, 76 cfs, and 74 cfs) for the seven variables (Table 4: A-B-C). The means of the inflection points for width/depth ratio are 453, 195, and 57 for riffles, runs and pools respectively (Table 5: A-B-C). Width/depth ratio had the greatest coefficient of variation for the seven variables.

Cross sectional area is width times depth. In contrast to width/depth ratio, cross sectional area is lowest on riffles, and highest in pools. Cross sectional area was the variable with the highest mean of the inflection points on riffles (111 cfs) and it was 80, 202, and 522 square feet for riffles, runs, and pools, respectively (Table 5: A-B-C).

Average velocity is an important criterion for distinguishing habitat types. Riffles have faster currents and larger particle size while runs and pools typically have lower velocities and sandy substrates. The mean of the inflection points for the velocity/flow relationship was 1.5 ft/sec in riffles, 0.6 ft/sec in runs and 0.2 ft/sec in pools (Table 5: A-B-C). Velocities of 1.0 ft/sec are maintained on some riffles at flows as low as 20 cfs to 40 cfs. At these riffles the channel confines the current to the narrowest part of the thalweg, so velocity is maintained but in a narrow inner channel. But even on these riffles, velocity very quickly drops to near zero as flow continues to be reduced.

PHYSICAL HABITAT SIMULATION

Colorado Squawfish Habitat Availability

Gross wetted area (GWA) is simply the wetted surface area of the river at a given flow. Since most fish require a certain minimum depth, GWA does not represent fish habitat availability. GWA was determined for 6 clusters in Strata 6, and 7 clusters in strata 8 (Figure 6). The inflection point for the mean curves was identified to be 80 cfs for Strata 6 and 150 cfs for Strata 8, and 80 cfs for all clusters. Strata 8 has higher GWA at all modeled flows compared to Strata 6. At 150 cfs the GWA for Strata 8 was 16.5% higher than at Strata 6 (199,336 versus 171,117).

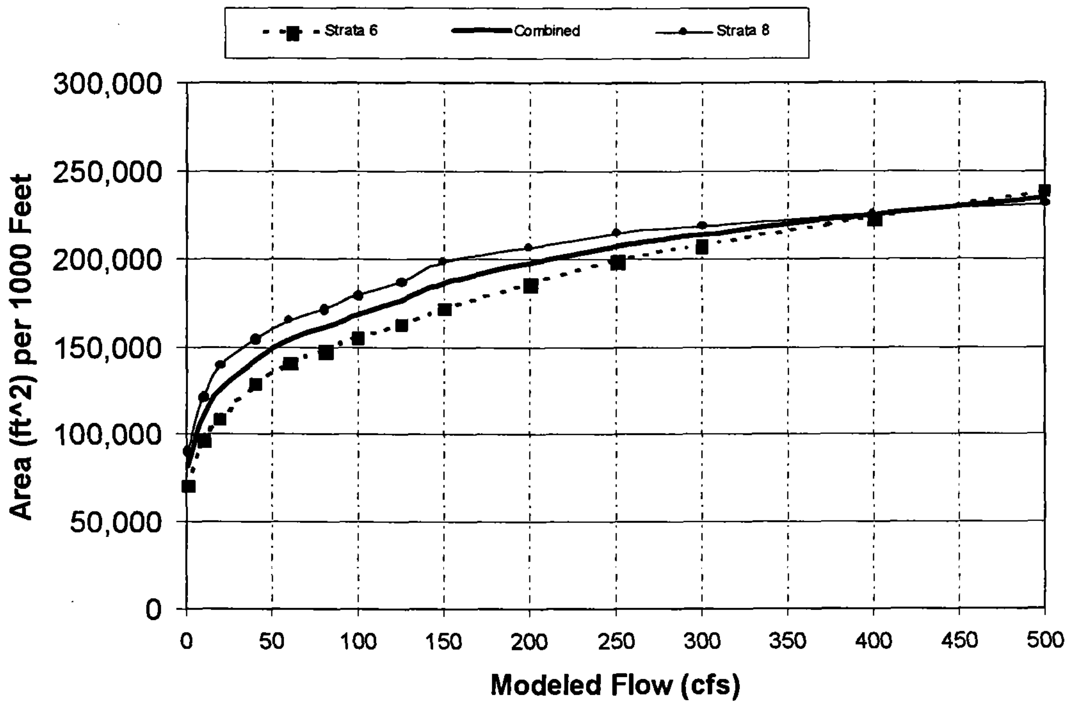

Figure 6. Gross Wetted Area (GWA) versus flow relationship for Strata 6 and 8.

Daytime or resting habitat was found to be restricted to pools/runs over at least 1.5 feet deep and half the observations where in pools/runs over 3.8 ft deep (Chapter 2). The inflection point for the mean curve of the squawfish daytime habitat/flow relationship was 100 cfs for Strata 6, Strata 8, and both combined (Figure 7). At flows over 125 cfs Strata 8 had more WUA, but at flows below 80 cfs Strata 6 was greater. Squawfish daytime WUA at 500 cfs was 30,000 sq. ft, and dropped to about half that at 80 cfs. A flow of 100 cfs had 64% of the WUA that was provided at a flow of 300 cfs.

