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White River Base Flow Study for Endangered Fishes, Colorado and Utah, 1995-1996

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LIST OF KEY WORDS

White River, base flow, Colorado pikeminnow, PHABSIM, hydraulic model, curve break, wetted perimeter

estimates of habitat areas were only rough approximations; estimates of riffle wetted perimeter are better, but simulated wetted perimeters at discharges <134 cfs are suspect because of extrapolation problems. The study would have benefitted if current site specific habitat suitability curves had been developed. The greatest shortcoming, however, was that the study design should have included seasonal flow and fish habitat use, not just base flows.

Finally, under the current flow regime (the past 20 years), the Colorado pikeminnow population has done well in the White River. Unfortunately, it is unknown why it attracts so many Colorado pikeminnow. Until additional information becomes available, we recommend continuation of the current flow patterns to protect the Colorado pikeminnow in the White River.

INTRODUCTION

The White River drains 13,260 km^2 in northwest Colorado and northeastern Utah and is the second largest tributary entering the Green River. As with most intermountain rivers of the west, the hydrology of the White River is characterized by high spring flows caused by runoff from snow melt followed by low, relatively stable, base flows between August and February. Compared to many western rivers, water depletions from the White River have been minor, approximately 5% of the annual basin yield (Lenstch et al. 2000). Although the hydrology of the White River is relatively unaltered, a mainstem impoundment, Taylor Draw Dam, was constructed in 1985 near Rangely, Colorado, at river mile (RM) 105. Although Taylor Draw Dam is a barrier to upstream fish passage, the dam operates under the guidelines of a Federal Energy Regulatory Commission permit requiring "run of the river" management. Under this management, the water volume leaving the reservoir must equal the volume entering the reservoir, with minor adjustments permitted for minimal electrical generation (Ann Brady, Rio Blanco Water Conservancy District, personal communication). Thus, the water yield and hydrograph of the White River have not been greatly altered.

As part of the Recovery Implementation Program for the Endangered Fishes of the Upper Colorado River Basin (RIP), instream flow requirements for endangered fishes need to be determined. In the Green River system, recommendations for the mainstem were defined by Muth et al. (1999), and for the Yampa River by Modde et al. (1999), and recommendations for the Duchesne and Price rivers are currently being reviewed by the RIP. This study was conducted in tandem with the accompanying study by Schmidt and Orchard (2002), "Geomorphic analysis in support of a channel maintenance flow recommendation for the White River near Watson, Utah", to identify the instream flow needs of endangered fishes in the White River. Our report uses habitat availability data to try to define base flow needs for endangered fishes, whereas the Schmidt and Orchard (2002) study addresses geomorphological criteria that affect channel changes, i.e., high flow needs, to maintain existing habitat.

Endangered fish occupying the White River are primarily limited to the adult life stage of the Colorado pikeminnow (*Pytchocheilus lucius*). No humpback chub (*Gila cypha*) or bonytail (*G. elegans*) populations have been identified in the river and only a few razorback sucker (*Xyrauchen texanus*) or juvenile Colorado pikeminnow have been collected, most of which have been found in the lower reach of the river. Although the current hydrograph is similar to the historic flow, approximately 30% of the upstream habitat available to Colorado pikeminnow has been reduced by the main-channel barrier, Taylor Draw Dam, near Rangely, Colorado. Despite the reduction in range, the highest catch rates of adult Colorado pikeminnow in the upper Colorado River basin have been recorded in the White River (McAda et al. 1994, 1998, 2002). Preliminary population estimates suggest that the density of Colorado pikeminnow in the White River are two to three times the density of Colorado pikeminnow in the Yampa River (Bestgen et al. 2002). Thus, the White River represents a significant factor in the recovery of Colorado pikeminnow in the upper Colorado River basin.

The purpose of this report was to identify the base flow needs of endangered fish, i.e., adult Colorado pikeminnow, in the White River. The scope of work outlined three objectives:

1. Determine meso- and microhabitat availability for adult Colorado pikeminnow during three low flow scenarios.

2. Compare habitat measurements from above with Colorado pikeminnow habitat use found in previous studies (Miller et al. 1982, Chart 1987, Tyus 1991, and Irving and Modde 1994) and habitat suitability curves given in Valdez et al. 1987.

3. Incorporate data from above to develop an interim year-round flow recommendation for Colorado pikeminnow and guidelines for discharge fluctuations a Taylor Draw Dam.

As a basis for formulating flow recommendations, we took two approaches, protection of Colorado pikeminnow habitat and protection of riffle habitat to maintain biological productivity. We measured meso- (pool, run, eddy, and riffle) and microhabitat (depth, velocity, substrate, and cover) changes at three experimental flows. However, we were unable to obtain the low flow we needed to determine the habitat-discharge relations; as a result, we used physical habitat simulations to assist in determining these relations.

METHODS

Study Site

The study area (Figure 1) included the White River from its confluence with the Green River near Ouray, Utah (i.e., Green River at RM 245), to Taylor Draw Dam, near Rangely, Colorado (RM 0.0-105).

Sampling Design

A stratified cluster sampling scheme (Scheaffer et al. 1979, Bovee 1982, Armour et al. 1983) was used to collect mesohabitat data on the White River. The river was divided into four strata (see Figure 2 for descriptions, lengths, and locations). The first three strata corresponded to those used in earlier studies (Archer et al. 1980; Miller et al. 1982) prior to completion of Taylor Draw Dam (1985), and the fourth stratum ended at the dam.

All strata were further subdivided into smaller sampling units called habitat clusters (Figures 2 and 3). The length of each habitat cluster contained at least two representative pool-run-riffle habitat sequences. Leopold et al. (1964) and Bovee (1982) found that a simple pool-run-riffle habitat sequence repeated itself in distance equivalent to five times the mean channel width. The habitat cluster length in the White River was equal to 10 times the mean channel width to capture two habitat sequences. The mean river channel width was calculated from measurements taken from aerial photographs.

Each habitat cluster was numbered and located by RM on a topographic map. A random numbers table was used to select 25 habitat clusters in each stratum to sample mesohabitat data during each flow and year (25 clusters * 4 strata * 3 flows * 2 years = 600 clusters). One habitat cluster was strategically placed at the Watson, Utah, U.S. Geological Survey (USGS) gage, just downstream from Ignacio Bridge on Highway 45, to aid in making comparison with the historical USGS gage data.

Two habitat cross sections were randomly placed perpendicular to the flow across the river in each habitat cluster to collect mesohabitat (pool, riffle, eddy, run) and microhabitat (depth, velocity) data. Figures 2 and 3 describe habitat clusters in each stratum and how cross sections were located.

Data Collection

Field crews conducted a reconnaissance float trip down the White River in the early summer of 1995 to inspect, ground truth, and mark each habitat cluster and cross section with wooden stakes and plastic flagging.

Six sampling trips, three each in 1995 and 1996, were planned in late summer and early fall to collect meso- and microhabitat data at each of three experimental flows. Some adjustments, however, had to be made after the 1995 field season. The number of habitat clusters and cross sections that realistically could be sampled had to be reduced because the experimental flows out of Taylor Draw Dam could only be sustained for 5 days. Also, only one sampling trip was made in late summer 1995 because of extended spring runoff and high flows. The number of habitat clusters and cross sections sampled for 1995 and 1996 are given in Figure 2.

The habitat types found along each cross section were recorded. Habitat criteria developed by Bisson et al. (1982) and Modde et al. (1991) were modified to define each habitat type (Appendix 1). Field measurements were taken in accordance with Bovee and Milhous (1978). A measuring tape was stretched across each cross section and width, depth, and water velocity measurements were taken at 0.5 m intervals. Water velocity measurements were taken with a Marsh-McBirney flow meter at 0.6 of the water depth when depths were < 0.76 m, and at 0.2 and 0.8 the depth when water depths were > 0.76 m (Leopold et al. 1964, Buchanan and Somers 1969). Finally, water temperature was taken at each habitat cluster.

Experimental Flows

Three experimental flows were selected from past flow records (Ann Brady, Rio Blanco Water Conservancy District, personal communication; Lentsch et al., 2000): 150, 350, and 551 cfs. The lowest flow was requested for late fall 1995 and 1996 when routine maintenance work on Taylor Draw Dam was to be done. Unfortunately, this maintenance was not accomplished and the requested flow was not provided. Furthermore, high runoff in 1995 that extended relatively high flows into early October 1995 and high spring flows in 1996 hampered data collections at the lowest experimental flows. The actual flows when data were collected were 339, 424, and 552 cfs. Because the experimental flows did not encompass the entire range of flows that we wanted to consider, we modeled the habitat change-discharge relation, using the data from the experimental flows as calibration, that would have occurred between 1 and 600 cfs.

Gaged flows for the White River were taken from USGS gaging stations near Rangely, Colorado (Boise Creek) and near Bonanza, Utah (Watson).

Habitat Models

Hydraulic model. Changes in depth and velocity were simulated using the channel conveyance module RHABSIM (version 2.0; Payne 1995). The channel conveyance module used Manning's equation and three sets of calibration velocity measurements obtained at the experimental flows to calculate a channel roughness coefficient (n) for each channel segment. Water surface elevations (wsl) were calculated for each cross section using log/log regression estimated from measured wsl and discharge at the three experimental flows. Hydraulic parameters were simulated for flows of 1, 10, 20, 40, 60, 80, 100, 150, 200, 250, 300, 400, 500, and 600 cfs. The hydraulic parameter of most interest was wetted perimeter, defined as the distance across the streambed in contact with the water.

Physical habitat model. The cross sections in each habitat cluster divided the stream reach into a number of rectangular cells. Each cell was considered to have a unique combination of habitat type, depth, velocity, and substrate at any particular discharge. Cells near the edge of the stream may have had surface areas that varied with discharge, whereas cells in the center of the channel generally had fixed surface areas.

Flows simulated from the hydraulic model were translated into useable habitat when a cell met the microhabitat criteria for Colorado pikeminnow (Bovee 1986). The evaluation produced a weighted useable area (WUA) score for each cell; the cell scores were totaled for each cluster and extrapolated to strata and to the study reach. WUA was calculated for each simulated discharge.

The WUA was determined for each cell using habitat suitability indices (HSI) for depth and velocity that rated each cell between 0 (unsuitable habitat) and 1 (completely suitable). Weighted usable area was calculated for three sets of HSI. The first set was developed from depth and velocity data collected from the White River between April and November, presumably during day light, from a number of studies prior to 1987 and reported by Valdez et al. (1987, Curve Set 10). The second set was developed from data collected from the Yampa River above Cross Mountain during nocturnal observations of foraging fish in 1996 and 1997 and reported by Miller and Modde (1999). And the third set was for daytime resting fish, also developed from Yampa River data by Miller and Modde (1999). The depth and velocity suitability criteria used for modeling WUA are given in Appendix 2. A particular cell was assigned a weight by multiplying the HSI scores for depth and velocity.

Mesohabitat Composition

The areas of pool, riffle, run, and eddy habitats were estimated for each stratum at each experimental flow. RHABSIM was used to calculate the area of each habitat type for each sample cluster, and the clusters were expanded to make estimates for the strata.

In order to examine a wider range of flows than the actual experimental flows, we simulated the mesohabitats at differing discharges between 1 and 600 cfs for each habitat cluster sampled and then extrapolated the result to represent the totals for each stratum and for the entire length of the study area.

Riffle Wetted Perimeter and Area vs. Discharge

We analyzed the riffle habitat-discharge relationship in two ways. First, wetted perimeter-discharge relation was simulated using the hydraulic model for each cross section where riffle was the only habitat type. The percentage of the total wetted perimeter at various discharges was determined by assuming the wetted perimeter at 600 cfs was the maximum available.

A curve break approach (Gippel and Stewardson 1998) was used to determine at what discharge habitat conditions declined most rapidly, such that small additional reductions in discharge result in disproportionate loss to stream riffle area. A similar approach was taken to determine base flows for the Yampa River (Modde et al. 1999) and several other streams (Gippel and Stewardson 1998). The rate of greatest change was determined by fitting a linear regression through the wetted perimeter-discharge relationship and finding the discharge that gives the largest positive residual. An example is given in Figure 4. When the wetted perimeter-discharge relationship was linear (determined by eye), no curve break was calculated.

The second way we analyzed the riffle habitat-discharge relation was to calculate riffle surface area for each habitat cluster and expand the result to the entire study area at each simulated discharge.

Fish Passage

For each riffle cross section, the deepest portion of the transect was identified (called thalweg depth) and the hydraulic model was used to determine the thalweg depth at discharges between 100 and 300 cfs. Following Burdick (1997) and Modde et al. (1999), a depth of 30 cm was assumed to provide enough depth for fish passage.

RESULTS

River Flows During the Study Period

The mean daily flow of the White River at the Watson gage from 1 August through 31 October 1995 averaged 558 cfs and ranged from 427 to 922 cfs (Figure 5). For the same period in 1996, the flow averaged 420 cfs and ranged from 237 to 607 cfs.

River Cross Sections

A total of 43 habitat clusters consisting of 2 cross sections per cluster were sample at each of the 3 experimental flows. Appendix 3 provides a summary of the location and description of each cross section. A typical river cross section showing the data collected and hydraulic simulation is given in Figure 6.

Habitat Description by Stratum

All strata were dominated by riffle-run reaches; pools and eddies were usually secondary components of main channel runs and riffles. Habitat composition among strata was very similar, consisting of 32% riffle, 33% run, 10% pool, and 25% eddy habitat. Stratum 1, a meandering reach with wide open floodplain and low gradient (0.05%) near the confluence with the Green

River, had the fewest pools, and stratum 3, a mostly canyon bound reach with the greatest gradient (0.16%), had the most and deepest eddies (Tables 1 and 2).

WUA varied among strata depending on the habitat suitability curve used (Table 3). The daytime resting curve developed from Yampa River data showed stratum 3 averaged 7.3 m^2 per100 m^2 of surface area; the other strata all averaged <4.3. The daytime resting curve gave highest scores for habitats >1.2 m deep. The night foraging curve, also developed from Yampa River data, and the White River curve showed similar results because the HSI's were similar (Appendix 1). All strata had similar WUA for these two curves, with stratum 3 the highest score of 65.4 m^2 per 100 m^2 surface area and stratum 1 with the lowest score of 46.8.

Mesohabitat Composition vs. Discharge

Habitat composition changed little among the three experimental flows (Table 1), in part the result of the small range of discharge (339--552 cfs). Pool, riffle, run, and eddy habitats are characterized as to width, depth, and velocity in Table 2. As expected, all increased with increasing flow.

To examine a wider range of flows, we simulated the habitat-flow relation. The modeled habitat composition for flows between 150 and 600 cfs was stable at 32% riffles, 33% runs, 10% pools and 25% eddies; however, as flows dropped below 150 cfs, riffles increased to approximately 42% and eddies decreased to 13% (Figure 7).

Riffle Wetted Perimeter and Area vs. Discharge

Wetted perimeter-discharge relationships for individual cross sections showed a range from classical fast rise and abrupt turn to an asymptote with an obvious curve break to a linear relation with no obvious curve break (see Appendix 4, cross section 10102 for classical relation and cross section 10401 for linear relation). We classified 32 of 42 riffle transects as having curve breaks and 10 as linear and therefore no curve break (Table 4). Curve break discharges ranged from 80 to 200 cfs and averaged 161 cfs. The curve breaks covered, on average, 77% of the riffle wetted perimeter (range 34-95%). The riffle mean wetted perimeter-discharge relation was slightly non-linear and increased most rapidly with discharge between 1 and 150 cfs and then gradually approached a plateau near 500 cfs before again increasing at 550 cfs (Figure 8). Because of the approximate linear nature of the relation, no curve break was determined.

The total riffle surface area-discharge relationship was nearly linear for all flows examined (Figure 9), and thus no curve break point was produced.

Curve breaks were also calculated for width, depth, and velocity (Appendix 5). The mean curve break point for riffle and run width was 155 cfs, depth 152 cfs, and velocity 131 cfs.

WUA vs. Discharge

WUA was calculated for three sets of criteria for each of the three experimental flows. All three criteria showed approximate linear relations for the discharges examined (339, 424, and 552 cfs; Table 5). Appendix 6 gives a detailed breakdown for each habitat cluster at discharge 339 cfs.

We modeled the WUA-discharge relation between 1 and 600 cfs (Figure 10). The first criterion was that developed from the White River data. It showed an almost linear increase in WUA as flows increased from 10 to 600 cfs. The second criterion was the night foraging data from the Yampa River. It showed WUA score almost identical to the White River data. This was the result of very similar HSI data sets for both depth and velocity. The third criterion was for diurnal resting fish, also developed from Yampa River data. This showed very low WUA score for all White River flows. This was because Yampa River fish used depths >1.2 m and these were relatively rare in the White River. And finally, a fourth curve was the maximum WUA score possible, i.e., the total surface area available. It showed that suitable habitat for Colorado pikeminnow was less than half the total surface area available.

Fish Passage

Table 6 summarizes the thalweg (i.e.,maximum) depth at each riffle cross section at flows between 100 and 300 cfs. A discharge of 300 cfs produced thalweg depths >30 cm for 47 of 49 riffle cross sections, and the two that did not had a depth of 27 cm. At 250 cfs, 46 thalweg depths were >30 cm; at 200 cfs, 45; at 150 cfs, 45; and at 100 cfs, 45 had depths > 30 cm. One of the shallowest riffles was located just below Taylor Draw Dam at RM 104.4, the other shallow riffles were all between RM 20 and 48.

Frequency of Low Flows

The historic hydrograph (1979-1996) showed that mean base flow (August through October) discharge ranged from 272 to 939 cfs. The 50% exceedance discharge for August through October was 399 cfs. A discharge of 150 cfs during the same period had an exceedance value of about 95% (Figure 11). White River discharge during the base flow period 1923 to 1997 had dropped below 200 cfs less than 5% of the time and below 150 cfs less than 1% of the time.

DISCUSSION

This study took two approaches for identifying a base flow that would protect the needs of adult Colorado pikeminnow in the White River, protection of resting and foraging habitats and protection of riffle habitat to maintain biological productivity that supports the Colorado pikeminnow population. The foundation of our analysis was predicting how these habitats change with changing flow. The original scope of work called for measuring meso- and microhabitats at three experimental flows and using the empirical relations as a basis for determining this change. The realized flows during the study, however, did not cover a wide enough range for this analysis. As a result, we modeled the meso- and microhabitats-discharge relations over a broader range of flows to determine the appropriate relations.

Model Critique

The reliability of the physical habitat simulation results (WUA, riffle surface area, wetted perimeter) depends on the hydraulic model and the species habitat suitability criteria. We used the hydraulic model to predict depth and velocity for each cell at differing discharges. Its accuracy depends primarily on how far from the calibration flows those predictions are extrapolated. Bovee and Milhous (1978) recommended the useful range of extrapolation is 0.4 to 2.5 times the calibration flow. In our study, the calibration flows ranged from about 339 to 551 cfs, and we made 14 simulations between 1 and 600 cfs. Thus, simulated flows < 134 cfs are suspect and may result in 50 to 60 percent error.

