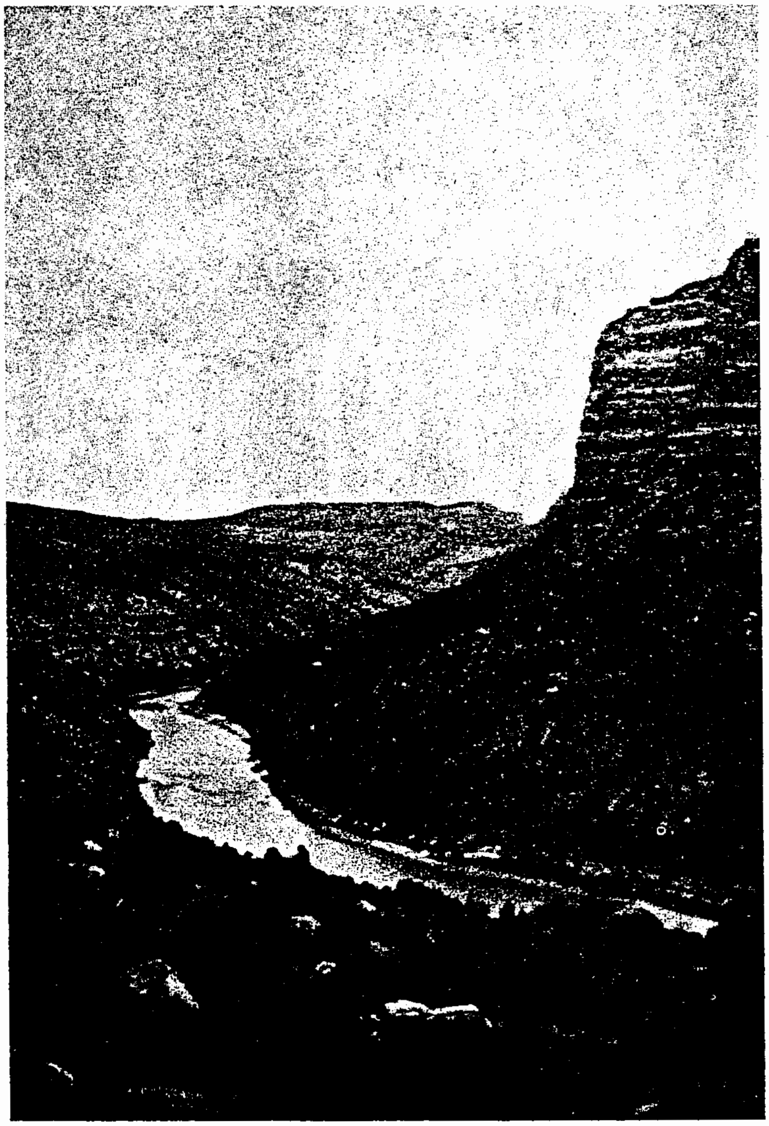
Determination of habitat availability, habitat use, and flow needs of endangered fishes in the Yampa River between August and October



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FINAL REPORT

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Edited by:

Timothy Modde
US Fish and Wildlife Service
Colorado River Fish Project
266 W. 100 North
Vernal, UT 84078

William J. Miller
Miller Ecological Consultants, Inc.
1401 Riverside Avenue, Suite 3
Fort Collins, CO 80524

and

Richard Anderson
Colorado Division of Wildlife
711 Independent Ave.
Grand Junction, CO 81506

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AUTHORS

CHAPTER 1: BACKGROUND AND APPROACH	Timothy Modde, U.S. Fish and Wildlife Service; Richard Anderson, Colorado Division of Wildlife
Chapter 2: HISTORICAL HYDROLOGY AND BIOLOGICAL COMPONENTS OF THE STUDY AREA	Richard Anderson, Colorado Division of Wildlife; William Miller, Miller Ecological Consultants; Timothy Modde, U.S. Fish and Wildlife Service
Chapter 3: HABITAT AVAILABILITY AND HYDRAULIC SIMULATION	Richard Anderson, Colorado Division of Wildlife; David Irving, U.S. Fish and Wildlife Service
Chapter 4: HABITAT USE	William Miller, Miller Ecological Consultants; Timothy Modde, U.S. Fish and Wildlife Service
Chapter 5: INTEGRATED FLOW RECOMMENDATION	Timothy Modde, U.S. Fish and Wildlife Service; Richard Anderson, Colorado Division of Wildlife

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Flow, habitat availability, endangered fishes, Colorado pikeminnow, humpback chub, Yampa River, baseflow