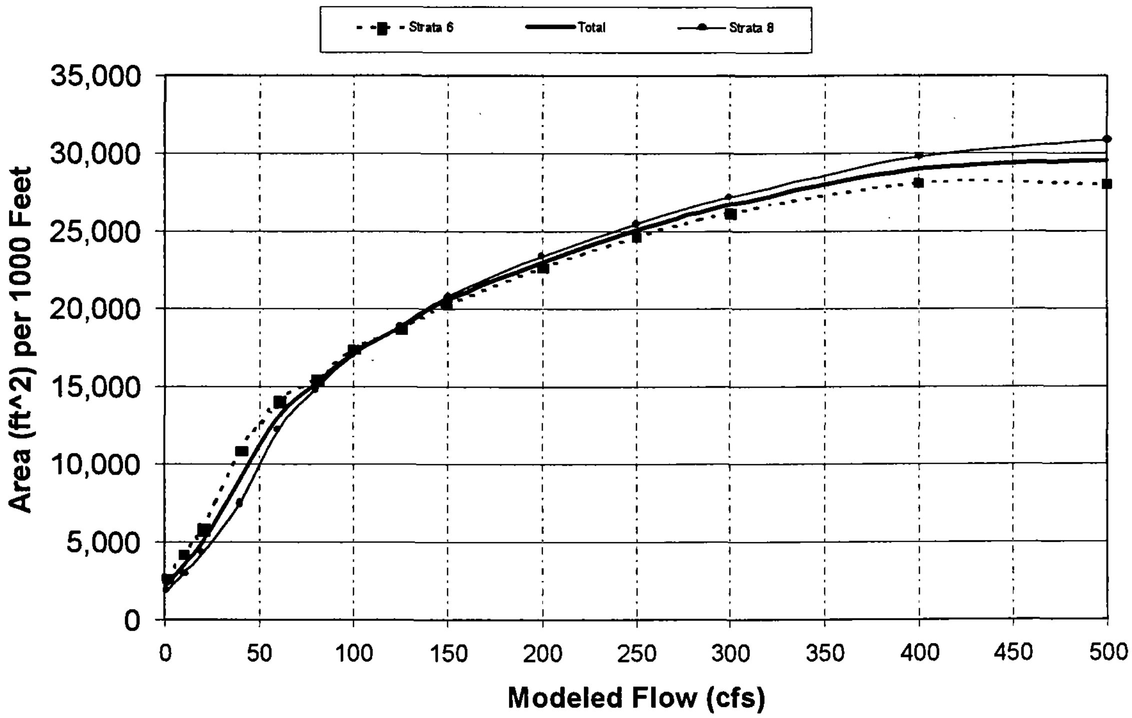

Figure 7. Squawfish-daytime-habitat/Flow relationship for Strata 6 and 8.

Colorado squawfish were observed to be active at night and were found to occupy run and riffle habitats presumably for foraging (Miller, 1997). The inflection point for the mean curves was 100 cfs for Strata 6, 8, and combined (Figure 8). Strata 8 averaged higher night (foraging) squawfish WUA at all flows. At 150 cfs, Strata 8 had 28% more WUA than Strata 6. Sixty-four percent of the habitat provided at 300 cfs was still available at a flow of 100 cfs.

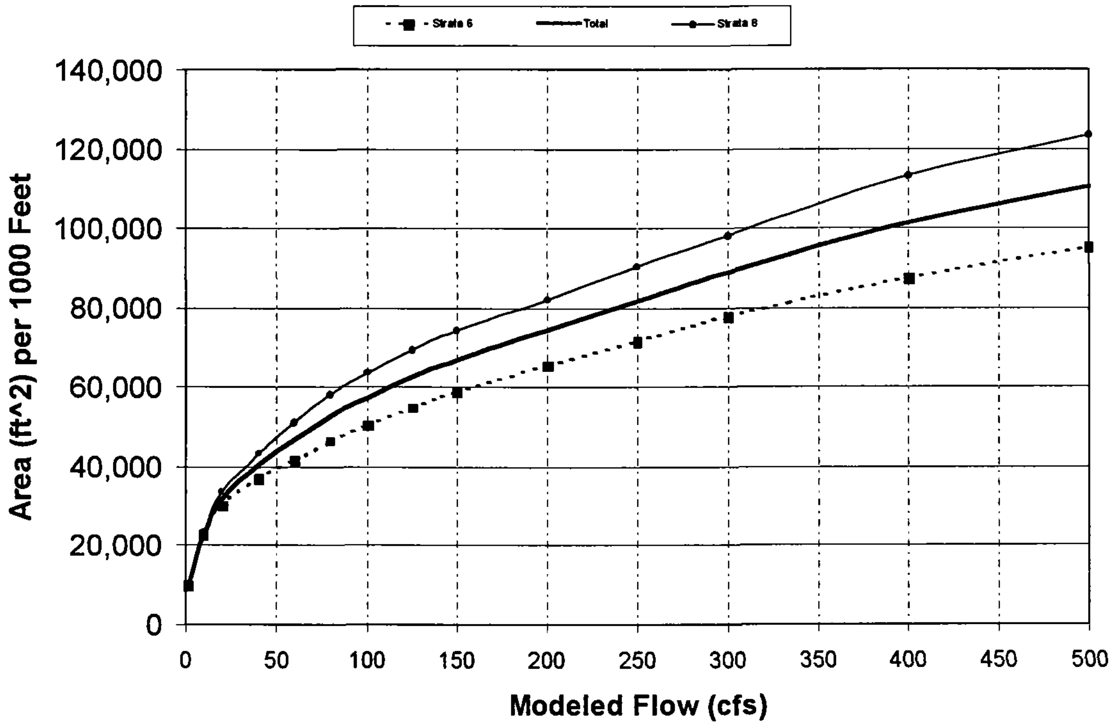

Figure 8. Squawfish-foraging-habitat/Flow relationship (Strata 6 and 8).