The hydraulic parameters, e.g., wetted perimeter, width, depth, and velocity, are more precisely estimated than the habitat areas. The hydraulic parameter estimates were determined for each cross section independently, whereas the habitat areas were determined by tying 2 cross sections together per habitat cluster, resulting in large cell surface areas and imprecise estimates. The recommended number of cross sections in a stream reach the size of the habitat clusters is 6 to 8 cross sections (Bovee et al. 1998).

The habitat suitability criteria can be questioned on several accounts. First, the data from which the curves were based for both the Yampa River (Miller and Modde 1999) and White River (Valdez et al. 1987) were from relatively few contacts (47 for daytime resting fish, 20 for night foraging fish, and 149 for White River fish). Second, most of these data were from fish located by triangulation using radio telemetry techniques, and it is difficult to know the precise water column depth and velocity of the habitat that fish were occupying.

Third, and most important, is the question of transferability of habitat suitability curves from one stream to another. Freeman et al. (1997) tested transferability for nine fishes (darters and shiners) in Alabama streams and concluded microhabitat criteria for riffle fishes were more likely to be transferable than for fishes that occupied a variety of pool and riffle habitats. On the other hand, two reasons give us confidence that the White River and night foraging suitability curves give approximately correct results. It is reassuring that the White River data and the night foraging data from the Yampa River gave similar curves, and it is understandable that the Yampa daytime resting curve does not apply to the White River, because depths >1.2 m are rare in the White River. And finally, other depth and velocity curves similar to those we used have been developed (Valdez et al. 1987).

Colorado Pikeminnow Habitat

Colorado pikeminnow in previous studies in the Colorado, Green and Yampa rivers used a variety of habitat types throughout the year (Archer and Tyus 1984, Tyus and Karp 1989, Maddux et al. 1993, Osmundson 2001). Studies in the White River found that adult Colorado pikeminnow used primarily pool and run habitats (Valdez et al. 1987, Irving and Modde 1994, Irving and Modde 2000). This study found that most of the habitats in the White River consisted of riffle and run habitats; that the pool and eddy habitat were secondary components of main channel riffle and run habitats; that habitat proportions remained relatively constant from 600 to 150 cfs; and that riffle habitat increased in proportion to the other habitats when flows dropped below 150 cfs.

In the Yampa River, adult Colorado pikeminnow apparently used different habitats during day and night (Miller and Rees, 1997; Miller and Modde, 1999). In daylight the fish remained in pools or deep runs >1.2 m. After sunset, fish moved to feeding areas, primarily riffles, and were very active. Miller and Modde (1999) pointed out that base flow management should address both resting and active behaviors and focus on the most limiting flow for habitat needs.

Our simulations of daytime resting habitat for the White River indicated that the availability of quality habitat was low, because depths >1.2 m were relatively rare in the White River, even at flows greater than base flow. The Colorado pikeminnow in the White River apparently found suitable daytime resting areas in habitats with depths much less than 1.2 m.

Simulations of night foraging habitats showed a linear increase with flow and therefore no curve break to identify a minimum flow below which habitat was lost at an increasing rate.

Osumundson (2001) found that habitat use by adult Colorado pikeminnow varied seasonally. In the winter they favored low-velocity habitats like pools and backwaters; in the spring, when water velocities were high and main-channel temperatures low, they tended to use warm off-channel, low-velocity sites, like backwaters and flooded gravel pits; and in the summer use increased in runs and eddies and pools and backwaters remained important.

Riffle Productivity

Invertebrate production in riffles is greater than other riverine habitats (Brown and Brussock 1991). In the upper Colorado River basin, riffles in steeper river reaches are capable of supporting very productive benthic food webs, and these food webs are more stable, complex, and productive in upstream reaches associated with cobble substrate (Stanford 1994). Data from the Upper Colorado River suggest that primary and secondary production is greatest in the upstream, higher gradient reaches with more riffles (Lamarra 1999), which also coincides with highest fish densities (Osmundson 1999). Anderson and Irving (1999) pointed out that physical conditions that maintain riffles should be preserved, because a strong relationship between stable and predictable environment and stability and integrity of the aquatic community, is well supported in the literature (Allan 1995, Brown and Brussock 1991, and Brusven et al. 1990).

Flows between 400 and 500 cfs cover 95% of available surface area for most riffles, and this seems to us adequate to provide for near maximum riffle production during the base flow period.

We used two criteria for defining minimum riffle needs for fish. First, we examined riffle surface area vs. discharge and found, not surprisingly, the same linear relationship as with night foraging habitat. And second, we examined wetted perimeter vs. discharge and found a curve break suggesting more rapid loss in riffle habitat at flows < 161 cfs. It is our opinion that the wetted perimeter method is more informative. As stated in the *Model Critique* section, the physical habitat simulations of habitat areas produced approximations but are not precise. Wetted perimeter estimates, on the other hand, required fewer assumptions and are more precise. Similar curve break flows were found for depth, width, and velocity. That these hydraulic parameters have similar curve break values as wetted perimeter is not surprising because they are governed by similar hydraulic dynamics.

The Instream Flow Council (2002) concluded that wetted perimeter should be considered only one component of a recommendation that uses additional analyses, and that it does not provide the necessary regime of flows that is critical to riverine ecology. They recommended ". . . that the flow prescribed be that discharge that covers at least 50% of the wetted perimeter in streams that are less than 50 feet wide (and between 60 and 70% in larger streams. . .) or the breakpoint on the wetted perimeter discharge relation, which ever is higher." In this study, that flow was 161 cfs.

Fish Passage

Flows >300 cfs are required to pass Colorado pikeminnow over all the riffle transects, assuming 27 cm is the minimum depth needed. We point out, however, that the transects were randomly placed across the riffles and were not necessarily placed at the shallowest cross section. In other words, minimum flows needed for passage might be >300 cfs. The shallowest riffle was just below Taylor Draw Dam, and three others were between RM 20 and 48.

Uncertainties in Determining Flow Requirements for the White River

This study had several shortcomings as a basis for determining future flow needs of Colorado pikeminnow in the White River. (1) As described in *Model Critique*, the precision of estimates of habitat areas were only rough approximations; estimates of riffle wetted perimeter are better, but simulated wetted perimeters at discharges <134 cfs are suspect because of extrapolation problems. (2) The use of habitat suitability curves developed from Yampa River data and from White River data collected before Taylor Draw Dam closure are open to various interpretations and lead to confusion. The study would have benefitted from current site specific curves.

3 The greatest shortcoming was that the study design should have included seasonal flows and fish habitat use, not just base flows. Although a geomorphology study, "Geomorphic analysis in support of a channel maintenance flow recommendation for the White River near Watson, Utah," was conducted to address flood flow during spring runoff, the biology component was limited to the base flow period. Most of the results from this study were based on the wetted perimeter-discharge relation. The Instream Flow Council (2002) has admonished researchers to move away from the use any one tool and toward the use of a suite of methods.

Colorado pikeminnow Flow Requirements in the White River

Despite the uncertainties and shortcomings above, we make the following comments on the flow requirements. Adult Colorado pikeminnow occupy the White River year-round. The fish undergo spawning migrations of hundreds of miles to sites in the Yampa and Green rivers. Typically, sexually mature fish migrate out the White River by mid-May or mid June and return by mid- to late August (Irving and Modde 2000). The downstream migration is thought to be cued by descending spring runoff flows and temperature(Tyus 1990, Modde and Smith 1995). Fish passage over shallow riffles is dependent on adequate flow, especially for the return trip in August. Maximum riffle production occurs during base flow period in summer and early autumn, which supports the prey of Colorado pikeminnow.

Multiple flow levels are required to meet the needs of the White River Colorado pikeminnow. To cue the fish to migrate, a natural hydrograph is needed during spring runoff. To provide for passage over riffles, flows >300 cfs are apparently needed. To maintain riffle productivity during base flow period (i.e., cover 95% of the surface area), flows of 400–500 cfs are needed; and if flows fall below 161 cfs, riffle habitat declines rapidly. However, between 1923 and 1997 baseflow (August through October) discharge in the White River (Watson gage) has only dropped below 200 cfs less than 5% of the time. Further, baseflow discharge on the White River (Watson gage) has been below 150 cfs less than 1% of the time.

Finally, we point out that under the current flow regime (the past 20 years), the Colorado pikeminnow population has done well in the White River. Preliminary population estimates suggest that the density in the White River are two or three times the density in the Yampa River (Bestgen et al. 2002), and Interagency Standardized Monitoring Program suggests that Colorado pikeminnow numbers have increased in recent years (1986–2000) and that the White River has increased most of all (McAda 2002). Irving and Modde (1994) suggested that Taylor Draw Dam may concentrate fish by preventing upstream movement and may have increased the prey base downstream and artificially increased carrying capacity for large predators such as Colorado pikeminnow. Or perhaps the relatively large base flows, at least compared to the near by Duchesne River, may attract more fish. Unfortunately, we do not yet know why it attracts so many Colorado pikeminnow.

CONCLUSIONS

1. There is a great deal of uncertainty in the precision, interpretation, and scope of this study, but listed below are the results we found.

2. Although the absolute area of each habitat declined with reduced flows, riffle, run, pool, and eddy habitat composition remained relatively constant for discharges above 150 cfs; below 150 cfs, riffle area increased as a percentage of total area and eddy area decreased.

3. Weighted useable area for adult Colorado pikeminnow increased nearly linearly from 1 to 600 cfs.

4. Riffle surface area also increased linearly as a function of flow for all flows examined.

RECOMMENDATIONS

1. Until additional information becomes available, we recommend continuation of the current flow patterns to protect the adult Colorado pikeminnow population in the White River.

2. Conduct a study that includes seasonal flow needs of Colorado pikeminnow including base flow needs, thus permitting determination of flow regimes that will maximize preferred habitats.

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Table 1. Mesohabitat composition by experimental flow and river stratum.

Discharge (cfs)	Stratum	Area (ha) Pool	Riffle	Run	Eddy	Total
339	1	6.5	38.8	38.8	32.4	116.6
	2	30.0	95.4	65.2	55.1	246.0
	3	18.6	56.2	89.8	60.0	224.6
	4	6.4	22.3	19.1	12.8	60.6
	Total	61.5	212.7	213.0	160.3	647.8
424	1	7.0	41.8	41.8	34.9	125.4
	2	31.9	101.5	69.3	58.6	261.6
	3	23.5	59.0	94.3	62.9	239.9
	4	6.7	23.6	20.3	13.5	64.2
	Total	69.2	225.9	225.7	169.9	691.1
552	1	8.9	52.9	52.9	44.2	159.0
	2	33.6	106.7	72.9	61.6	275.0
	3	26.5	70.4	110.1	74.9	281.6
	4	6.9	24.3	20.9	13.9	66.0
	Total	75.9	254.3	256.8	194.6	781.6

Table 2. Mean (SD) width, depth, and velocity for habitat type at each experimental flow and stratum. n = number of habitat types sample in the stratum.

Flow (cfs)	Str	Habitat	n	Width (m)	Depth (m)	Velocity (m/sec)
339	1	Pool	1	2.99	0.09 (0.09)	0.18 (0.17)
	2	Pool	6	13.29 (6.77)	0.45 (0.26)	0.50 (0.34)
	3	Pool	7	8.93 (10.61)	0.32 (0.29)	0.29 (0.23)
	4	Pool	2	11.25 (1.07)	0.53 (0.29)	0.51 (0.23)
	1	Riffle	6	26.73 (5.82)	0.38 (0.28)	0.61 (0.41)
	2	Riffle	19	32.16 (11.92)	0.39 (0.22)	0.68 (0.37)
	3	Riffle	15	31.09 (9.51)	0.37 (0.23)	0.56 (0.31)
	4	Riffle	7	32.71 (11.19)	0.40 (0.20)	0.68 (0.31)
	1	Run	6	29.63 (11.89)	0.55 (0.41)	0.42 (0.20)
	2	Run	13	26.46 (13.29)	0.40 (0.23)	0.52 (0.27)
	3	Run	24	28.35 (11.13)	0.55 (0.34)	0.40 (0.26)
	4	Run	6	25.91 (9.63)	0.52 (0.30)	0.53 (0.33)
	1	Eddy	5	5.27 (4.33)	0.52 (0.39)	0.37 (0.15)
	2	Eddy	11	6.92 (5.03)	0.26 (0.21)	0.41 (0.30)
	3	Eddy	16	7.50 (5.79)	0.64 (0.46)	0.27 (0.22)
	4	Eddy	4	3.87 (1.13)	0.44 (0.35)	0.16 (0.15)
424	1	Pool	1	3.99	0.17 (0.14)	0.23 (0.19)
	2	Pool	6	14.30 (6.98)	0.49 (0.28)	0.51 (0.37)
	3	Pool	7	9.60 (10.12)	0.35 (0.30)	0.31 (0.24)
	4	Pool	2	11.49 (0.70)	0.59 (0.31)	0.54 (0.27)
	1	Riffle	6	29.02 (5.27)	0.52 (0.28)	0.62 (0.34)
	2	Riffle	19	33.53 (13.08)	0.44 (0.23)	0.70 (0.39)
	3	Riffle	15	33.22 (11.46)	0.40 (0.24)	0.59 (0.34)
	4	Riffle	7	34.14 (11.92)	0.45 (0.22)	0.75 (0.35)
	1	Run	6	30.63 (11.92)	0.68 (0.44)	0.49 (0.21)
	2	Run	13	28.25 (12.41)	0.43 (0.24)	0.53 (0.33)
	3	Run	24	30.14 (11.13)	0.58 (0.37)	0.42 (0.29)
	4	Run	6	28.04 (10.03)	0.58 (0.35)	0.58 (0.44)
	1	Eddy	5	6.89 (3.93)	0.58 (0.41)	0.39 (0.20)
	2	Eddy	11	8.35 (7.25)	0.28 (0.21)	0.43 (0.35)
	3	Eddy	16	7.65 (5.82)	0.65 (0.47)	0.30 (0.24)
	4	Eddy	4	4.75 (1.86)	0.45 (0.38)	0.17 (0.16)
552	1	Pool	1	3.99	0.35 (0.14)	0.33 (0.18)
	2	Pool	6	14.30 (6.98)	0.58 (0.27)	0.54 (0.42)

3	Pool	7	7.71 (8.05)	0.45 (0.41)	0.37 (0.30)
4	Pool	2	11.49 (0.70)	0.62 (0.31)	0.51 (0.31)
1	Riffle	6	42.61 (13.78)	0.66 (0.36)	0.57 (0.37)
2	Riffle	19	34.84 (14.23)	0.50 (0.25)	0.72 (0.43)
3	Riffle	16	27.25 (26.40)	0.43 (0.28)	0.61 (0.44)
4	Riffle	7	34.72 (12.04)	0.47 (0.23)	0.77(0.39)
1	Run	6	32.83 (13.90)	0.76 (0.49)	0.51 (0.26)
2	Run	13	29.87 (13.78)	0.51 (0.26)	0.56 (0.38)
3	Run	24	27.34 (21.67)	0.68 (0.43)	0.40 (0.28)
4	Run	6	31.21 (10.36)	0.59 (0.38)	0.58 (0.50)
1	Eddy	5	9.88 (4.69)	0.59 (0.45)	0.37 (0.25)
2	Eddy	11	8.63 (7.16)	0.37 (0.21)	0.45 (0.41)
3	Eddy	16	6.55 (4.82)	0.59 (0.53)	0.28 (0.28)
4	Eddy	4	5.00 (2.01)	0.45 (0.40)	0.15 (0.17)

Table 3. Mean (SD) weighted usable area for each habitat cluster for three habitat use curves (day[a], night[b], suit[c]) at discharge 339 cfs. Dimensions are m^2 per 100 m^2 surface area.

Stratum	Day	Night	Suit
1	4.3 (7.54)	46.8 (8.14)	46.0 (6.19)
2	0.5 (0.83)	52.5 (17.86)	54.7 (11.54)
3	7.3 (10.99)	65.4 (25.51)	63.8 (17.72)
4	0.8 (0.59)	58.6 (17.44)	52.6 (16.88)

[a] Day is the WUA derived from the habitat use curve for daytime resting adult Colorado pikeminnow in the Yampa River.
[b] Night is the WUA derived from the habitat use curve for night foraging adult Colorado pikeminnow in the Yampa River.
[c] Suit is the WUA derived from the habitat use curve for adult Colorado pikeminnow in the White River. The curves are given in Appendix 1.

Table 4. Discharges at which 50, 75, and 95% of riffle coverage occurred, and curve break discharge and percent riffle coverage. Only cross sections that were entirely riffle were included.

Cross section	RM	Riffle coverage (cfs) 50%	75%	95%	Curve break discharge (cfs)	Curve break coverage (%)
10102	1.0	100	190	520	200	76
10302	12.3	123	225	585	200	74
10401	16.2	125	265	490		
10501	17.2	510	560	590		
10602	21.1	512	555	590		
20201	28.2	70	190	450	200	80
20202	28.2	25	145	550	150	77
20302	29.9	255	375	475		
20402	30.4	32	175	250	200	90
20501	32.3	11	98	305	150	88
20502	32.3	40	150	498	100	71
20701	38.7	63	98	300	150	91
20802	44.8	105	160	300	200	91
20902	46.3	100	240	475	200	69
21002	47.7	140	240	475	200	72
21101	50.8	42	63	300	80	82
21102	50.8	149	285	485		
21201	54.1	16	83	500	150	87
21202	54.1	41	175	420	200	78
21302	57.7	41	195	580	150	71
21401	59.2	7	36	290	100	84
21402	59.2	145	300	480		
30102	62.1	500	580	595	150	34
30701	75.9	75	240	480	150	65
30802	77.1	38	190	380	100	67
31001	79.4	275	360	475		
31201	80.5	12	215	410		
31202	80.5	125	185	300	250	61
31301	82.4	175	315	485		
31302	82.4	125	385	520		
31401	83.9	75	275	515	100	58
31402	83.9	82	185	480	150	72
31502	87.0	39	200	450	150	73

31601	89.7	30	77	390	80	77
31701	93.4	58	140	225	200	92
31702	93.4	20	175	400	250	86
40102	94.6	30	125	275	200	92
40202	96.1	30	75	100	100	95
40401	103.3	45	200	410	80	64
40402	103.3	38	175	320	250	93
40501	104.2	45	150	390	150	75
40502	104.2	88	135	390	150	84
average		108.5	218.7	426.1	160.6	77.2

Table 5. Total area and WUA for three habitat use curves (day[a], night[b], suit[c]) at three experimental flows for each river stratum.