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EXECUTIVE SUMMARY

Purpose and Approach

The goal of this study is to define the baseflow needs of endangered fish populations in the Yampa River. The approach taken was to simulate habitat availability associated with several low flow scenarios and relate changes in habitat availability to habitat use by endangered fishes. Specific objectives identified to accomplish this goal include:

1) Determine the composition, dimensions and characteristics of the riverine habitat at randomly selected sites in the Yampa River during the baseflow period (August – October) 1996 and 1997.
2) Determine the relationship between channel morphology characteristics and flow in the Yampa River, and relate them to passage criteria for endangered fishes.
3) Monitor movements of Colorado pikeminnow, humpback chub, channel catfish, and northern pike in the Yampa River during low flows to determine the range of movement and habitats occupied during the baseflow period.
4) Determine the relationship of riffle characteristics at various flows to passage requirements of endangered fishes
5) Using the data collected above and from previous studies in the Yampa River, determine whether a low flow management plan for the Yampa River Basin is necessary.

Our approach to defining flow needs was to identify the relationship of habitat availability to discharge and relate availability to habitat use by endangered fishes. Initially the study area of the Yampa River was stratified into the lower gradient reach above Yampa Canyon and the higher gradient reach in Yampa Canyon. River channel variables were used to identify similarities and differences between reaches. Three approaches were used to identify flows that will maintain habitat for endangered fishes: 1) identifying of the greatest rate of change in stream morphology as flows decline, i.e., curve break analysis, 2) estimating of available habitat based on suitability curves, and 3) defining barriers to fish passage. The first approach is a general, holistic approach that defined the flow at which the greatest rate of decline in major features of the channel, as well as potential for instream productivity (wetted perimeter) using hydraulic simulation (RHABSIM). The second approach was based on the Instream Flow Incremental Methodology (IFIM) RHABSIM that integrated suitability curves of depth, velocity and substrate from fish capture or telemetry observations with hydraulic simulation to generate a set of weighted useable area estimates for simulated flows. The lowest flow required for fish passage over riffles was determined by estimating riffle depth at various flows using RHABSIM. The rate of habitat loss or habitat isolation due to flow reductions (flow/habitat relationship) can be accurately predicted using hydraulic simulation models (Bovee 1982). However, due to concerns related to estimation of suitability curves (i.e., few observations, life stage dependency, concerns regarding whether observations truly reflect suitable habitat [Tyus 1992], and other criticisms of the PHABSIM approach [Stanford 1994], etc.), the primary basis for developing low flow needs were changes in river channel characteristics (curve break analysis). In our approach, the use of weighted useable areas estimates for RHABSIM was used only as a comparison to the curve break analysis approach.

The curve break analysis is a threshold approach using hydraulic simulation that was used to estimate channel characteristics at various baseflow scenarios. The application of this approach assumes that the Yampa River channel is in equilibrium. Our approach used telemetry data to identify which mesohabitat types (runs, riffles, or pools) were important to Colorado pikeminnow *Ptychocheilus lucius* and humpback chub *Gila cypha*. In addition, riffles were emphasized in the analysis because of their importance to invertebrate production (Brown and Brussock 1991) as well as habitat use (as discussed in Chapter 4). Guidance from the RIP expert panel (Drs. Stephen Ross, University of Southern Mississippi; Robert White, Montana Cooperative Fish and Wildlife Research Unit, and William Trush, McBain and Trush, Inc. and Humboldt State University) during two meetings in March 1997 and January 1998 emphasized the importance of riffles in the analysis because they are the most sensitive mesohabitat to reductions in discharge. The curve break analysis was used to define the flow below which the greatest loss in habitat availability occurred for each mesohabitat type (i.e. maximum degradation in stream profile of the mesohabitat type). The rationale behind the curve break analysis is: 1) native fishes, including listed species, in the Yampa River are adapted to local channel characteristics as they have existed historically, and 2) that baseflows below the curve break flow represent the greatest loss of habitat and is, therefore, detrimental to recovery of the fishes. However, because variability in low flows as well as high flows is recognized as essential in maintaining native fish communities (Poff et al. 1997), we recognize that endangered fishes have maintained persistent populations in the Yampa River despite periods of very low flow. Therefore, the recommendation of this report is to maintain flows above levels that were identified by habitat availability simulations integrated with an understanding of variability within the context of the historical flow record.