The results of WUA/flow relationships for each cluster are given in Table 6. The inflection points for gross area for the 13 clusters ranged from 40 to 150 cfs and the mean was 87 cfs. The wetted area for these inflection point flows ranged from 118,000 to 217,000 square feet. The smaller area is a reflection of a narrower channel, since stream length is standardized. The mean of the inflection points for daytime habitat is 104 cfs (Table 6). The area of daytime habitat was very poor in eight clusters (less than 9% gross), moderate at three (10-19% of gross) and daytime habitat was common at only three clusters (more than 20%). Colorado squawfish nighttime WUA was more common and uniform between clusters. The mean of the inflection points for nighttime WUA was 85 cfs (Table 6).

The mean of the inflection points (90, 104, 85 cfs) for gross, daytime and nighttime habitat (Table 6) was similar to the inflection point found after the data was averaged (80, 100 and 100 cfs, respectively). The advantage of identifying the inflection points first is that range and variation between the clusters are known. For example, over half the clusters sampled had poor pool habitat availability indicating this habitat is not evenly distributed.

Table 6. Inflection points for GWA and WUA for all clusters sampled above Cross Mountain.

	Inflection point Gross area		Inflection point Daytime CS habitat			Inflection point Nighttime CS habitat		
Cluster	(cfs)	Sq. ft.	(cfs)	%	Sq. ft.	(cfs)	%	Sq. ft.
59.8	80	129488	125	2	3062	100	30	40123
62.8	60	149281	80	4	5488	100	38	60177
69.8	60	123715	200	4	6981	150	39	59733
73.3	80	117706	60	26	28264	150	28	36314
74.5	150	195706	60	15	21583	40	25	31757
76.3	100	248613	60	7	14917	60	33	67644
77.8	60	171555	100	29	51164	40	46	75694
94.0	60	163296	100	6	9647	100	47	80882
104.5	40	190169	100	18	35564	80	30	59245
115.5	150	217276	100	8	11220	150	28	60228
117.5	60	189526	40	1	2091	40	25	45353
119	150	213449	200	1	3038	40	13	18831
121.5	80	187621	80	18	33378	60	33	60905
124.0	125	179847	150	27	49764	80	50	78825
Mean	89.6	-	103.9	-	-	85.0	-	-

DISCUSSION

Currently, there is no reliable method capable of predicting the response of stream biota to changes in flow regime (Allen 1995). Lacking methods that have been rigorously tested against biological variables, the hydraulic model was used to examine channel morphology. Stream channel morphology is a function of streamflow duration and magnitude, size and type of transported sediment, and the bed and bank materials of the channel, valley morphology, and basin relief. Stream width can be modified by several factors such as, direct channel disturbance i.e. channelization, changes in riparian vegetation that alter bank resistance and susceptibility to erosion, changes in stream flow regime, and changes in sediment regime (Rosgen 1996). The channel dimensions reported in this study result from a complex interplay of these variables and the results of our cross section analysis provide a basic understanding of Yampa River channel morphology.

The inflection points identify threshold flows where there are breaks in the energy dynamics of flow. Riffles have the highest slope and therefore the highest inertial and gravitational forces. Fast currents flowing over large stable substrates creates turbulent or broken flow (Gordon 1992). As depths and velocities are reduced the characteristic turbulent flow of riffles transforms into more laminar flow. This can impact the riffle community since these organisms are adapted to experiencing broken flow conditions. An underlining assumption of the inflection point approach is that there is a strong relationship between a stable and predictable environment and stability and integrity of the aquatic community, and this is well supported in the literature (Allen 1995).

Since this study is interested in minimum flows during the base flow period, effort was placed on flows typically found between August and March. Inflection points identified in the results, represent maximum changes in slope that are related to the inner part of the channel, that part which typically contains flow in the base flow period. The Montana method for minimum flow identification uses an inflection point based on the entire channel, from grassline to grassline (Leathe and Nelson (1989). The Montana approach would have produced inflection points at much high flows than the inner channel method. For example, it was observed in strata 6 that the channel begins to fill at flows of around 1,200 cfs, and bankfull flow occurs at flows of near 8,000 cfs. Because we focused on the base flow period (flows ranging for 1 to 300 cfs) we feel we identified flows necessary to avoid severe habitat degradation as opposed to flows that maintain riffle habitats in fair to good condition.

Flows identified by inflection points were within a fairly narrow range within and between habitat types. For all three habitat types, the mean values fell within a range of 61 to 113 cfs. The mean of the inflection points for riffles ranged from 83 to 113 cfs. Riffles inflection points were found to be at somewhat higher flows than for runs and pools. Flows of 100 to 125 cfs would be sufficient to meet or exceed 70% of the riffles surveyed and presumably maintain the majority of riffle habitats and the organisms associated with them.