		Area (ha)			
Discharge (cfs)	Stratum	Total (SE)	Day (SE)	Night (SE)	Suit (SE)
339	1	116.64 (12.13)	4.22 (3.05)	46.33 (3.29)	45.48 (2.50)
	2	246.03 (11.69)	0.84 (0.38)	89.94 (8.18)	93.66 (5.28)
	3	224.58 (12.02)	11.66 (4.24)	104.01 (9.84)	101.36 (6.83)
	4	60.58 (2.85)	0.39 (0.11)	27.49 (3.34)	24.67 (3.23)
	Total	647.82 (11.02)	17.11 (2.19)	267.77 (7.36)	265.17 (5.10)
424	1	125.36 (10.73)	5.61 (4.24)	53.75 (5.57)	60.73 (4.51)
	2	261.65 (12.11)	1.07 (0.50)	104.19 (7.98)	106.18 (5.68)
	3	239.91 (13.98)	13.44 (5.02)	109.59 (9.66)	108.54 (7.20)
	4	64.22 (2.72)	0.62 (0.20)	31.81 (3.12)	27.14 (3.44)
	Total	691.13 (11.58)	20.74 (2.74)	299.35 (7.64)	302.59 (5.77)
552	1	159.03 (12.49)	5.54 (3.71)	75.07 (10.28)	73.74 (8.23)
	2	274.95 (14.27)	1.87 (0.67)	125.03 (9.69)	126.31 (8.35)
	3	281.58 (22.37)	18.34 (9.05)	120.65 (11.64)	118.79 (10.07)
	4	65.98 (2.59)	0.77 (0.26)	32.61 (2.75)	27.97 (3.52)
	Total	781.54 (15.60)	26.51 (4.10)	353.97 (9.80)	346.81 (8.45)

[a] Day is the WUA derived from the habitat use curve for daytime resting adult Colorado pikeminnow in the Yampa River from Miller and Modde (1999), given in Appendix 2, Table 1.

[b] Night is the WUA derived from the habitat use curve for night foraging adult Colorado pikeminnow in the Yampa River from Miller and Modde (1999), given in Appendix 2, Table 2.

[c] Suit is the WUA derived from the habitat use curve for adult Colorado pikeminnow in the White River from Valdez et al. 1987, given in Appendix 2, Table 3.

Table 6. Riffle thalweg depth (cm) at various discharges. A depth of 30 cm is needed to pass adult Colorado pikeminnow over riffles.

Cross section	RM	Discharge (cfs) 100	150	200	250	300
20302	29.9	9	14	18	23	27
21002	47.7	15	20	25	30	35
10602	21.1	5	11	18	28	39
31701	93.4	30	34	38	41	43
20502	32.3	24	29	34	37	41
20402	30.4	27	33	37	41	45
20501	32.3	24	29	34	37	41
40602	104.4	10	15	20	24	27
40402	103.3	29	34	39	42	45
20602	33.6	26	33	40	45	50
31402	83.9	38	44	49	53	57
21402	59.2	27	32	37	41	45
10102	1.0	34	43	50	56	62
20301	29.9	35	41	46	51	55
30102	62.1	30	37	44	50	55
20902	46.3	34	41	46	51	55
31601	89.7	27	33	37	41	45
10302	12.3	34	44	52	59	65
40401	103.3	28	34	39	43	46
40501	104.2	34	39	44	47	51
20401	30.4	36	43	48	53	57
31401	83.9	40	47	53	57	61
40502	104.2	49	58	64	70	75
20701	38.7	46	55	61	66	70
20702	38.7	44	52	58	63	68
21302	57.7	27	35	43	50	57
21102	50.8	49	58	64	70	75
31301	82.4	49	58	65	71	77
31702	93.4	34	41	46	51	55
30802	77.1	34	41	47	52	56
40202	96.1	35	43	49	54	59
10401	16.2	41	50	58	64	70

31302	82.4	34	44	52	59	66
31202	80.5	49	58	64	70	75
21101	50.8	43	51	58	64	69
20901	46.3	41	50	56	62	67
20201	28.2	48	57	65	71	77
40102	94.6	44	52	59	66	71
31602	89.7	38	47	53	59	65
20202	28.2	38	47	55	61	67
31502	87.0	44	52	58	63	68
31001	79.4	37	48	57	66	74
21401	59.2	28	36	43	49	54
30701	75.9	51	61	69	77	83
40601	104.4	49	57	64	69	74
20101	23.3	36	41	45	48	50
10501	17.2	73	84	93	100	107
10502	17.2	42	54	62	70	76
30601	75.3	72	91	108	122	135

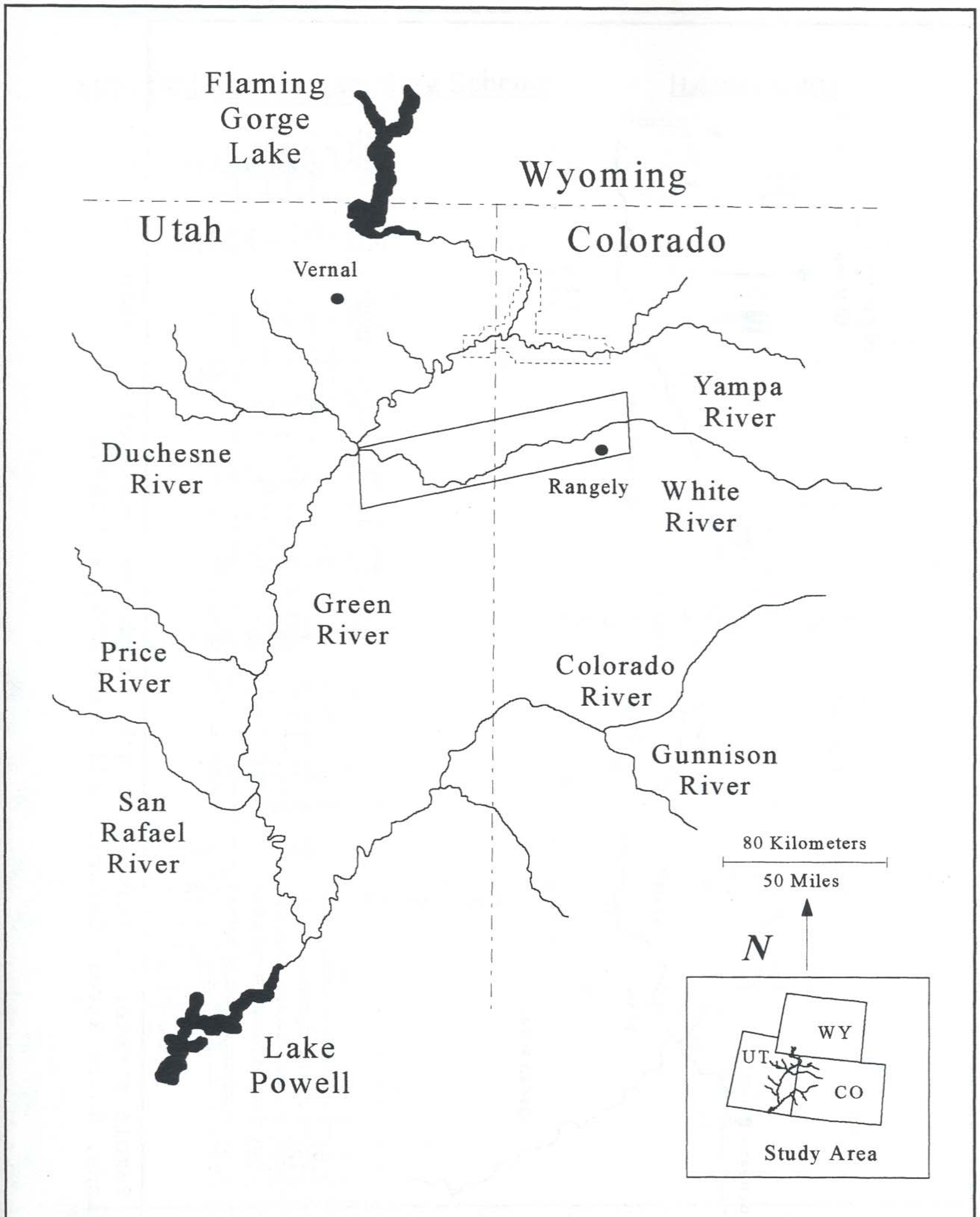
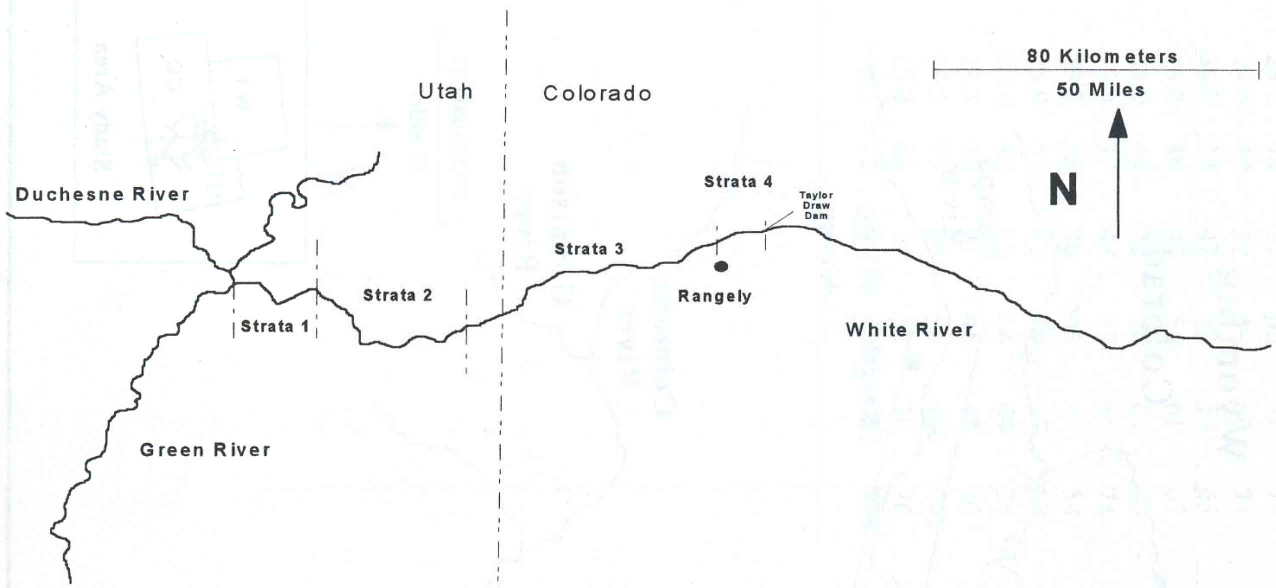


Figure 1. White River study area in the Green River Drainage, Utah and Colorado, 1995 and 1996.



Strata	Rm (Rk)	Location	Total Length rm (rkm)	Total Length ft (m)	Mean Width ft (m)	Habitat Cluster Length*10 ft (m)	Total Estimated No. of Habitat Clusters (%)	No. of Clusters Sampled in 1995 (%)	No. of Cross-Sections Sampled in 1995	No. of Clusters Sampled in 1996 (%)	No. of Cross-Sections Sampled in 1996
1	0.0-21.7 (0.0-34.9)	White and Green Ri ver confluence to Mt. Fuel Bridge	21.7 (34.9)	114,576 (34,900)	74.93 (22.84)	749.3 (228.4)	153 (18.7)	6 (3.9)	12	6 (3.9)	12
2	21.7-59.3 (34.9-95.4)	Mt. Fuel Bridge to Ignacio Bridge on Highway 45	37.6 (60.5)	198,528 (60,500)	65.72 (20.03)	657.2 (200.3)	302 (36.9)	14 (4.6)	28	28 (9.3)	56
3	59.3-94.2 (95.4-151.6)	Ignacio Bridge on Highway 45 to Rangely Bridge on Highway 64	34.9 (52.6)	184,272 (56,200)	65.09 (19.84)	650.9 (198.4)	283 (34.6)	13 (4.6)	26	34 (12.0)	68
4	94.2-104.5 (151.6-168.2)	Rangely Bridge on Highway 64 to Taylor Draw Dam	10.3 (16.6)	54,384 (16,600)	67.98 (20.72)	679.8 (207.2)	80 (9.8)	6 (7.5)	13	12 (15)	26
All	0.0-104.5 (0.0-168.2)	White and Green River confluence to Taylor Draw Dam	104.5 (168.2)	551,760 (168,200)	68.43 (20.86)	684.3 (208.6)	818 (100.0)	39 (4.8)	79	80 (9.8)	162

Figure 2. Sample strata, locations, length, width and number of clusters and cross-sections, White River, Colorado and Utah, 1995 and 1996.

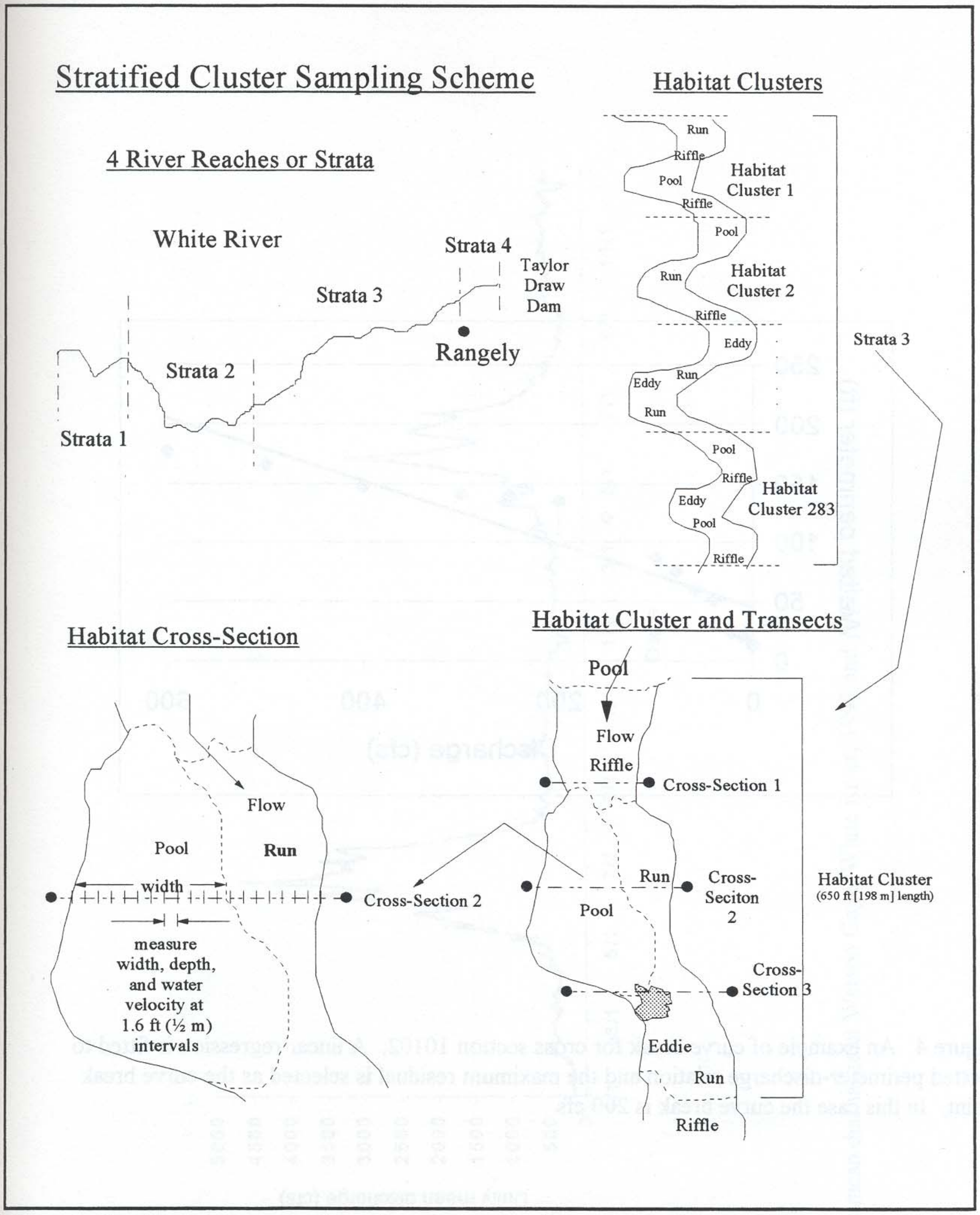


Figure 3. Stratified cluster sampling scheme, river reaches or strata, habitat clusters (pool-run-riffle sequences), habitat cross sections and mesohabitat data, White River, Colorado and Utah, 1995 and 1996.

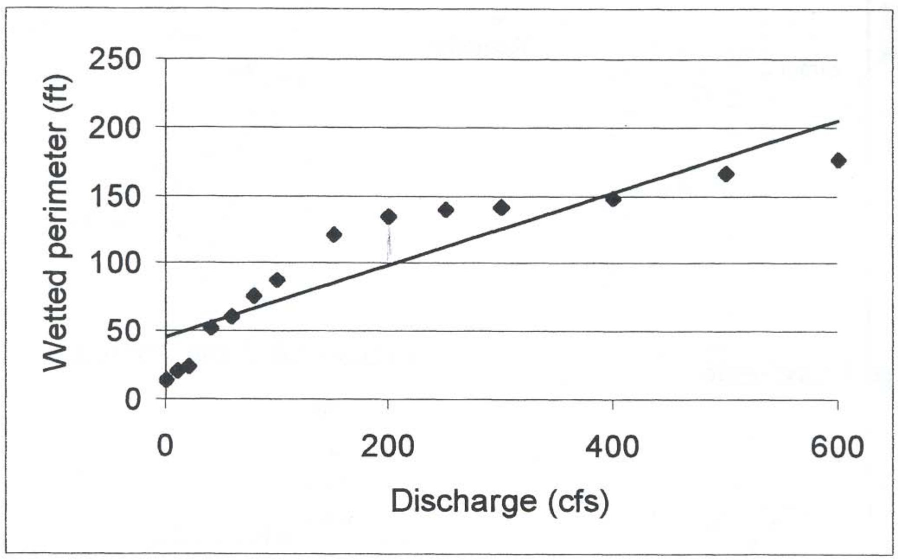


Figure 4. An example of curve break for cross section 10102. A linear regression is fitted to wetted perimeter-discharge relation and the maximum residual is selected as the curve break point. In this case the curve break is 200 cfs.