Habitat Availability

Testing the physical properties of the six study strata showed differences: however, only wetted width indicated a geographical pattern which segregated the three Yampa Canyon strata from the three upper strata. Correlation analysis suggested that depth, wetted width, and velocity explained the greatest variability in stream morphology among all strata. A linear regression was used to estimate the point at which decreases in flow caused the greatest habitat change in each channel within each mesohabitat (i.e., run, riffle, or pool). The point of the regression curve where the greatest rate of decrease in stream channel variables occurred with flow was identified as the curve break. Each habitat variable (wetted width, depth, velocity, etc.) was plotted against low flow scenarios (1 to 300 cfs) identifying where the largest residual occurred in the graph (i.e., the greatest difference between regression line values and the corresponding actual data points). The curve break, indicated the specific flow (cfs) that a given habitat variable (e.g. width, depth, etc.) declined at the greatest rate per mesohabitat type. Analysis of variance indicated that no differences in the curve break flows for riffles was detected among strata, therefore, the entire study area could be considered a single reach for purposes of the flow recommendation. Because riffles are the most sensitive mesohabitat type to changes in flow, their importance to foraging behavior of pikeminnow, and their role in invertebrate production, they were emphasized relative to development of flow recommendations.

Flows identified by curve breaks were within a fairly narrow range both within and among mesohabitat types. The mean curve break flow for riffles, 93 cfs, was somewhat higher than the flow for runs and pools. The curve break flow for suspected nocturnal foraging pikeminnow was 88 cfs, which suggests that the 93 cfs will also maintain adequate foraging habitat for endangered Colorado pikeminnow in the upper strata. Curve breaks generated from estimates of weighted useable area were similar to, but, somewhat higher than the mean generated from channel variables.

Habitat Use

Radio telemetry observations showed that Colorado pikeminnow in the Yampa River above Yampa Canyon exhibited different behaviors during day and night. After sunset, pikeminnow moved actively within a discrete habitat (e.g. pool, run or riffle) suspected to be foraging-related movements within or to another discrete habitat. In 1996, a low baseflow year, radio-tagged fish remained within the habitat unit (pool or run) where they were observed during the daylight hours. After sunset, fish either actively moved over the entire habitat or moved to the upstream or downstream interface with the adjoining habitat. In 1997, an extremely high baseflow year, fish showed similar diel activity behavior as in 1996. Fish were most active after sunset and exhibited what appeared to be a foraging behavior. Some of the fish remained within a discrete habitat while other fish were observed to move to another habitat during this apparent foraging behavior. Two of the fish observed in 1997 did move through several discrete mesohabitats during the 24-hour observations. On these occasions the fish returned to its starting location within the 24-hour period.

It is not known if fish observed in 1996 moved to an adjoining habitat due to low flows or remained in the discrete mesohabitat in response to prey availability. Fish were observed moving between mesohabitats during the lowest flows in 1996 (approximately 70 cfs), but fish were not observed moving between discrete mesohabitats during the 24-hour observations. The movement between adjoining mesohabitats in 1997 may be in response to several factors. The higher baseflows (> 320 cfs), could have more readily allowed movement between mesohabitats. The movement also could have been in response to location of prey species.

In Yampa Canyon two humpback chub (river mile (RM) 18.1 and 35.3) were monitored over a twenty-four hour period between 6-8 August 1997. No other humpback chub were located on the ground during the 1997 field season. Both fish remained in the general vicinity that they were located throughout the 24 four period showing only short local movements. One fish was found below Teepee Rapid and remained in shallow water, nearshore habitat throughout the 24 hours monitored. Average water column depth used was 1.3 ft, average water column velocity was 0.52 ft/s and the dominant substrate was boulder. Another fish was located at river mile 18.1, above Mathers Hole, and also remained in nearshore habitat and did not move outside of the eddy habitat it occupied. The second fish was found in deeper water, exceeding 5.9 ft, but used nearly the same average water column velocity (0.56 ft/s) and was also found associated with boulder or bedrock substrate. Despite using different depths, both humpback chub used habitats adjacent to the shoreline. In the absence of a large telemetry database on habitat use, a summary of habitat use data by the humpback chub in Yampa Canyon was analyzed. A comparison of 153 humpback chub collected from Yampa Canyon between 1980 and 1997 indicated that most fish were collected in eddy or eddy-related habitats. The same database indicated that most fish collected were associated with shoreline structure rather than main channel or side channel habitats.