Habitat diversity of the Yampa River above Cross Mountain appears to be very low. Runs were by far the dominate habitat type (80% plus) and this may be the result of habitat simplification processes attributable to land use practices. Runs have limited potential as habitat for invertebrates because sand is generally considered to be a poor substrate, due to its instability, and because tight packing of sand grains reduce the trapping of detritus and can limit the availability of oxygen. Because runs are generally poorer quality habitats and are not limited in the river, efforts need to be directed to maintaining as many functioning riffle habitats as possible.

Colorado Squawfish Habitat Availability

Gross wetted area is basically mean stream width times stream length and therefore is an average of all cross sections in a cluster. The mean of the inflection points for gross wetted area was 89.6 cfs for all clusters, similar to results for the mean inflection point by habitat types, 93 cfs for riffles, 86 cfs for runs, and 87 cfs for pools. The mean of the inflection point for riffles (93 cfs) was the highest of the three habitat types and should produce a curve break at a higher flow than when all habitat types are averaged (GWA). The curve break for GWA was found to be consistent with the riffle curve break, the primary tool used to base a minimum flow recommendation.

GWA is a useful reference for identification of habitat availability. For habitat availability, WUA is much more informative than individual pool cross sections, since it includes both pool and run area exhibiting observed depth and velocity requirements. The mean of the inflection points for WUA for adult Colorado squawfish day habitat was at 104 cfs. These results suggests that minimum flows meant to protect Colorado squawfish daytime habitat may need to be about 14 cfs higher than those determined by riffle inflection points (90 cfs).

The distribution of pools was found to be very patchy and often separated by long distances. The patchy nature of pools in the channel suggests that pool habitat availability may be limited during times of very low flows. Larger and deeper pools may provide better conditions during low flow events when fish can not migrate up or down stream due to shallow riffles. If, however, squawfish movement between pools is not restricted by low flow, then pool habitat availability is probably not a concern.

During their evening forays squawfish moved across shallow riffles taking temporary positions in the shallower/faster habitats (Miller 1997). The mean of the curve break for nighttime habitat was 85 cfs in strata 6 and 8 combined, very similar to the mean curve break for runs (86 cfs) in those strata. The inflection points for foraging squawfish WUA is less than found for riffles (93 cfs). This suggests that a 93 cfs minimum flow based on riffle maintenance will also be adequate to provide foraging habitat for endangered Colorado squawfish in the upper strata.

The maintenance of passage flows supercedes the concerns about habitat availability for endangered fish because they are able to select their habitats. Squawfish movement patterns were different between the high and low flow years. Movements were longer and more dramatic in the high flow summer of 1997, than in the low flow summer of 1996 (Miller 1997). In 1996, when low flows were near 100 to 125 cfs for ten days in September, squawfish were apt to forage within a run/riffle sequence. During low flow events, larger and deeper pools will presumably offer more foraging potential than smaller pools. Burdick (1996) proposed that the maximum depth of a riffle should be at least 1.0 ft of depth to provide unrestricted passage. The median riffle had a 1.0 ft maximum depth at a flow of 123 cfs for the riffles surveyed in this study (Anderson et al 1998). Flows under 111 cfs appear to have high potential for restricting squawfish movements to within a single or low number of riffle/run sequences. At flows over 111 cfs, fish movements should not be a problem on at least half the riffles.

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Table 1. Curve breaks at RIFFLE cross section for the relationships between flow (cfs) and the given variables.

Riffle No.	Strata	XSEC ID	Wetted Width	Mean Depth	Mean Velocity	Rise in Stage	W-D Ratio	S-C Area
1	6	**6282**	60	125	125	60	125	100
2	6	**6287**	200	100	100	150	200	200
3	6	**6981**	80	60	60	80	80	100
4	6	**6982**	80	20	20	60	60	80
5	6	**6983**	80	125	100	80	40	80
6	6	**7081**	40	125	100	80	40	100
7	6	**7082**	40	100	100	80	100	100
8	6	**7083**	125	60	60	125	60	125
9	6	**7331**	80	150	125	80	150	80
10	6	**7332**	150	150	150	80	150	150
11	6	**7336**	60	150	125	60	60	80
12	6	**7451**	40	100	100	125	100	125
13	6	**7452**	60	125	100	100	125	80
14	6	**7453**	150	100	100	60	60	150
15	6	**7456**	150	100	100	150	125	150
16	6	**7531**	40	100	100	125	20	125
17	6	**7781**	20	125	100	100	125	80
18	6	**7785**	80	125	125	80	40	100
19	6	**7786**	125	80	80	100	125	125
20	8	**9201**	60	150	150	60	150	60
21	8	**9203**	125	80	80	125	80	125
22	8	**9401**	150	60	60	100	150	150
23	8	**9402**	40	100	100	125	20	150
24	8	**9404**	20	125	100	80	20	100
25	8	**9408**	20	100	80	125	80	125
26	8	**9901**	150	60	60	150	150	150
27	8	**9902**	40	125	100	80	125	80
28	8	**10251**	80	40	40	80	40	80
29	8	**10252**	40	100	100	80	20	80
30	8	**10451**	125	60	60	100	80	125
31	8	**10452**	40	125	125	60	40	100
32	8	**10551**	200	40	40	80	80	200
33	8	**10801**	60	125	100	80	20	100
34	8	**10981**	80	80	100	100	40	150
35	8	**11131**	40	125	100	80	60	80
36	8	**11551**	100	100	80	100	20	100