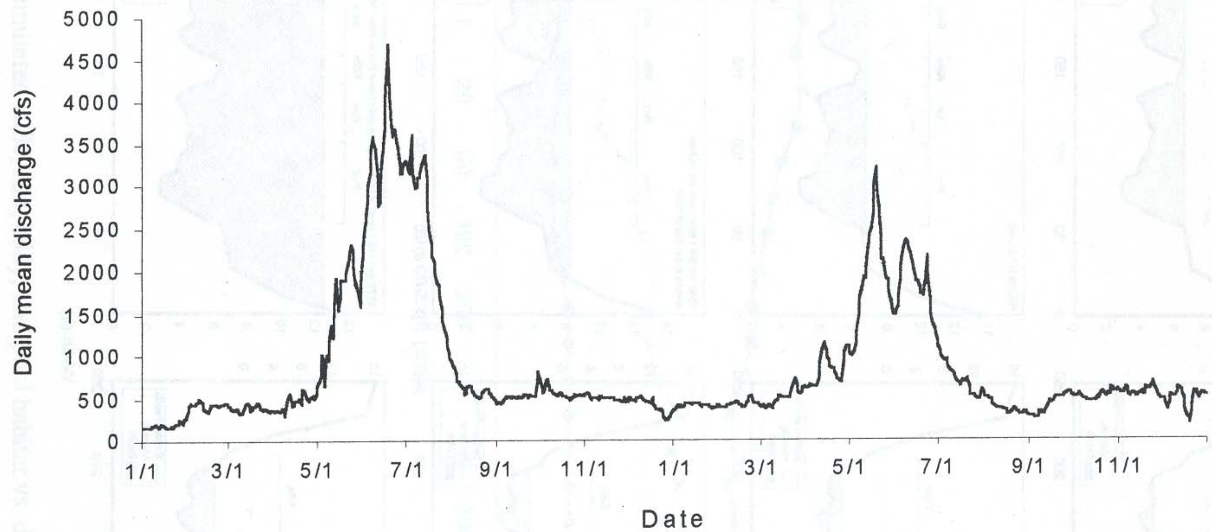


Figure 5. Daily mean discharge at Watson Gage, White River, 1995 and 1996

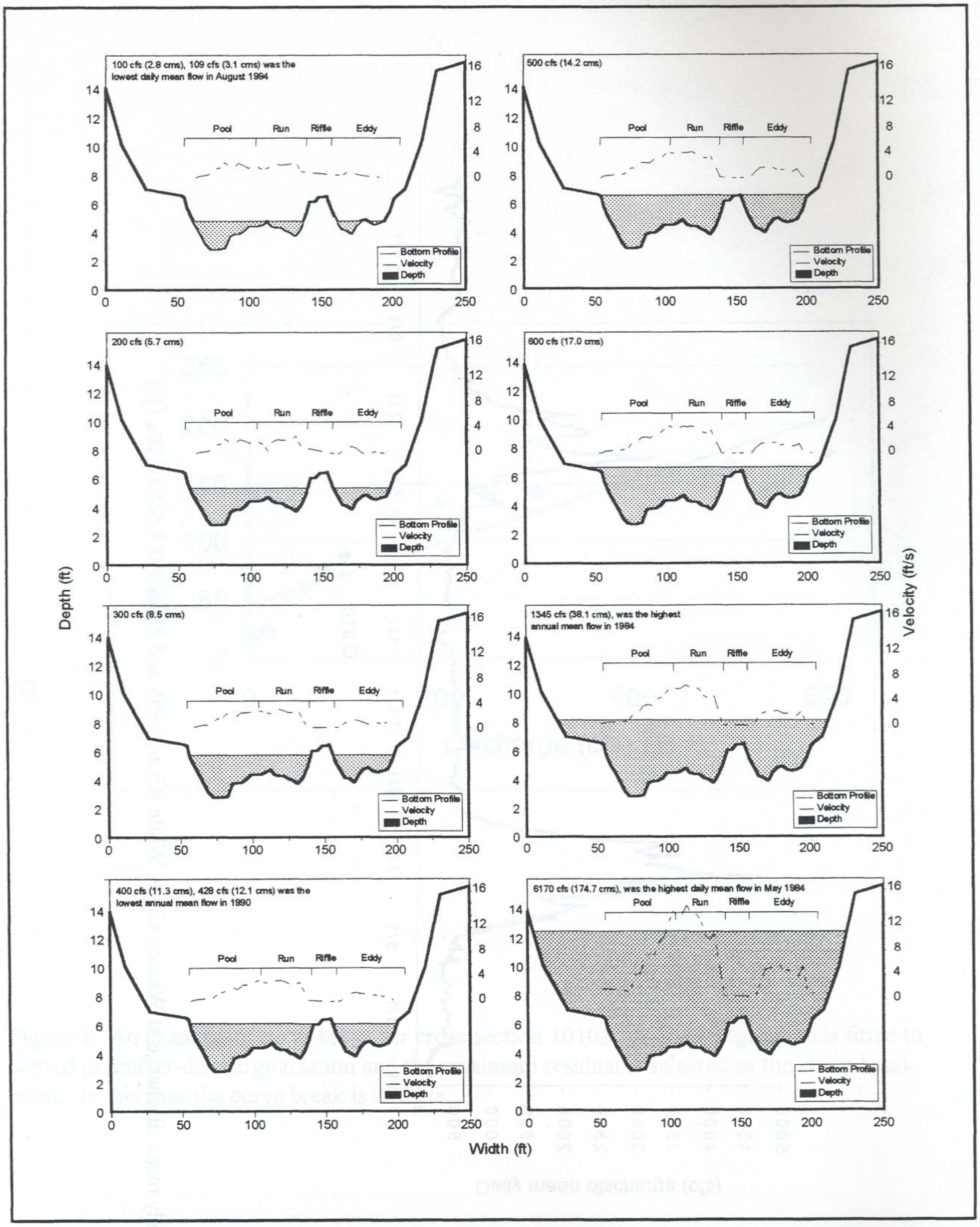


Figure 6. Typical river profile at several different river discharge levels on the White River, 1995 and 1996.

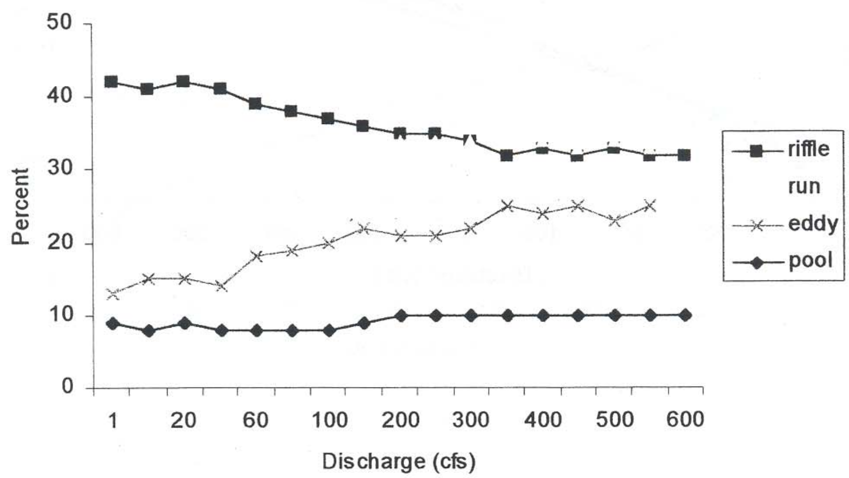


Figure 7. Percent simulated riffle, run, eddy, and pool habitat vs. discharge, White River, 1995 and 1996.

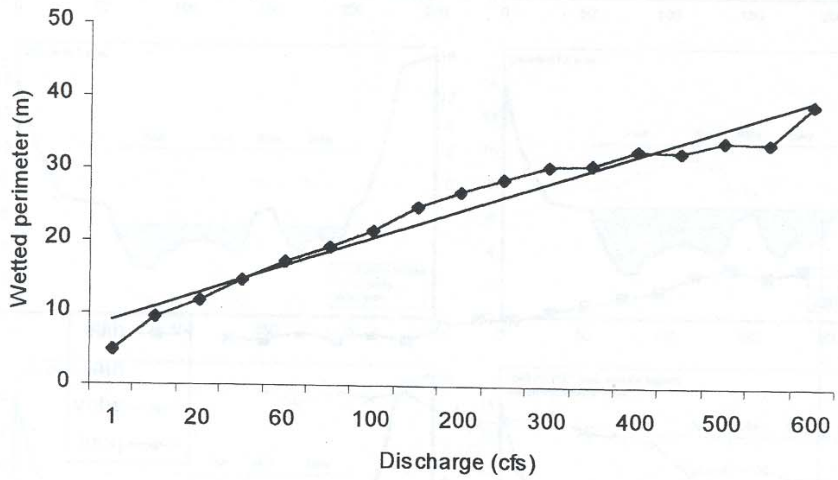


Figure 8. Simulated riffle mean wetted perimeter vs. discharge, White River, 1995 and 1996.

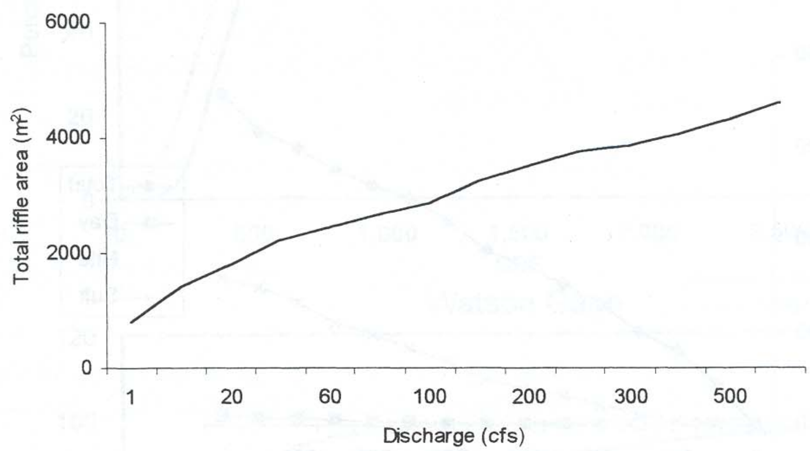


Figure 9. Simulated riffle surface area vs. discharge, White River, 1995 and 1996.

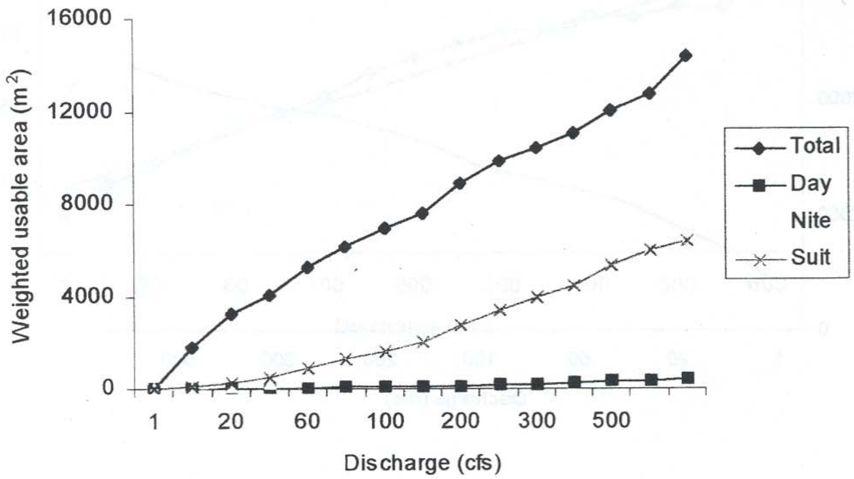


Figure 10. Simulated adult Colorado pikeminnow weighted usable area (WUA) vs. discharge, White River, 1995 and 1996. Total is the total surface area available. Day and night are the WUAs for daytime resting fish and night foraging fish, and Suit is the WUA for White River fish.

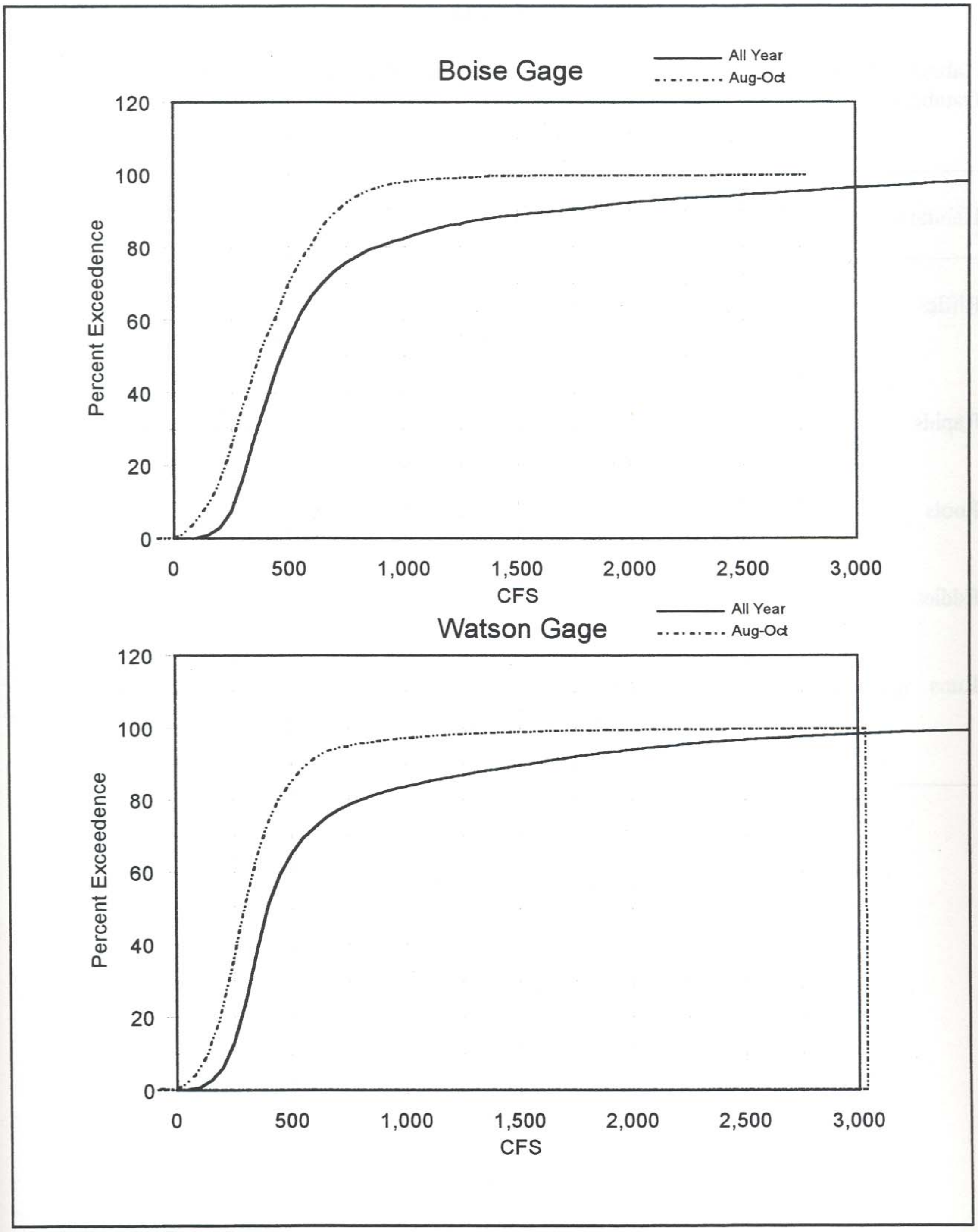


Figure 11. Percent exceedence curves for the White River at the Boise Creek Gage (near Rangely, Colorado) and Watson Gage (near Bonanza, Utah).

APPENDIX 1

Habitat types and descriptions adapted from Bisson et al. 1982 and Upper Colorado River Basin Database

Habitat Category	Habitat Description
Riffles	Shallow (<20 cm deep), moderate current velocity (20-50 cm/sec), moderate turbulence, substrate gravel, pebble, and cobble-sized particles (2-256 mm), gradient <4%
Rapids	Gradient >4%, swiftly flowing water (>50 cm/sec), considerable turbulence, substrate largely composed of boulders
Pools	A portion of stream that is deep and less velocity than run; often lies between riffles
Eddies	Presence of counter- current; usually deep and less velocity than main-channel
Runs	Possess attributes of both riffles and pools; characterized by moderately shallow water (10-30 cm deep) with laminar flow; substrate gravel and cobble.

APPENDIX 2 - Habitat Suitability Criteria

Table 1. Habitat use curve for adult Colorado pikeminnow for daytime resting (bottom velocities); from Miller and Modde (1999).

Velocity (m/s)	HSI	Depth (m)	HSI
0.000	0.25	0.000	0.00
0.027	0.50	0.427	0.00
0.030	1.00	0.792	0.125
0.244	1.00	0.914	0.25
0.366	0.500	1.158	0.50
0.396	0.25	1.280	1.00
0.427	0.00	6.096	1.00

Table 2. Habitat use curve for adult Colorado pikeminnow for night foraging (mean column velocities; from Miller and Modde, Chapter 4, in Modde et al. 1999).

Velocity (m/s)	HSI	Depth (m)	HSI
0.000	0.25	0.000	0.00
0.003	0.50	0.304	0.00
0.030	1.00	0.366	0.25
0.671	1.00	0.427	0.50
0.914	0.50	0.487	1.00
1.097	0.25	1.280	1.00
1.280	0.00	1.283	0.50
2.743	0.00	1.402	0.25
		1.524	0.00
		6.096	0.00

APPENDIX 3

Table 1.-The location, description and length in river miles/kilometers (rm/rkm) of river strata, length in feet/meter (ft, m) of habitat cluster and transect, and habitat type sampled during the White River survey, Colorado and Utah, 1995 and 1996.

Strata[a] No.	Location, Description and Gradient	Start-End rm (rkm)	Length rm (rkm)	Cluster[b] No.	Length rm (rkm)	Transect[c] No.	Ft (m) From Top of cluster	Habitat Type/Sequence[d]
1	White River mouth - Mt. Fuel Bridge, Ut. Wide open meandering floodplain with a 0.05% gradient.	0-21.7 (0-34.9)	21.7 (34.9)	1	1.0 (1.6)	1 2	16 (5) 627 (191)	Run (R) Riffle (R)
				2	7.5 (12.1)	1 2	276 (84) 407 (124)	Eddy, Run (R) Eddy, Run,Eddy (R)
				3	12.3 (19.8)	1 2	82 (25) 679 (207)	Run, Eddy (R) Riffle (R)
				4	16.2 (26.0)	1 2	131 (40) 282 (86)	Riffle (R) Run (R)
				5	17.2 (27.7)	1 2	305 (93) 338 (103)	Riffle (R) Pool, Riffle, Run (R)
				6	21.1 (34.0)	1 2	125 (38) 709 (216)	Run, Eddy (R) Riffle (R)
2	Mt. Fuel Bridge - Ignacio Bridge, Highway 45, Ut. Canyon bound area with a 0.10% gradient.	21.7-59.3 (34.9-95.4)	37.6 (60.5)	1	23.3 (37.5)	1 2	312 (95) 571 (174)	Run, Eddy (L) Run, Riffle, Run (R)
				2	28.2 (45.4)	1 2	400 (122) 479 (146)	Eddy, Riffle (R) Riffle, Eddy (R)
				3	29.9 (48.1)	1 2	427 (130) 584 (178)	Run, Pool (R) Riffle (R)
				4	30.4 (48.9)	1 2	495 (151) 554 (169)	Eddy, Run (R) Riffle (R)
				5	32.3 (52.0)	1 2	66 (20) 466 (142)	Riffle (R) Riffle (R)
				6	33.6 (54.0)	1 2	62 (19) 394 (120)	Run (R) Riffle, Pool, Eddy (R)
				7	38.7 (62.3)	1 2	167 (51) 295 (90)	Run (R) Riffle, Pool (R)
				8	44.8 (72.1)	1 2	358 (109) 387 (118)	Run (R) Riffle, Pool (R)

Table 1.-Continued.