Of the five Colorado pikeminnow implanted with radio transmitters in Yampa Canyon in 1996, two left Yampa Canyon during the second week of August, one month following implantation. One fish either died or lost its transmitter and two fish remained in Yampa Canyon through the low flow period until at least 29 October 96. Of the two Colorado pikeminnow that remained in Yampa Canyon, one remained in upper reach of the canyon and the other in the mid- to lower- reach of the canyon. Both fish appeared to remain in a general area of the river following August 1996. One fish ranged from RM 12.1 to 20.1, and the other from 39.1 to 43.3 between mid August and late September. On 29 October those same two fish were found at RM 21.6 and 29.7. On 22 April 1997, both pikeminnow were still in Yampa Canyon suggesting that both fish may have spent the winter low flow period in the canyon. Both fish were located in the vicinity of the spawning area during the first aerial contact on 24 July 1997, and both fish moved upstream afterward. On 13 August 1997, both fish were still in Yampa Canyon.

Passage

Results from riffle cross sections were emphasized for concerns related to passage because this mesohabitat type is most likely to restrict movement during low flows. Selection of an average depth criterion is important because a small change in average depth can result in large differences in concomitant flows. The average depth for all riffles at a flow of 93 cfs was 0.52 ft. The passage criterion used for adult pikeminnow was a maximum depth of at least 1.0 ft in at least one point on a cross section (Burdick 1996). The mean flow required for riffles to produce a maximum depth of 1.0 ft was 153 cfs.

The potential for low flow barriers to postspawning migrant Colorado pikeminnow in the Yampa River was evaluated in 1997 by monitoring movement through two potential barriers, Cross Mountain Canyon (RM 58.8) and the Maybell Diversion (RM 89.4). Six-month transmitters were surgically implanted in five Colorado pikeminnow in the second week of May 1997 in the Yampa River between Government Bridge (RM 98.8 and Morgan Gulch (RM 103.7). Telemetry data was unable to identify passage barriers in 1997 because of extremely high base flows. Travel times indicated that individual fish only occupy the spawning area for a portion of the entire spawning period. Bestgen et al. (1997) estimated the duration of Colorado pikeminnow spawning in the Yampa River between 1990 and 1996 ranged from 24 and 38 days (mean = 29.5). Similarly, Tyus (1990) estimated pikeminnow spawning between 1981 and 1988 ranged from 31 and 39 days (mean = 35.6). The average time pikeminnow spent near the spawning area in 1997, a high baseflow year, was only 15.5 days. Although is likely that individual fish do not remain in the spawning area for the duration of the spawning period, what factors cause fish to leave the spawning area is not known. Although evidence suggested low flows in early to mid-July may be detrimental to spawning, it is unlikely the normal range of low baseflows are a factor in preventing passage of postspawning migrant adults.

Recommendations

The magnitude of spring runoff flows in the Yampa River are relatively natural, with average flows reduced only about 5% to 6%. In contrast, baseflows have been reduced from historical flows by an average of 30% and up to 80% in dry years. As flows recede below a certain threshold, characteristics such as depth, wetted width, velocity, cross sectional area, etc., rapidly decline, creating loss of habitat stability, quality and quantity. The flow management recommendations in this report were determined by identifying curves breaks in geomorphic and hydraulic variables that form habitat for endangered fishes. Curve break flows represented the condition of maximum change in selected variables with reduced flow, and thus the greatest impact on the environment of endangered fishes. The lack of significant differences in curve break flows among variables and strata suggested a consistent response in the river channel as a function of flow. Estimates of the maximum rate change among river channel variables with low flows were comparable with, and supported by, estimates of weighted useable area for both Colorado pikeminnow and humpback chub, and risk estimates of potential barriers to migrational and local movement of fishes.

Curve break analysis of channel variables suggested that baseflow management for endangered fishes in the Yampa River below Craig, Colorado should target 93 cfs. This baseflow management recommendation is slightly lower than curve breaks based on simulated (RHABSIM) habitat availability for endangered fishes and the flow defined as needed to prevent barriers to local movement. Instream migrational barriers do not appear to be problematic for returning postspawned Colorado pikeminnow. However, it is evident from the historic record that flows less than 93 cfs have been recorded at the Maybell gage. In 31 of 84 years of record less than 93 cfs have been recorded at the Maybell gage. During the same 84 years of record, flows of less than 93 cfs for a period in excess of 14 days or more have occurred in 19 years. Because flows have dropped below 93 cfs during the period of record at the Maybell gage, and endangered fishes are extant in the Yampa River, it appears that 93 cfs in not a threshold flow and will not reduce endangered fish populations if violated within the realm of historical frequency. Therefore we conclude that flows below 93 cfs is near the threshold flow that may be limiting to productivity of aquatic invertebrates and other aquatic organisms dependent on viability of riffle habitats. For long term recovery and stability of endangered fish populations, it is reasonable to maintain those organisms in the system that are dependent upon riffle production.