37	8	**11553**	150	100	100	150	150	150
38	8	**11751**	60	125	150	60	60	100
39	8	**11755**	125	100	100	125	100	125
40	8	**11756**	80	40	40	80	80	100
41	8	**11757**	40	80	100	125	80	125
42	8	**11901**	40	100	100	125	20	80
43	8	**11902**	80	125	100	100	20	100
44	8	**12041**	125	100	100	80	40	125
45	8	**12081**	40	150	150	40	40	60
46	8	**12082**	125	40	40	80	40	125
47	8	**12083**	60	125	125	80	40	80
48	8	**12151**	60	40	40	60	60	125
			Width	**Depth**	**Velocity**	**Stage**	**Ratio**	**Area**
MEAN FOR STRATA 6			88	102.00	94.50	91.75	94	111.5
MEAN FOR STRATA 8			81	93.79	90.34	93.45	66	112.1
MEAN FOR ALL			84	97.14	92.04	92.76	77	111.8

Table 2. Curve breaks at RIFFLE cross sections for the relationships between flow and the given variable.

Riffle No.	Strata	XSEC ID	Wetted Width	Mean Depth	Mean Velocity	Rise in Stage	W-D Ratio	S-C Area	% Wet. Perm.
1	6	**6282**	264	0.46	1.00	0.84	625	109.4	60.0%
2	6	**6287**	167	0.50	2.91	1.14	380	73.7	48.9%
3	6	**6981**	161	0.70	0.83	1.54	251	119.8	58.3%
4	6	**6982**	173	0.49	1.50	1.25	482	64.5	55.0%
5	6	**6983**	167	0.41	1.56	0.64	527	54.8	51.4%
6	6	**7081**	126	0.64	1.25	0.81	361	79.9	43.9%
7	6	**7082**	87	0.63	1.70	0.89	148	59.0	29.9%
8	6	**7083**	109	0.65	1.43	1.33	99	80.1	33.5%
9	6	**7331**	105	0.56	2.28	0.61	200	41.6	40.0%
10	6	**7332**	84	1.16	1.54	1.17	73	97.7	23.2%
11	6	**7336**	194	0.46	1.45	0.74	691	65.1	50.9%
12	6	**7451**	145	0.38	1.53	0.63	452	80.0	38.0%
13	6	**7452**	153	0.46	1.33	0.79	426	64.2	45.0%
14	6	**7453**	241	0.45	1.21	1.00	410	116.6	48.9%
15	6	**7456**	129	0.56	2.53	1.20	149	64.3	33.3%
16	6	**7531**	60	0.92	1.55	1.41	130	78.2	19.6%
17	6	**7781**	166	0.61	1.00	0.65	312	87.2	54.1%

18	6	**7785**	197	0.35	1.74	0.58	764	62.5	76.0%
19	6	**7786**	209	0.53	1.22	1.07	410	106.3	86.4%
20	8	**9201**	145	0.69	1.24	0.86	255	64.4	31.6%
21	8	**9203**	155	0.70	1.60	1.16	102	88.6	46.6%
22	8	**9401**	158	0.51	1.15	1.08	232	107.6	57.8%
23	8	**9402**	101	0.72	1.26	1.37	289	114.9	39.3%
24	8	**9404**	150	0.56	1.26	0.55	749	79.6	54.9%
25	8	**9408**	96	0.57	1.26	0.89	235	92.5	28.6%
26	8	**9901**	79	0.80	2.06	1.90	91	68.8	41.0%
27	8	**9902**	80	0.76	1.72	0.78	116	50.3	36.8%
28	8	**10251**	126	0.47	1.04	0.87	173	68.9	53.6%
29	8	**10252**	100	0.77	1.21	1.13	268	71.8	40.4%
30	8	**10451**	222	0.43	0.86	0.93	399	124.0	65.7%
31	8	**10452**	210	0.49	1.10	0.71	809	99.3	55.2%
32	8	**10551**	212	0.38	1.69	0.97	319	100.9	53.0%
33	8	**10801**	161	0.54	1.20	0.80	644	83.4	45.8%
34	8	**10981**	193	0.36	1.25	0.62	511	108.4	48.2%
35	8	**11131**	190	0.55	1.04	0.48	525	85.0	50.1%
36	8	**11551**	210	0.27	1.68	0.41	1079	56.2	52.1%
37	8	**11553**	218	0.78	1.30	1.71	351	135.4	60.4%
38	8	**11751**	145	0.43	1.90	0.58	483	60.9	31.7%
39	8	**11755**	108	0.56	1.90	0.91	168	63.9	35.4%
40	8	**11756**	174	0.45	0.93	1.22	370	97.0	46.1%
41	8	**11757**	217	0.59	0.66	0.96	381	177.7	78.9%
42	8	**11901**	132	0.49	1.23	0.87	493	70.3	26.8%
43	8	**11902**	211	0.64	0.80	1.03	566	125.3	64.7%
44	8	**12041**	142	0.44	1.79	0.92	358	67.3	45.4%
45	8	**12081**	76	0.63	2.74	0.55	246	30.3	19.6%
46	8	**12082**	133	0.32	2.07	0.63	189	52.3	33.0%
47	8	**12083**	121	0.50	1.90	0.64	253	49.6	29.4%
48	8	**12151**	307	0.19	0.99	0.55	1537	99.8	53.6%
			Width	**Depth**	**Velocity**	**Stage**	**Ratio**	**Area**	**%WP**
MEAN FOR STRATA 6			155	0.57	1.56	0.96	363	79.2	47.2%
MEAN FOR STRATA 8			158	0.54	1.41	0.90	420	86.0	45.7%
MEAN FOR ALL			156	0.55	1.47	0.92	398	83.3	46.3%