Strata[a] No.	Location, Description and Gradient	Start-End rm (rkm)	Length rm (rkm)	Cluster[b] No.	Length rm (rkm)	Transect[c] No.	Ft (m) From Top of cluster	Habitat Type/Sequence[d]
2	Mt. Fuel Bridge - Ignacio Bridge, Highway 45, Ut. Canyon bound area with a 0.10% gradient.	21.7-59.3 (34.9-95.4)	37.6 (60.5)	9	46.3 (74.5)	1 2	26 (8) 187 (57)	Run, Eddy (R) Riffle (R)
				10	47.7 (76.8)	1 2	197 (60) 548 (167)	Run, Eddy, Run, Pool (L) Run, Eddy, Riffle (R)
				11	50.8 (81.8)	1 2	26 (8) 614 (187)	Riffle, Eddy (R) Riffle, Pool, Eddy (R)
				12	54.1 (87.0)	1 2	174 (53) 210 (64)	Riffle (R) Riffle (R)
				13	57.7 (92.8)	1 2	75 (23) 545 (166)	Run, Pool (R) Riffle (R)
				14	59.2 (95.3)	1 2	3 (1) 394 (120)	Riffle (R) Run, Riffle (R)
3	Ignacio Bridge, Hiway 45, Ut. - Highway 64 Bridge, Rangely, Co. Some floodplain, but mostly canyon area, 0.16% gradient.	59.3-94.2 (95.4-151.6)	34.9 (56.2)	1	62.1 (99.9)	1 2	0 (0) 161 (49)	Riffle, Run (R) Riffle (R)
				2	67.3 (108.3)	1 2	394 (120) 535 (163)	Run, Eddy (R) Run (R)
				3	68.0 (109.5)	1 2	30 (9) 614 (187)	Run (R) Run, Eddy (R)
				4	69.0 (111.1)	1 2	318 (97) 617 (188)	Eddy, Run (R) Eddy, Run (R)
				5	71.8 (115.6)	1 2	387 (118) 607 (185)	Run (R) Run, Eddy (L)
				6	75.3 (121.2)	1 2	95 (29) 328 (100)	Riffle, Pool, Eddy (R) Eddy, Run, Pool, Eddy (R)
				7	75.9 (122.1)	1 2	98 (30) 322 (98)	Eddy, Riffle (R) Run, Eddy (R)
				8	77.1 (124.0)	1 2	138 (42) 358 (109)	Pool, Run, Eddy (R) Run, Riffle, Eddy (R)
				9	78.8 (126.8)	1 2	554 (169) 643 (196)	Eddy, Run (R) Run (R)

Table 1.-Continued.

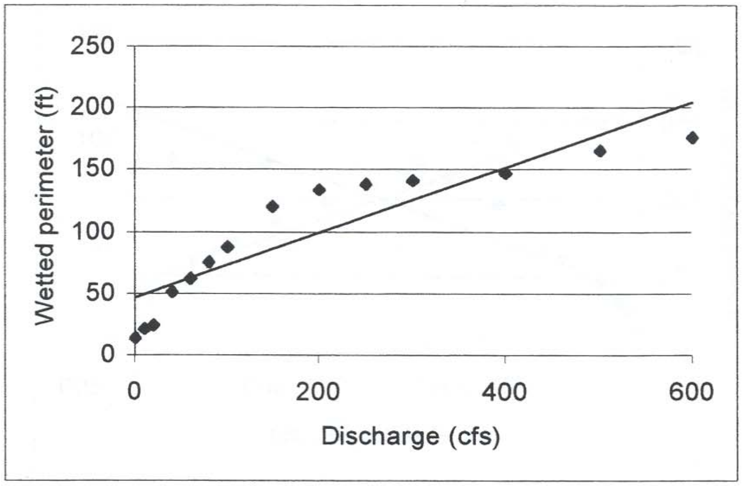
Strata[a] No.	Location, Description and Gradient	Start-End rm (rkm)	Length rm (rkm)	Cluster[b] No.	Length rm (rkm)	Transect[c] No.	Ft (m) From Top of cluster	Habitat Type/Sequence[d]
3	Ignacio Bridge, Hiway 45, Ut. - Highway 64 Bridge, Rangely, Co.	59.3-94.2 (95.4-151.6)	34.9 (56.2)	10	79.4 (127.8)	1 2	318 (97) 433 (132)	Run (R) Riffle, Run (R)
	Some floodplain, but mostly canyon area, 0.16% gradient.			11	80.0 (128.8)	1 2	20 (6) 486 (148)	Run, Eddy, Run (R) Run (R)
				12	80.5 (129.5)	1 2	358 (109) 551 (168)	Riffle, Eddy (R) Eddy, Riffle (R)
				13	82.4 (132.6)	1 2	187 (57) 285 (87)	Riffle, Pool (L) Riffle, Pool (R)
				14	83.9 (135.0)	1 2	220 (67) 299 (91)	Riffle (R) Riffle (R)
				15	87.0 (140.0)	1 2	125 (38) 636 (194)	Run (R) Riffle (R)
				16	89.7 (144.3)	1 2	148 (45) 361 (110)	Eddy, Riffle (R) Run (R)
				17	93.4 (150.3)	1 2	108 (33) 463 (141)	Run, Riffle, Pool (R) Pool, Riffle (R)
4	Highway 64 Bridge - Taylor Draw Dam, Rangely, Co.	94.2-104.5 (151.6-168.2)	10.3 (16.6)	1	94.6 (152.2)	1 2	66 (20) 295 (90)	Eddy, Run (R) Eddy, Riffle (R)
	Open canyon with some open floodplain, 0.13% gradient.			2	96.1 (154.7)	1 2	269 (82) 377 (115)	Eddy, Run (R) Riffle, Eddy (R)
				3	100.5 (161.7)	1 2	75 (23) 341 (104)	Run (R) Run (R)
				4	103.3 (166.3)	1 2	95 (29) 256 (78)	Riffle (R) Riffle (R)
				5	104.2 (167.7)	1 2	131 (40) 531 (162)	Riffle (R) Riffle (R)
				6	104.4 (168.0)	1 2	266 (81) 502 (153)	Pool, Run (R) Pool, Run (R)

[a]Strata were selected to decrease variation in differences within the White River.
[b]Habitat Clusters = 10 * the mean width of each strata, and assumed to capture two representative pool-run-riffle sequences.
[c]Habitat Transect = a line randomly placed across the river perpendicular to the flow where habitat width, depth and water velocity

measurements were taken.
[d]Habitat Sequences = The sequence of habitat types across the habitat transect starting at either the right (R) or left (L) bank, looking downstream.

Appendix 4

Wetted perimeter and riffle coverage-discharge relations for riffle cross sections.



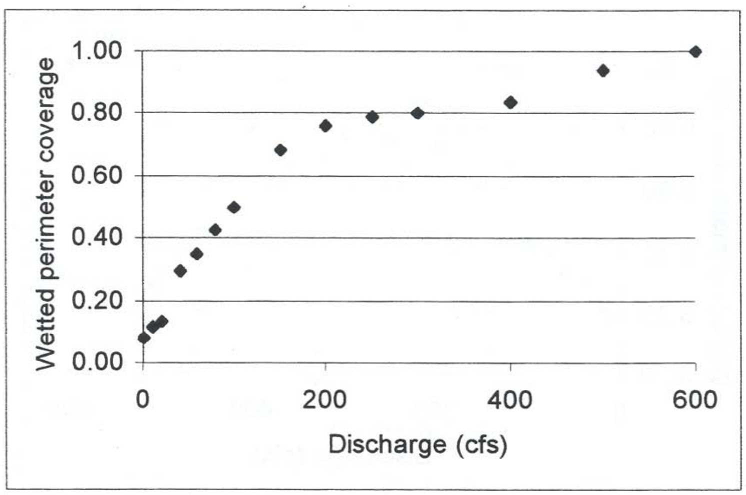
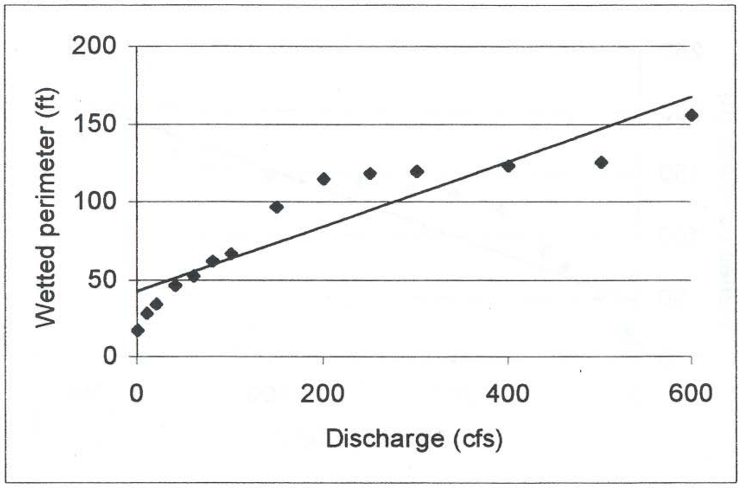


Figure A-1. Cross section 10102



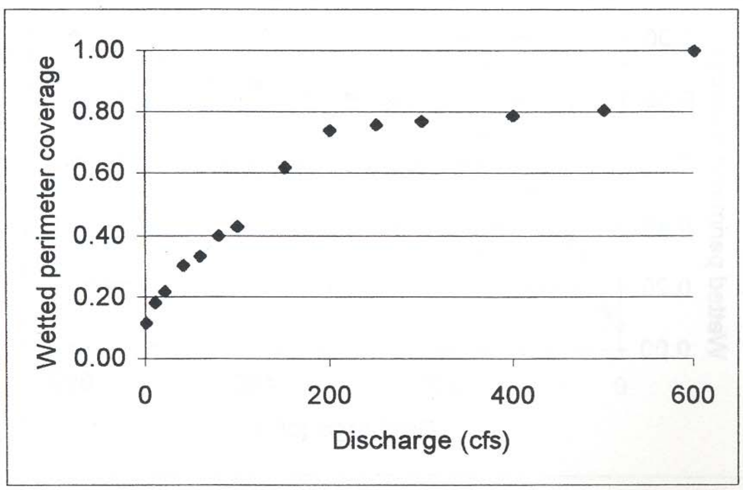


Figure A-2. Cross section 10302

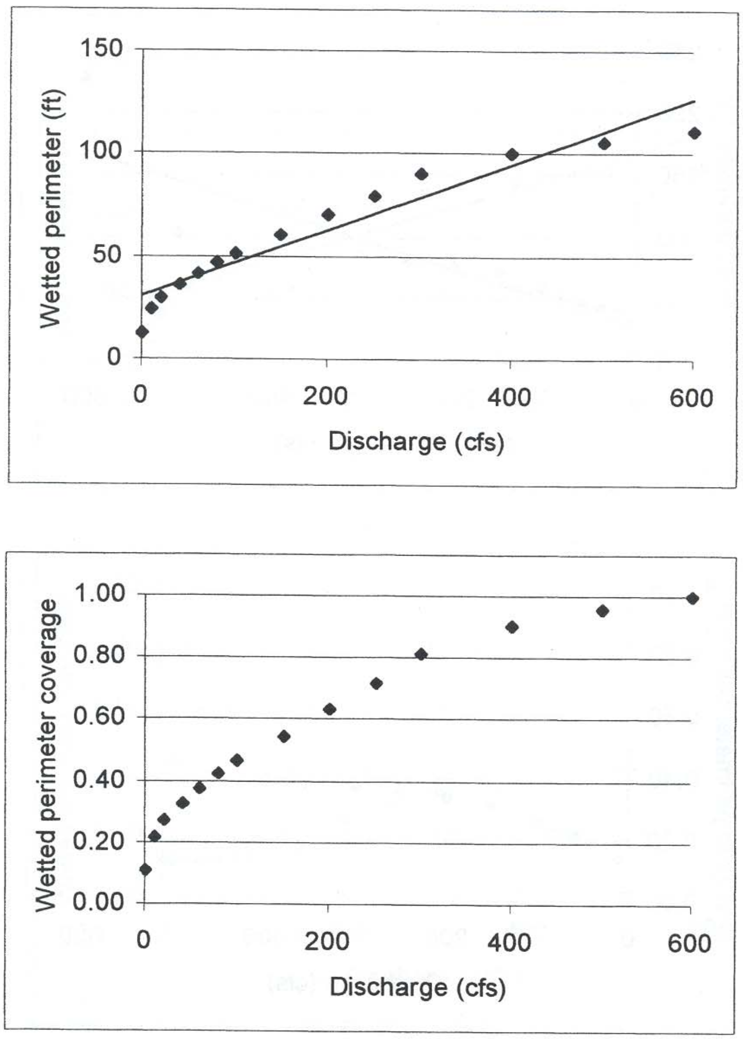
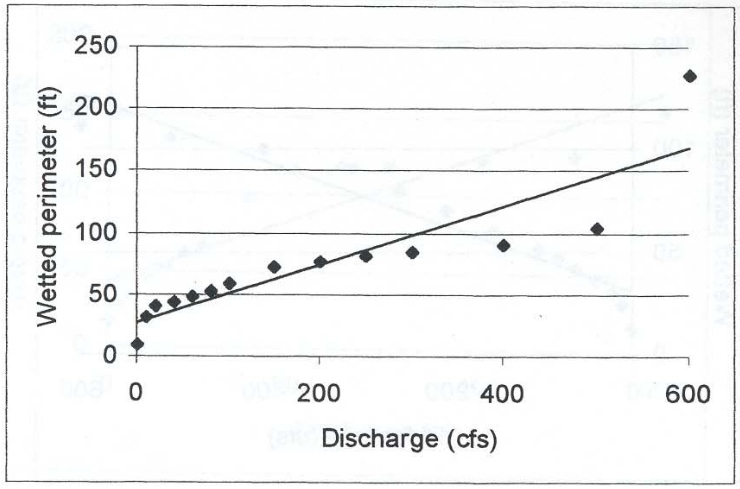


Figure A-3. Cross section 10401



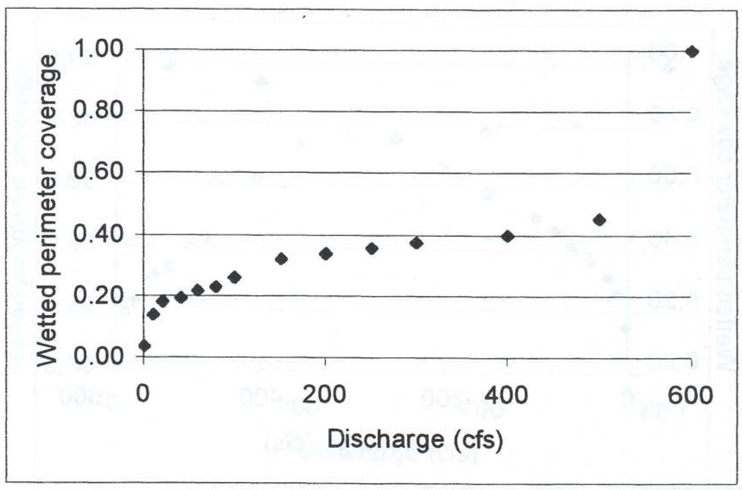
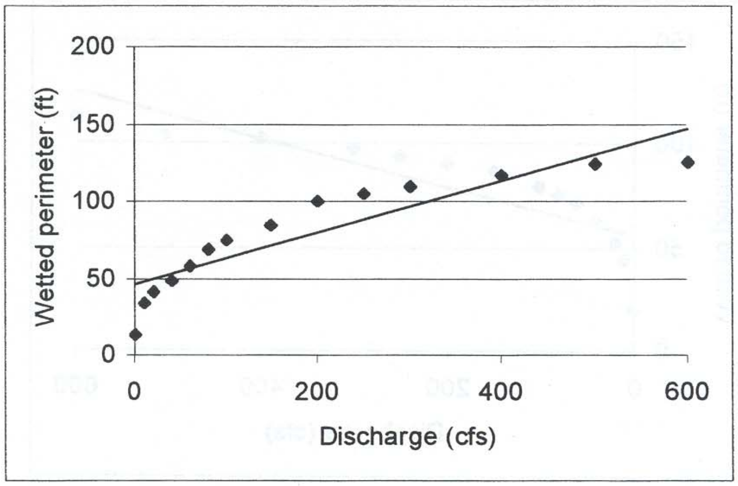


Figure A-4. Cross section 10501.



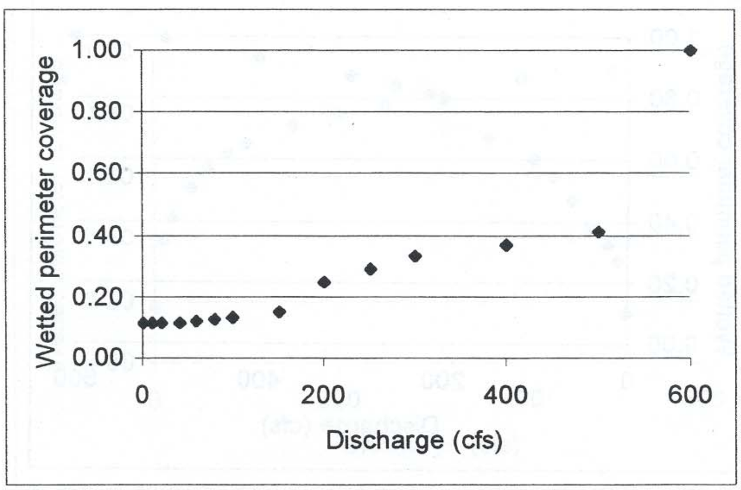
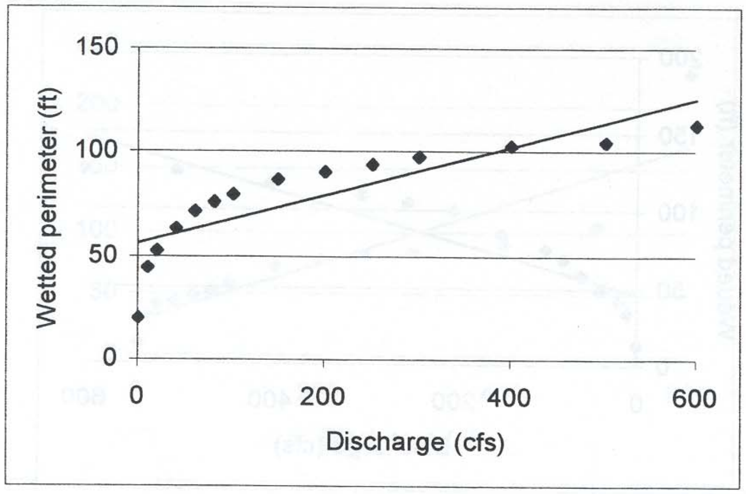


Figure A-5. Cross section 10602.