Table 3. Curve breaks at RUN cross sections for the relationships between flow (cfs) and the given variables.

Riffle No.	Strata	XSEC ID	Wetted Width	Mean Depth	Mean Velocity	Rise in Stage	W-D Ratio	S-C Area
1	6	**5981**	60	125	100	100	20	100
2	6	**5982**	40	125	125	100	125	80
3	6	**5983**	20	100	125	100	100	80
4	6	**5984**	125	60	40	80	60	40
5	6	**5985**	40	125	20	80	40	100
6	6	**5986**	150	150	100	80	150	80
7	6	**6281**	60	20	20	60	60	60
8	6	**6283**	40	100	100	40	125	80
9	6	**6284**	200	100	125	80	200	60
10	6	**6285**	20	100	125	60	100	80
11	6	**6286**	20	100	125	60	60	80
12	6	**6288**	60	100	100	100	40	100
13	6	**6984**	60	125	125	100	125	80
14	6	**6985**	60	150	80	80	20	100
15	6	**6986**	100	80	100	100	60	100
16	6	**7335**	100	60	60	100	60	100
17	6	**7633**	40	80	125	60	60	60
18	6	**7783**	150	80	150	150	125	80
19	8	**9202**	125	40	125	60	40	150
20	8	**9403**	80	100	100	80	80	100
21	8	**9405**	125	60	80	100	125	125
22	8	**9406**	125	80	125	100	60	100
23	8	**10453**	40	125	80	80	40	80
24	8	**10455**	60	80	125	100	80	80
25	8	**11552**	200	250	100	100	250	100
26	8	**11554**	150	60	40	150	150	150
27	8	**11555**	20	20	20	20	20	20
28	8	**11752**	40	125	100	80	20	100
29	8	**11753**	60	40	100	80	40	100
30	8	**11754**	40	20	100	80	20	100
31	8	**11903**	40	80	80	100	20	100
32	8	**11904**	150	80	100	100	80	80
33	8	**11905**	150	150	100	100	150	80
34	8	**12153**	80	60	125	60	60	80
35	8	**12154**	200	60	125	60	60	60
36	8	**12156**	40	100	100	80	20	80

37	8	**12401**	125	40	40	80	40	125
38	8	**12402**	40	40	100	80	40	80
39	8	**12404**	100	40	40	80	100	125
40	8	**12405**	125	20	20	60	20	125
MEAN FOR STRATA 6			75	99	97	85	85	81
MEAN FOR STRATA 8			96	76	88	83	69	97
MEAN FOR ALL			87	86	92	84	76	90

Table 4. Curve breaks at RUN cross sections for the relationships between flow and the given variables.

Riffle No.	Strata	XSEC ID	Wetted Width	Mean Depth	Mean Velocity	Rise in Stage	W-D Ratio	S-C Area	%WET PERM.
1	6	**5981**	171	1.0	0.60	1.3	360	167	42%
2	6	**5982**	150	1.40	0.52	1.3	123	197	48%
3	6	**5983**	74	1.87	0.70	1.3	47	154	29%
4	6	**5984**	153	0.43	1.31	1.3	248	31	35%
5	6	**5985**	123	0.87	0.83	1.2	300	109	22%
6	6	**5986**	137	0.99	0.96	1.7	138	92	54%
7	6	**6281**	140	1.09	0.38	2.6	125	156	42%
8	6	**6283**	181	1.1	0.48	0.8	179	188	61%
9	6	**6284**	239	1.24	0.55	1.0	206	186	78%
10	6	**6285**	135	2.07	0.41	0.9	68	277	34%
11	6	**6286**	65	1.39	1.16	1.0	54	94	16%
12	6	**6288**	128	1.62	0.46	1.2	93	219	49%
13	6	**6984**	70	0.88	1.71	1.2	95	56	19%
14	6	**6985**	106	0.90	1.05	1.1	104	90	30%
15	6	**6986**	169	1.63	0.35	1.3	101	286	70%
16	6	**7335**	120	0.86	0.80	1.5	101	116	43%
17	6	**7633**	175	1.41	0.45	0.8	131	246	63%
18	6	**7783**	178	1.76	0.46	0.8	410	287	71%
19	8	**9202**	157	1.1	0.6	0.9	122	233	53%
20	8	**9403**	232	1.6	0.27	1.1	158	367	81%
21	8	**9405**	199	0.9	0.49	0.9	195	203	85%
22	8	**9406**	140	2.2	0.38	0.9	63	309	63%
23	8	**10453**	221	1.02	0.42	0.8	315	194	65%
24	8	**10455**	212	1.60	0.33	0.8	133	342	83%
25	8	**11552**	104	1.04	1.00	0.9	142	101	31%
26	8	**11554**	359	0.67	0.69	1.8	589	219	74%
27	8	**11555**	218	1.11	0.08	0.9	196	242	60%
28	8	**11752**	225	0.9	0.52	1.0	648	193	49%
29	8	**11753**	210	1.42	0.28	1.0	139	354	62%
30	8	**11754**	171	0.85	0.41	1.0	196	243	49%
31	8	**11903**	180	0.62	0.68	1.09	450	139	52%

32	8	**11904**	192	1.02	0.63	1.07	138	143	42%
33	8	**11905**	239	1.04	0.50	1.1	230	183	71%
34	8	**12153**	184	1.39	0.45	0.59	126	254	40%
35	8	**12154**	161	2.17	0.36	0.6	68	319	48%
36	8	**12156**	176	0.72	0.76	0.8	535	115	58%
37	8	**12401**	184	0.85	0.55	1.6	101	195	49%
38	8	**12402**	200	1.92	0.18	1.7	104	506	44%
39	8	**12404**	123	0.79	1.03	1.7	155	119	35%
40	8	**12405**	220	0.50	0.75	1.1	107	142	65%
MEAN FOR STRATA 6			140	1.25	0.73	1.25	160	164	44.9%
MEAN FOR STRATA 8			196	1.15	0.52	1.06	223	232	57.1%
MEAN FOR ALL			170	1.20	0.61	1.14	195	202	51.6%

Table 5. Curve breaks at POOL cross sections for the relationships between flow and the given variables.

Run	**Strata**	**XSEC**	**Wetted**	**Mean**	**Mean**	**Rise in**	**W-D**	**S-C**	
#		**ID**	**Width**	**Depth**	**Velocity**	**Stage**	**Ratio**	**Area**	
1	6	**6289**	60	125	100	100	20	100	
2	6	**7333**	100	80	125	80	100	100	
3	6	**7334**	150	100	125	80	80	100	
4	6	**7454**	150	150	125	100	150	100	
5	6	**7455**	60	100	125	100	100	100	
6	6	**7634**	60	80	125	60	20	60	
7	6	**7782**	60	20	125	125	20	100	
8	6	**7784**	60	125	200	100	150	80	
9	8	**9407**	100	80	125	100	80	100	
10	8	**10454**	60	80	125	100	80	80	
11	8	**11556**	20	20	100	20	20	20	
12	8	**12155**	100	60	125	60	60	60	
13	8	**12403**	60	80	125	80	80	80	
MEAN FOR STRATA 6			87.5	97.5	131.3	93.1	80.0	92.5	
MEAN FOR STRATA 8			68.0	64.0	120.0	72.0	64.0	68.0	
MEAN FOR ALL			80.0	84.6	126.9	85.0	73.8	83.1	

Table 6. Curve breaks at POOL cross sections for the relationships between flow and the given variables.

Run #	Strata	XSEC ID	Wetted Width	Mean Depth	Mean Velocity	Rise in Stage	W-D Ratio	S-C Area	% Wet. Perm.
1	6	**6289**	165	2.46	0.25	1.20	84	397	80%
2	6	**7333**	108	3.24	0.34	1.10	34	349	41%
3	6	**7334**	142	4.26	0.21	1.10	32	583	86%
4	6	**7454**	224	2.31	0.25	1.03	97	469	93%
5	6	**7455**	137	4.25	0.20	1.04	33	594	76%
6	6	**7634**	148	2.77	0.29	0.77	56	405	71%
7	6	**7782**	181	3.53	0.18	0.74	48	662	90%
8	6	**7784**	179	2.27	0.43	0.67	82	391	62%
9	8	**9407**	175	2.22	0.29	0.92	78	404	80%
10	8	**10454**	168	4.01	0.18	0.83	42	673	83%
11	8	**11556**	191	3.74	0.14	0.90	51	714	78%
12	8	**12155**	161	3.76	0.20	0.61	42	597	46%
13	8	**12403**	174	3.09	0.21	1.66	57	544	52%
MEAN FOR STRATA 6			161	3.14	0.27	0.96	58	481	75%
MEAN FOR STRATA 8			174	3.36	0.20	0.98	54	586	68%
MEAN FOR ALL			166	3.22	0.24	0.97	57	522	72.2%