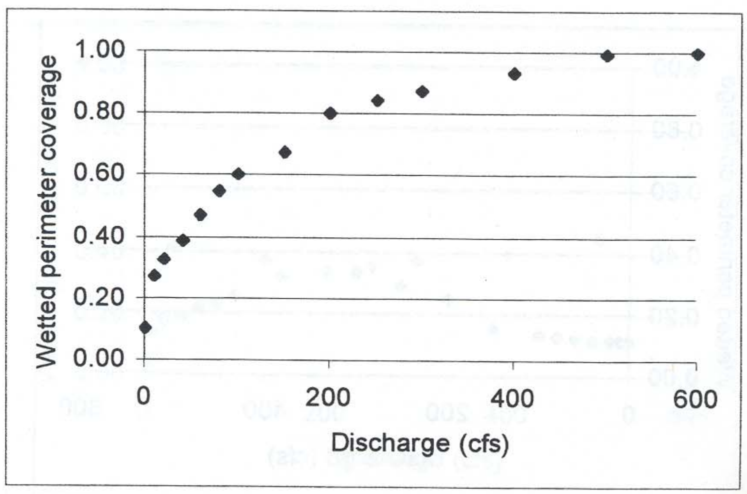


Figure A-6. Cross section 20201.

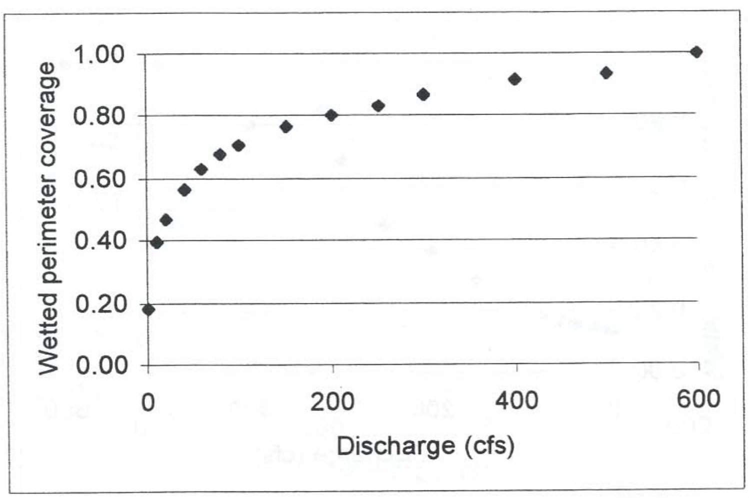
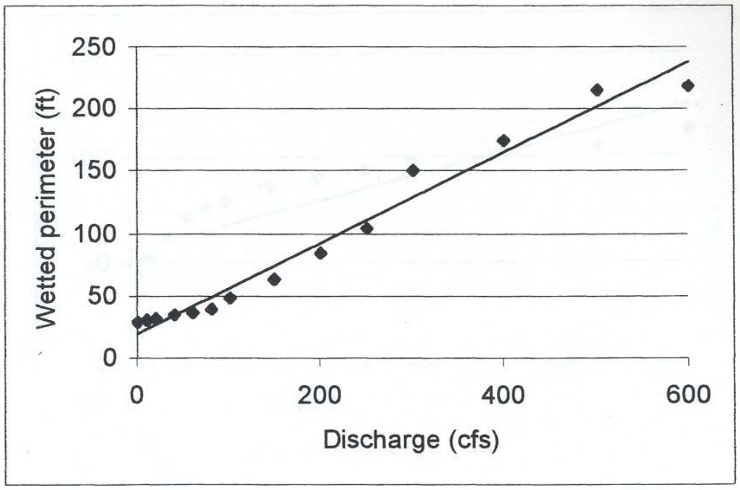


Figure A-7. Cross section 20202.



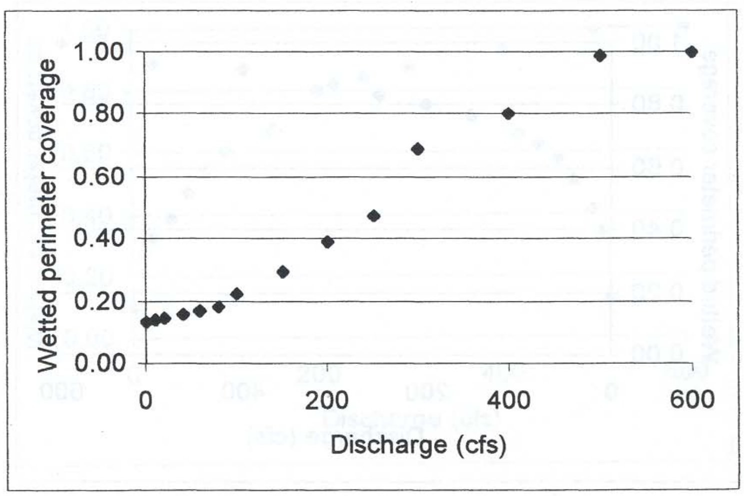
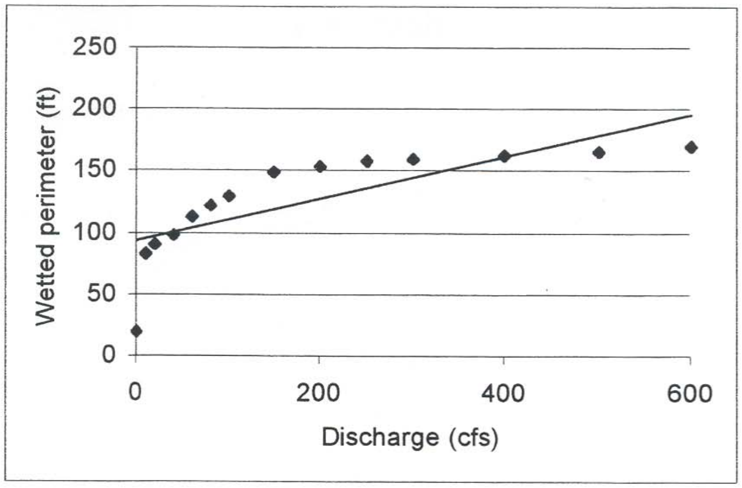


Figure A-8. Cross section 20302.



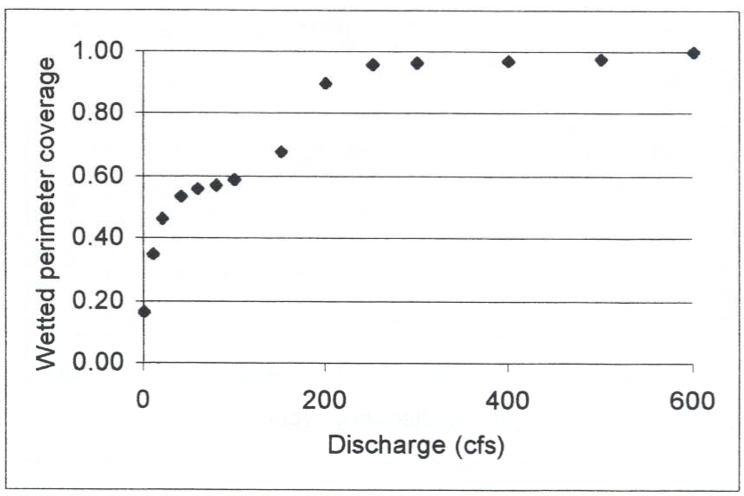


Figure A-9. Cross section 20402.

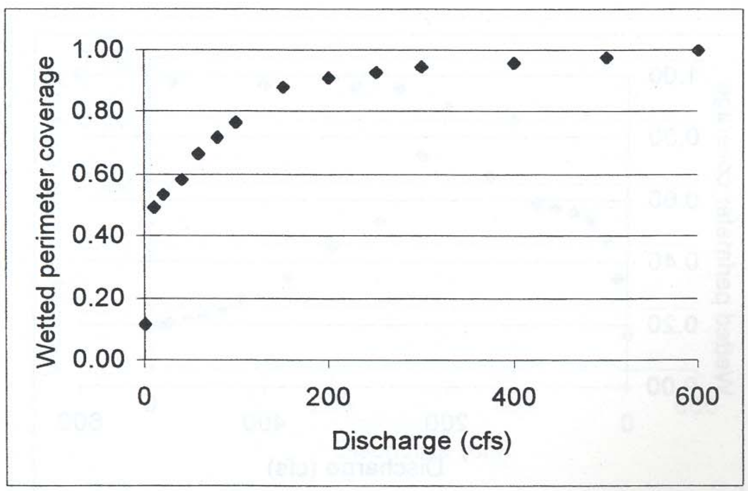
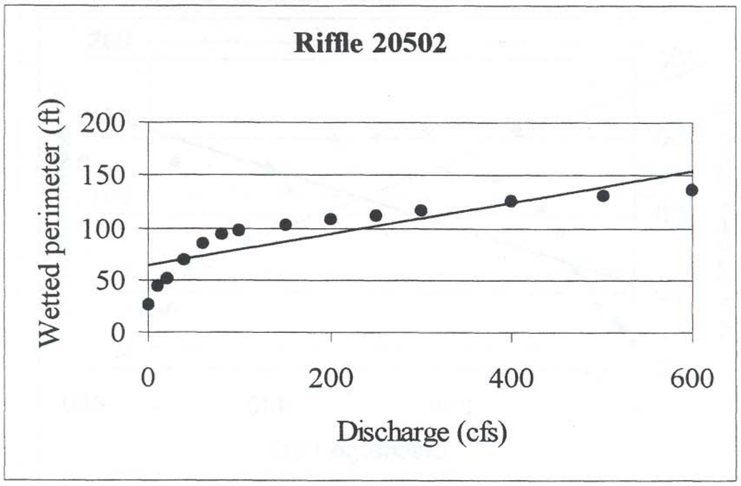


Figure A-10. Cross section 20501.



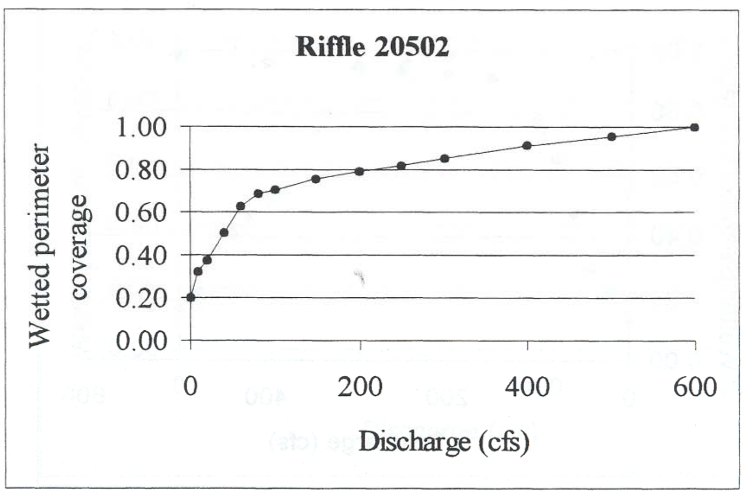
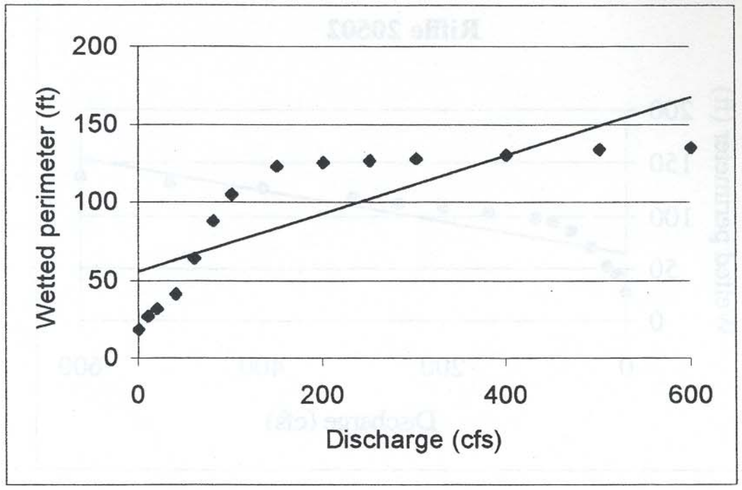


Figure A-11. Cross section 20502.



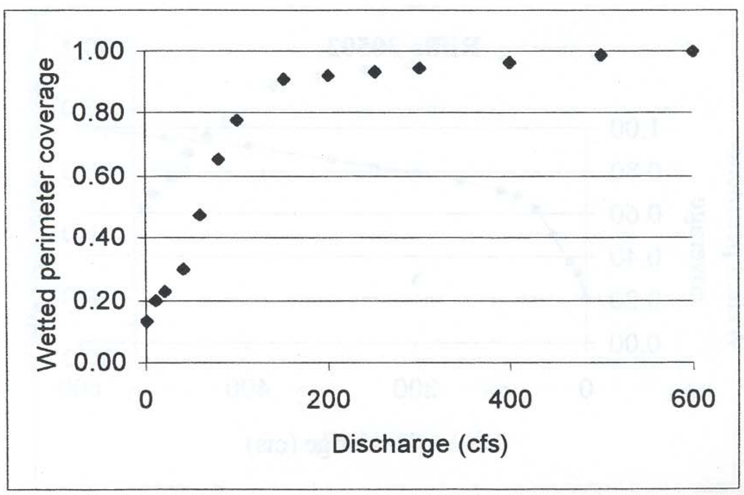
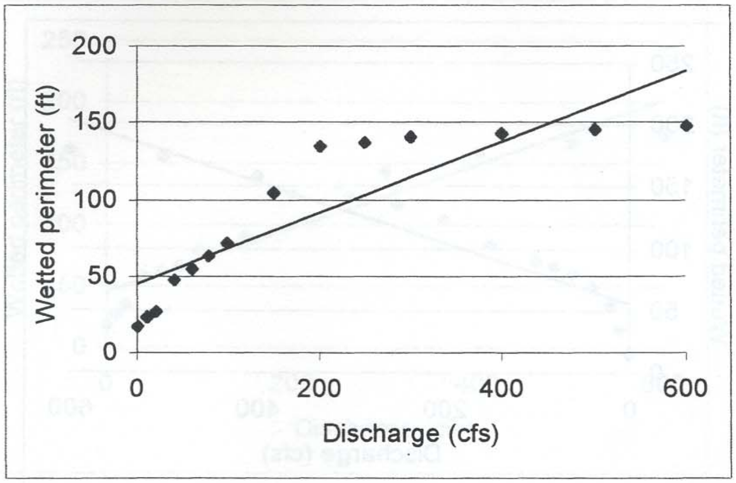


Figure A-12. Cross section 20701.



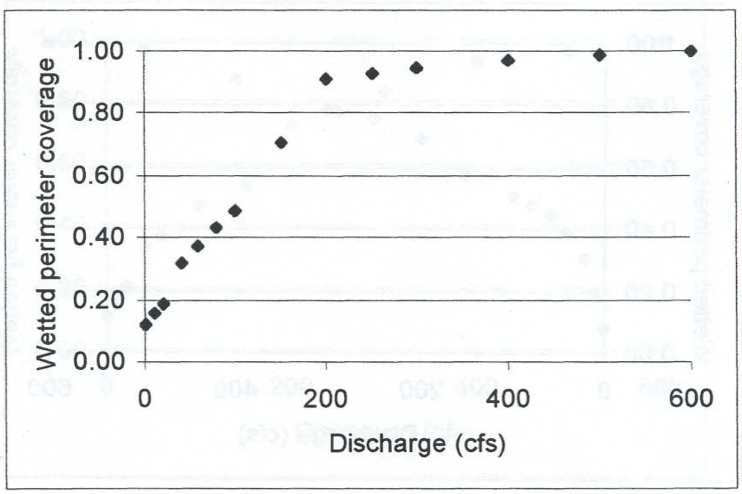
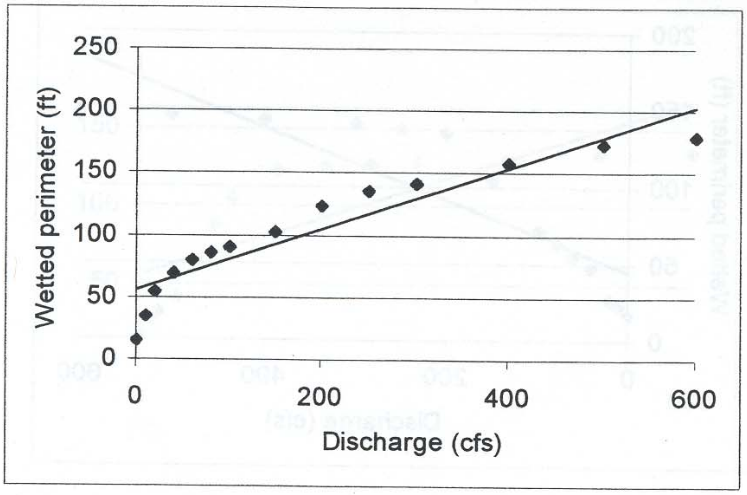


Figure A-13. Cross section 20802.



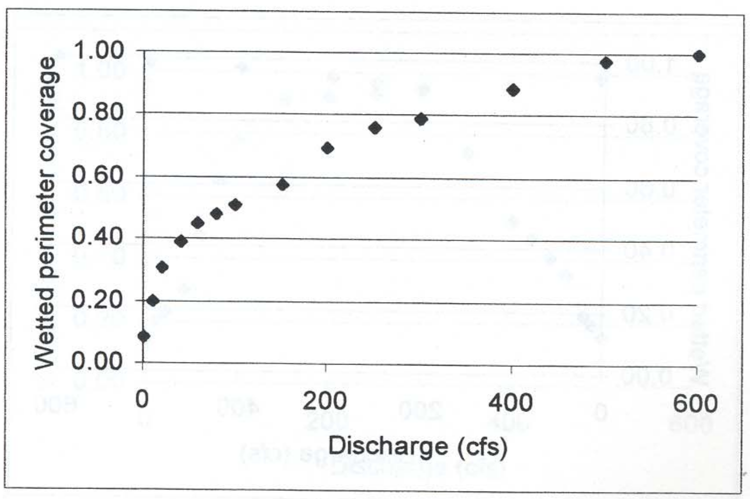
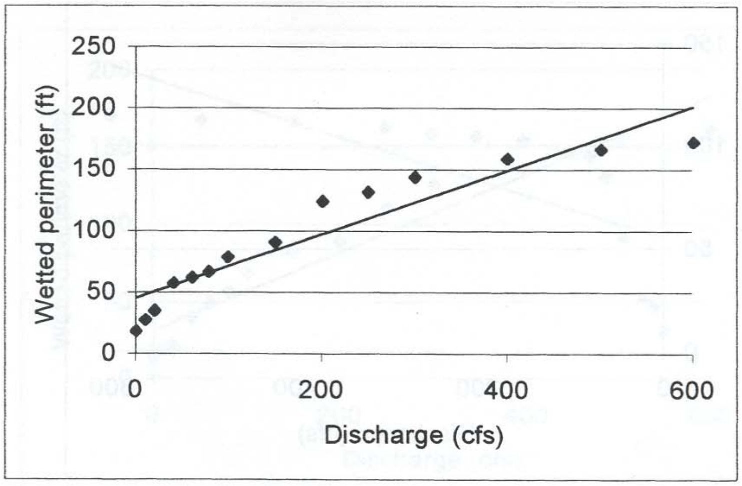


Figure A-14. Cross section 20902.



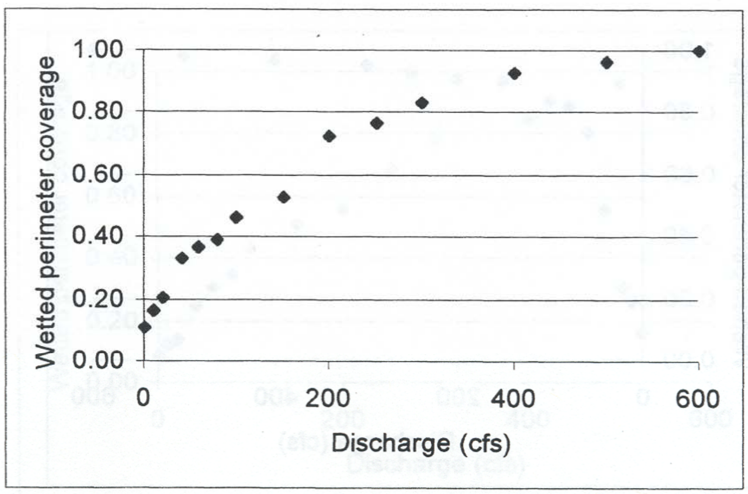
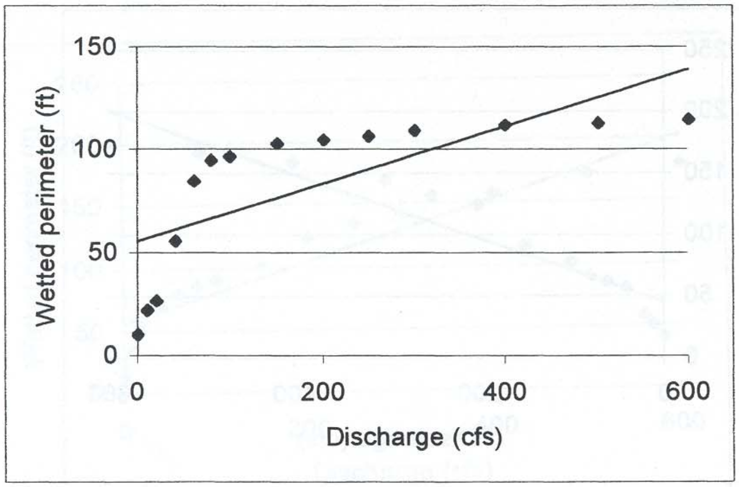


Figure A-15. Cross section 21002.



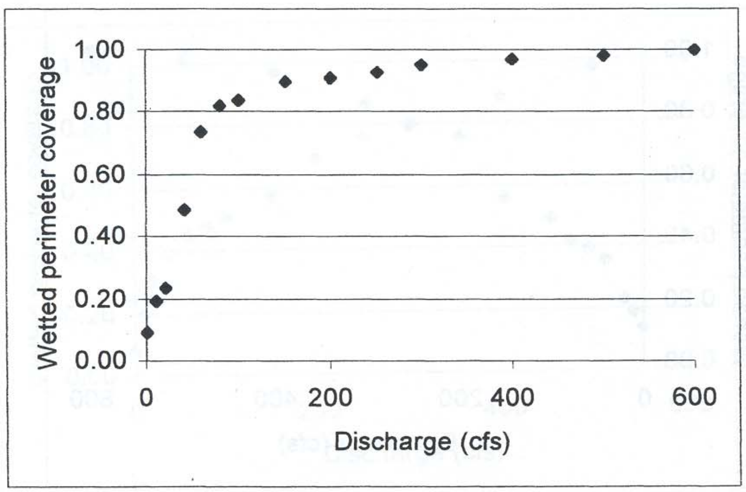
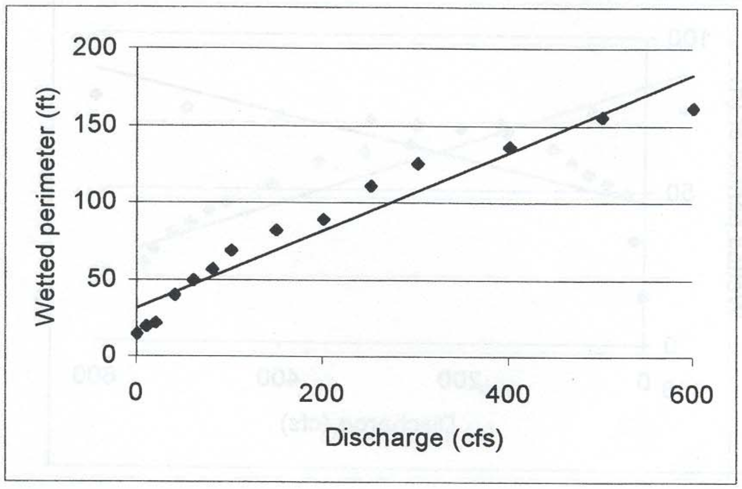


Figure A-16. Cross section 21101.



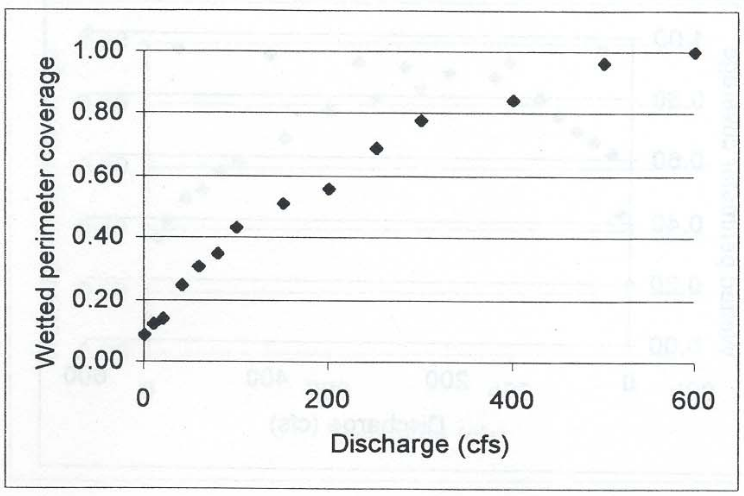
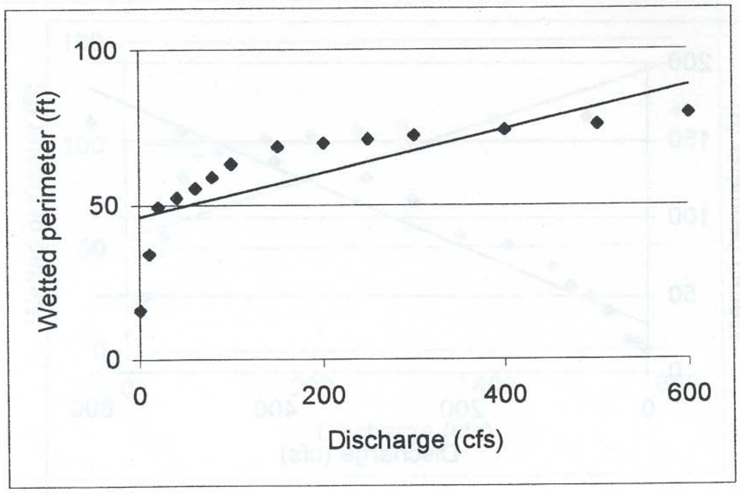


Figure A-17. Cross section 21102.



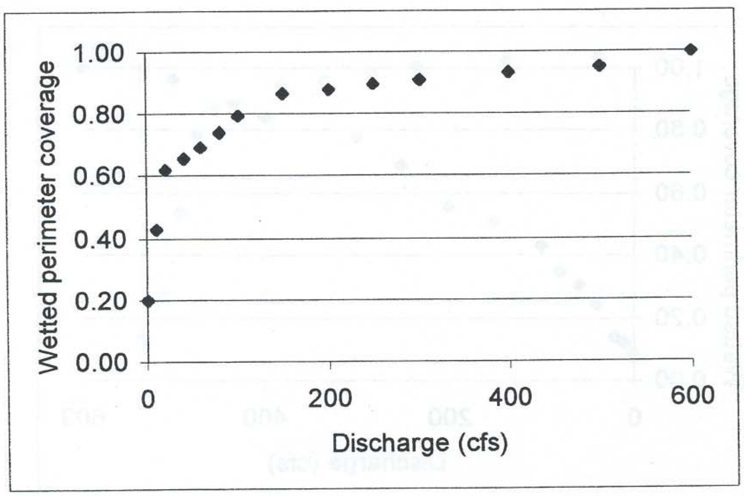
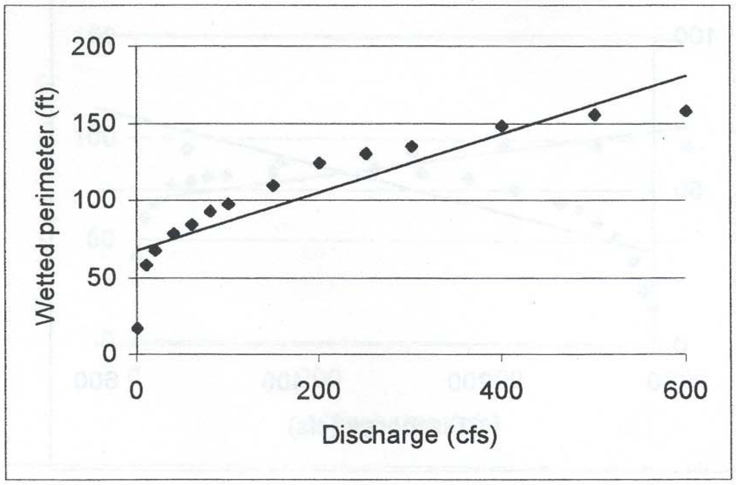


Figure A-18. Cross section 21201.



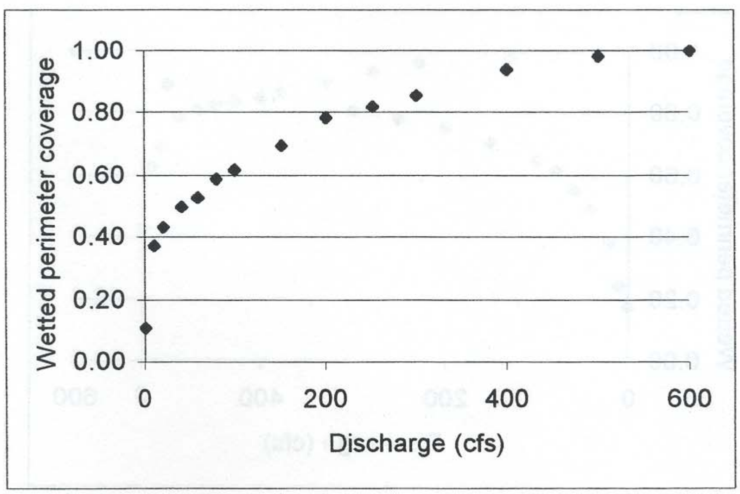
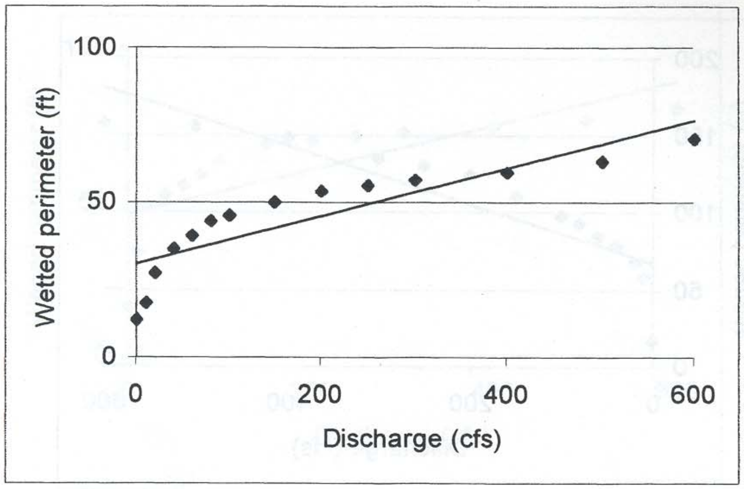


Figure A-19. Cross section 21202.



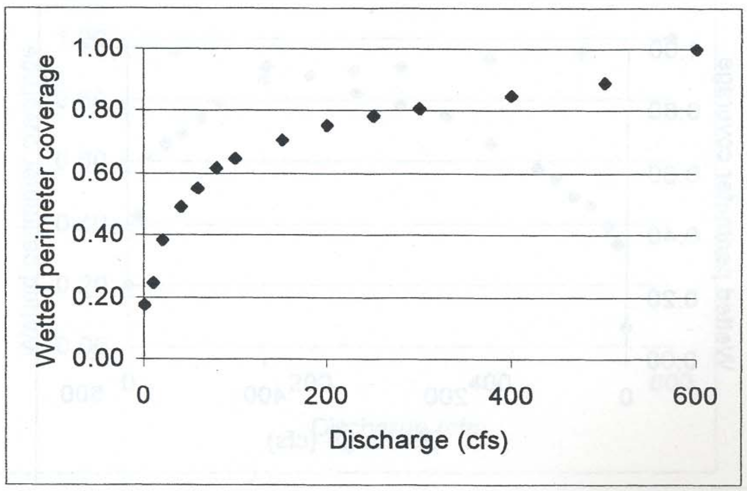
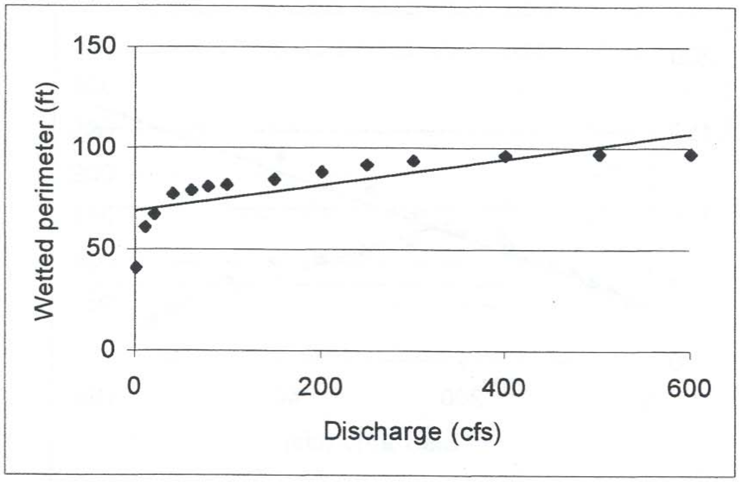


Figure A-20. Cross section 21302.



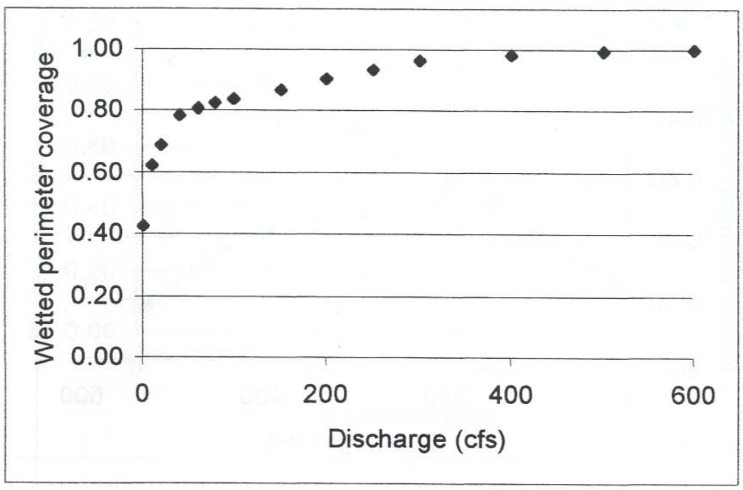
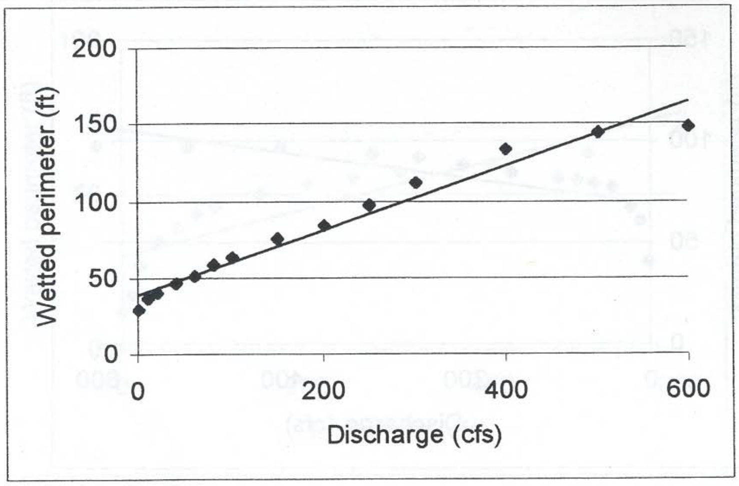


Figure A-21. Cross section 21401.



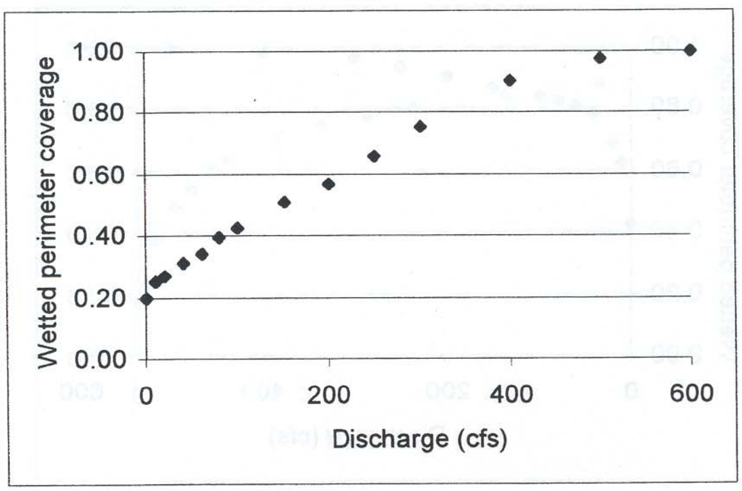


Figure A-22. Cross section 21402.