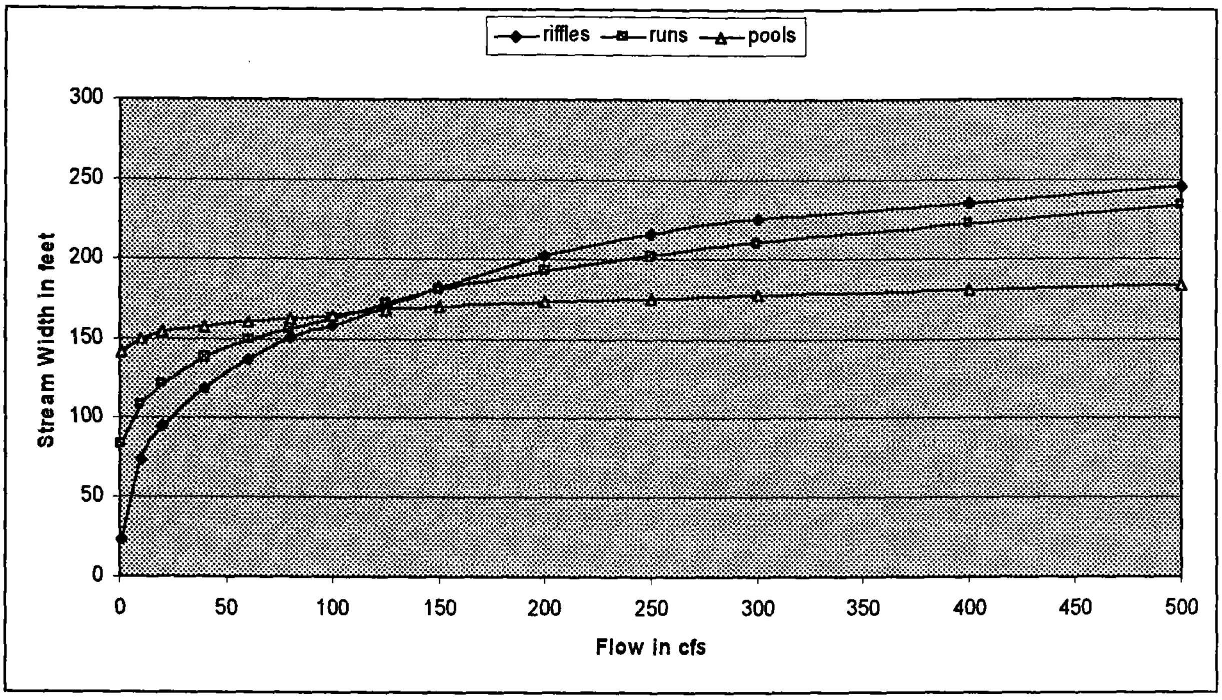

Figure 1. Average stream widths of riffles, runs and pools at flow between 1 and 500 cfs

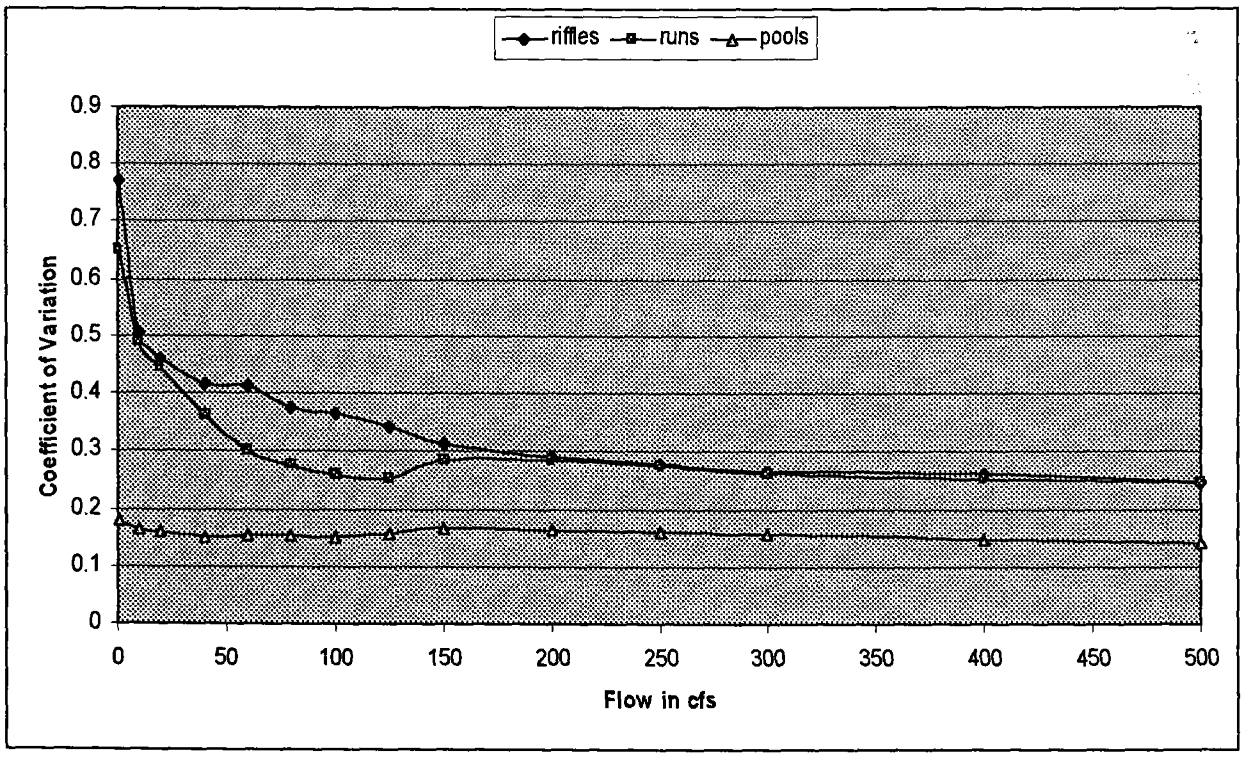

Figure 2. Coefficient of variation for stream width at flows between 1 and 500 cfs.