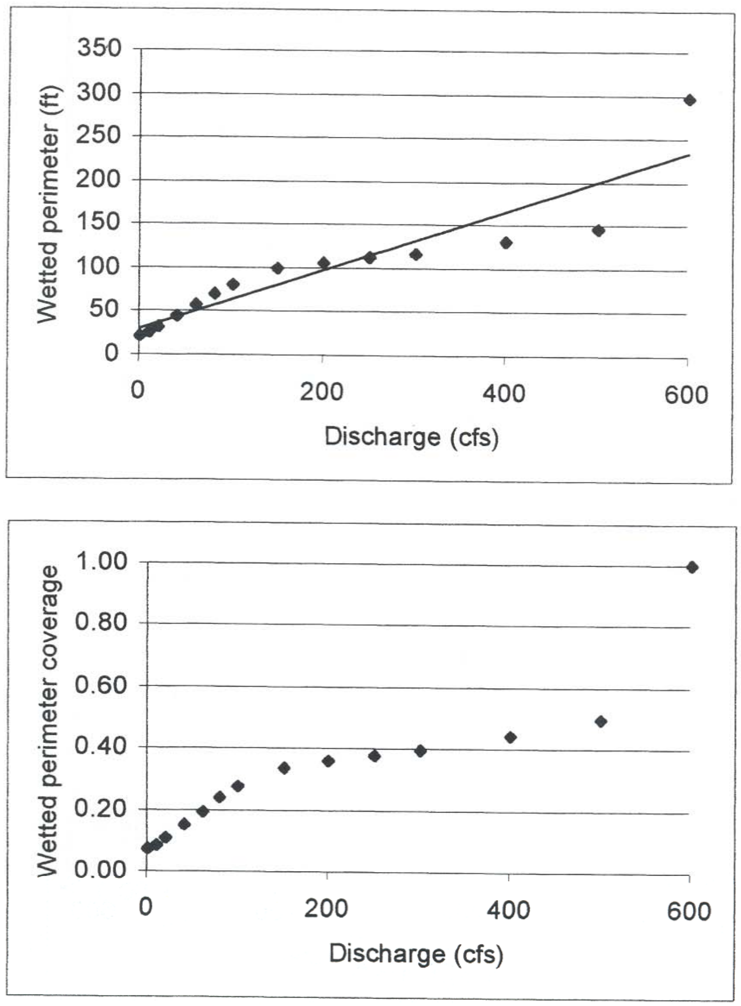
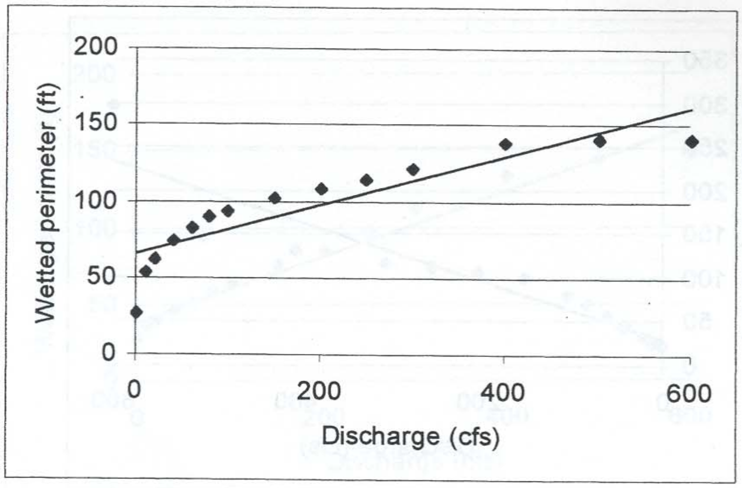


Figure A-23. Cross section 30102.



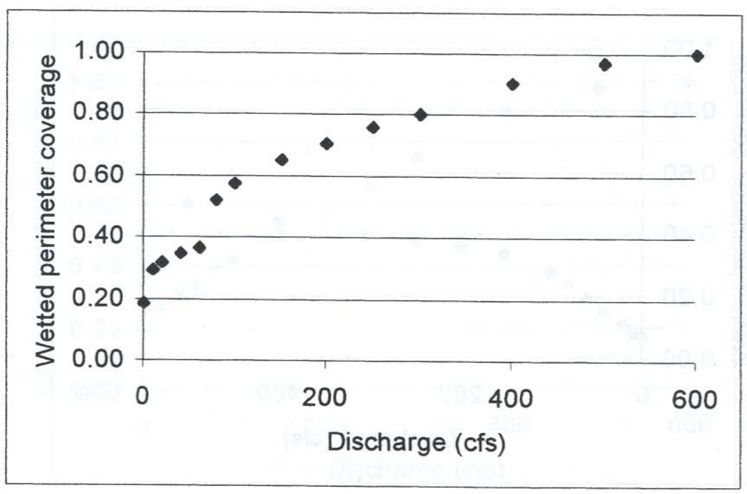


Figure A-24. Cross section 30701.

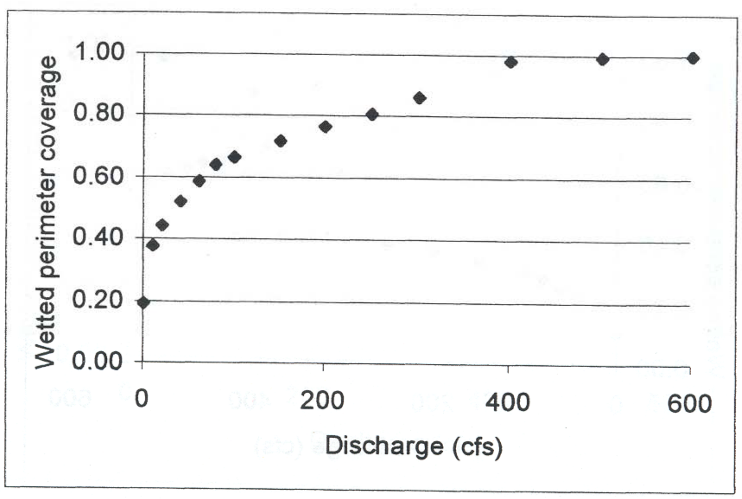
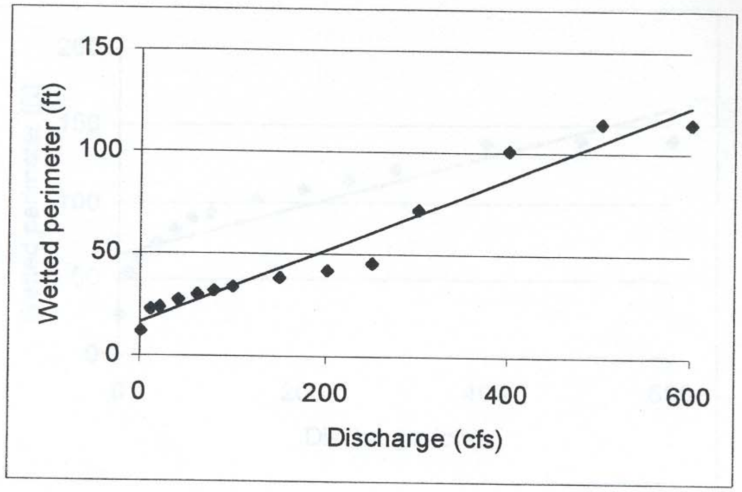


Figure A-25. Cross section 30802.



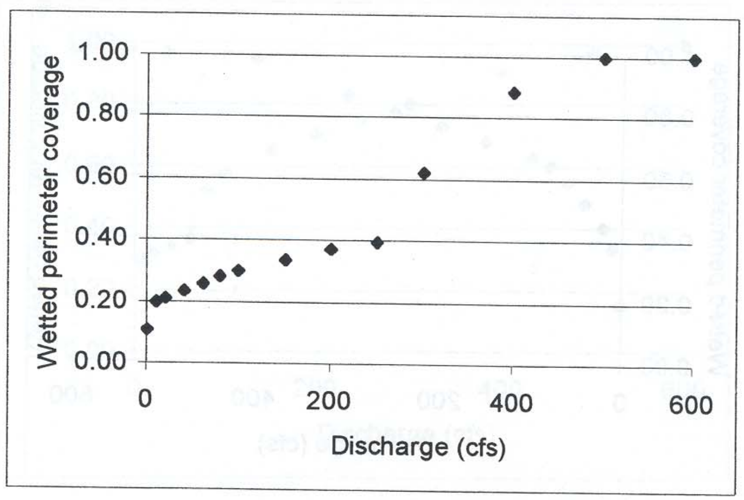


Figure A-26. Cross section 31001.

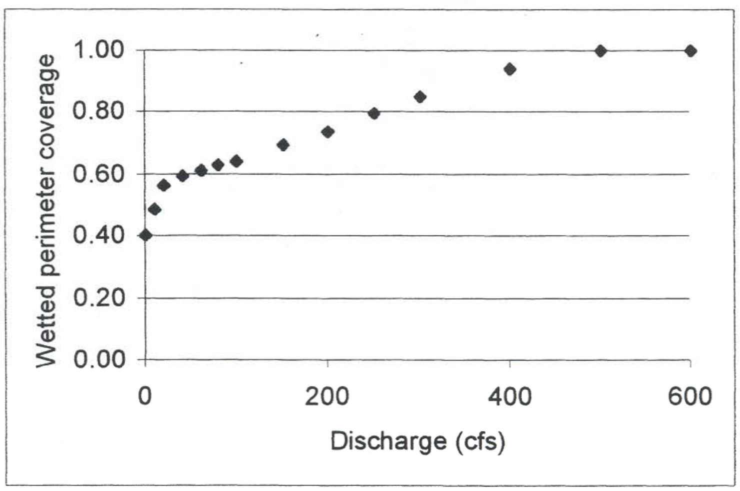
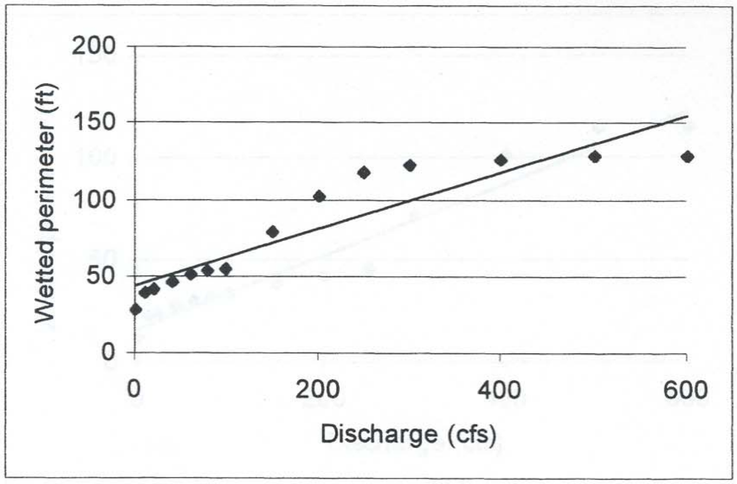


Figure A-27. Cross section 31201.



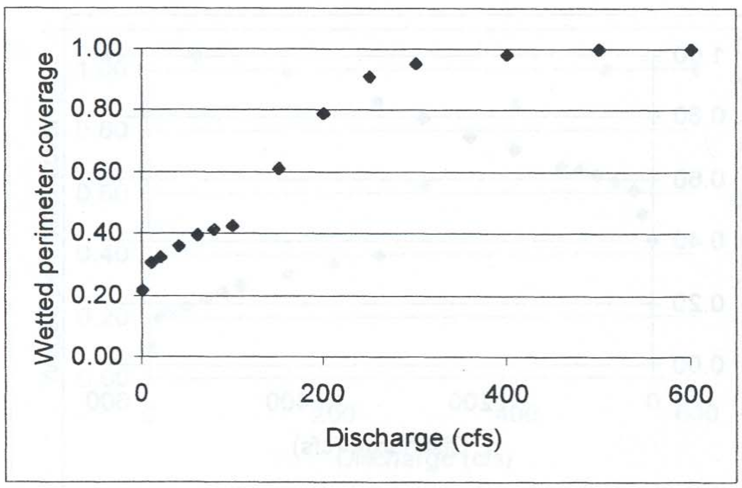


Figure A-28. Cross section 31202.

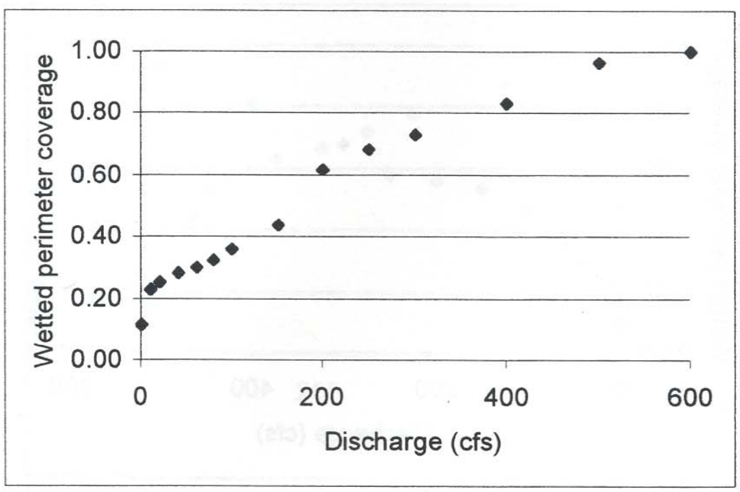
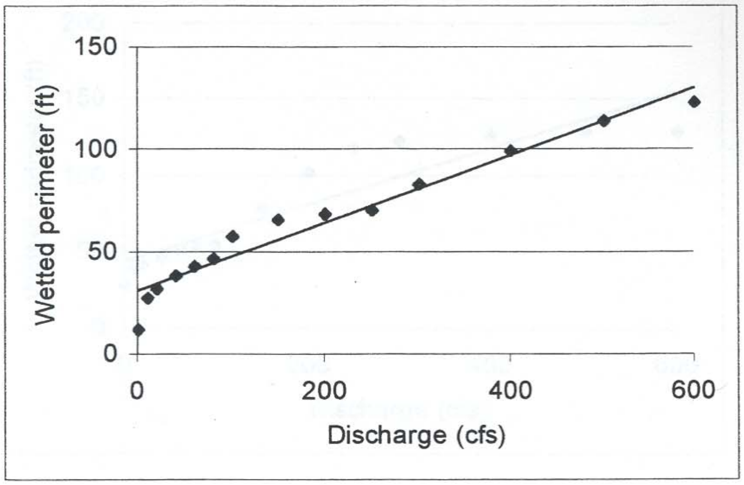


Figure A-29. Cross section 31303.



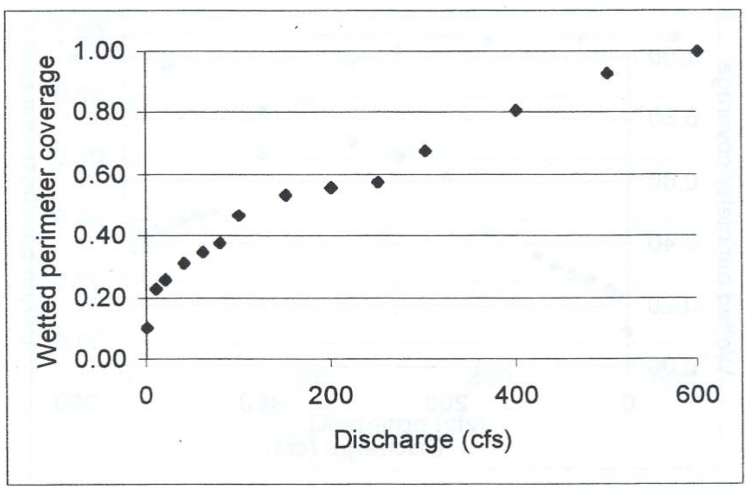


Figure A-30. Cross section 31302.

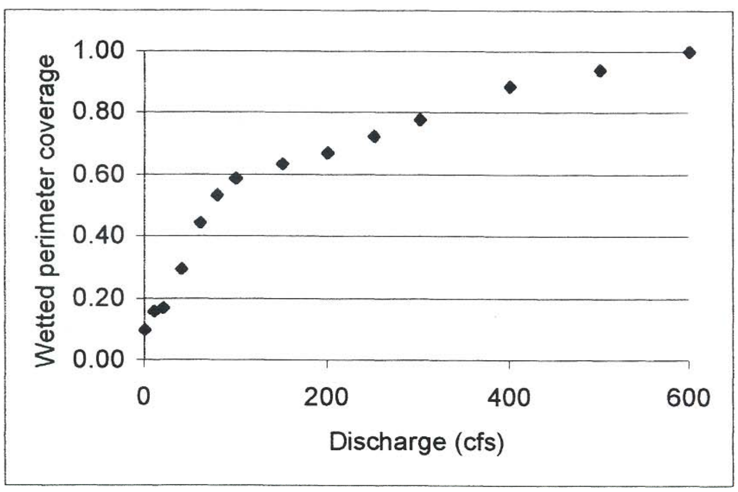


Figure A-31. Cross section 31401.

APPENDIX 5

Table 1. Discharge at break points for hydraulic parameters width, depth, and velocity by strata, and habitat type, White River, 1995 and 1996. **(note print from excel)**

APPENDIX 6

Weighted usable area for each habitat cluster for three habitat use curves (day[a], night[b], suit[c]) at discharge 339 cfs.

Stratum	Cluster	Area (m^2 per100 m^2 surface area) Day	Night	Suit
1.0	1.0	19.3	60.0	57.3
1.0	2.0	4.6	46.9	42.4
1.0	3.0	0.2	47.1	47.7
1.0	4.0	0.8	43.9	44.7
1.0	5.0	0.1	48.3	44.5
1.0	6.0	0.6	34.7	39.3
	ave	4.3	46.8	46.0
	SD	7.5	8.1	6.2
2.0	1.0	0.6	75.3	70.6
2.0	2.0	0.0	68.8	63.0
2.0	3.0	0.1	23.8	33.3
2.0	4.0	0.1	66.5	58.3
2.0	5.0	0.0	23.9	53.6
2.0	6.0	0.1	67.0	62.4
2.0	7.0	0.4	42.7	53.0
2.0	8.0	1.7	67.8	65.6
2.0	9.0	0.0	71.9	67.1
2.0	10.0	0.3	46.0	59.4
2.0	11.0	0.0	59.0	54.9
2.0	12.0	0.5	48.2	47.3
2.0	13.0	2.9	33.4	37.9
2.0	14.0	0.0	40.8	39.2
	ave	0.5	52.5	54.7
	SD	0.8	17.9	11.5
3.0	1.0	2.2	83.0	86.3
3.0	2.0	35.8	127.2	103.3
3.0	3.0	21.7	87.3	75.2
3.0	4.0	11.0	93.8	82.0
3.0	5.0	2.5	84.5	73.4
3.0	6.0	0.1	39.8	38.3
3.0	7.0	28.7	65.2	61.0
3.0	8.0	0.2	53.1	56.8
3.0	9.0	0.1	74.4	65.1
3.0	10.0	4.0	36.2	45.0

3.0	11.0	5.5	73.3	75.2
3.0	12.0	7.4	54.6	56.9
3.0	13.0	0.0	29.1	38.2
3.0	14.0	0.0	29.3	41.8
3.0	15.0	5.4	63.4	63.5
3.0	16.0	0.0	59.1	60.3
3.0	17.0	0.0	59.0	61.2
	ave	7.3	65.4	63.8
	SD	11.0	25.5	17.7
4.0	1.0	1.0	72.6	68.8
4.0	2.0	1.7	72.4	68.8
4.0	3.0	1.0	66.7	60.5
4.0	4.0	1.0	66.7	26.5
4.0	5.0	0.2	39.6	50.6
4.0	6.0	0.1	33.3	40.3
	ave	0.8	58.6	52.6
	SD	0.6	17.4	16.9

Cover Photo: White River, Fish and Wildlife Service

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