The role of variation has been reported to have particular significance to the ecology of lotic fishes. Several studies have shown that native fishes tolerate higher flow events than nonnative fishes in arid streams (Meffe and Minckley 1987, Minckley and Meffe 1987, Deacon 1988, Hoffnagle et al. In review, Muth and Nesler 1993) in the Southwest. Even if the current flow scenario would allow for the persistence of endangered fishes in the Yampa River, we know that additional depletions will occur over time. Two studies of the potential increase of human demands within the Yampa River basin (Yampa River Alternatives Feasibility Study - Hydrosphere 1993 and, Yampa Valley Water Demand Study - BBC Research and Consulting 1998) have suggested that water depletions will grow by approximately 49,000 acre feet annually to satisfy human demand over the next 50 years. Instances and duration of lower baseflows are likely to increase over present conditions. The number of years with high or optimal baseflow conditions (for endangered fishes) will most likely be fewer, while the number of years with low baseflows will increase in frequency. Given this scenario, we recommend the development of a water management plan for the Yampa River. We recommend this water management plan use 93 cfs as a target for the minimum instream flow. However, we also recommend that the flow management plan not be restricted to achieving 93 cfs in 100% of the years, but include examining the frequency, magnitude, and duration of flow events under 93 cfs observed during the period of record (1916-1998). This report was directed to determine the baseflow needs of fishes, and does not prioritize the needs of high spring flows as spawning cues and channel forming forces versus the baseflow needs of fishes during the summer months. Crucial to the next phase of a water management plan will be to evaluate and prioritize the temporal distribution of flow. The flow management plan needs to provide a suite of operational strategies on how a "carve out" and other water rights could be administered to satisfy both the high-flow needs of endangered fishes and the baseflow recommendation provided in this report.

CHAPTER 1: BACKGROUND and APPROACH

Background

The Yampa River is the largest tributary in the Upper Colorado River Basin with a relatively natural hydrograph and approximate historical flow magnitude (Tyus and Karp 1989). Yampa River flows are highly variable annually with spring runoff peaks greater, and summer baseflows lower than the Green River into which it empties (USGS records). Self sustaining populations of endangered Colorado pikeminnow *Ptychocheilus lucius* (Tyus 1990) and one of five known endangered humpback chub *Gila cypha* populations (Karp and Tyus 1990) reside in the Yampa River. In addition, this river contains one of only two documented spawning sites of both Colorado pikeminnow and razorback sucker *Xyrauchen texanus* (Tyus and Karp 1990). Because most Colorado pikeminnow spawned in the Yampa River drift downstream to nursery sites in the Uintah Basin, these offspring are important in defining pikeminnow recruitment in the Middle Green, White, and Yampa rivers. Despite, or because of, highly variable environmental conditions, native fishes are more abundant than nonnative fishes in the lower Yampa River (Modde and Smith 1995).

Water management recommendations for endangered fishes in the Yampa River began with interim flow recommendations proposed by the U.S. Fish and Wildlife Service in 1990 (USFWS 1990a). The interim recommendation emphasized the need for a natural hydrograph that preserved spring peak flows, but recommended that baseflows not fall below 50% exceedance flow. The 1990 interim recommendation was modified by Modde and Smith (1995) who reiterated that high spring peaks are needed for channel and habitat maintenance, and fish spawning cues, but recommended variable baseflows ranging between 20% and 80% exceedance flows based on the magnitude of the annual hydrograph. Following the modified interim flow recommendations, the Colorado Water Conservation Board filed for a water right to protect the instream flow habitat of endangered fish in the Yampa River (Case numbers 95CW156 and 95CW155, filed December 28, 1995). Since these water rights will be junior to existing rights, they will only influence future water development. Existing instream flows in the Yampa River appear to be adequate to maintain stable populations of Colorado pikeminnow and humpback chub (Tyus and Karp 1989). However, in some years, for example 1994, stream flows can be very low (approx. 10 cfs, USGS records). The frequency and duration of low flow periods may increase with continued water development until the state of Colorado develops its full allotment in accordance with the Upper Colorado River Compact agreement. Currently, estimated depletion of water from the Yampa River is approximately 110,000 acre-feet and is forecasted to be as much as 159,000 acre-feet by the year 2040

(Hydrosphere 1995). Because future depletions would be evenly distributed throughout the year and there is limited existing capacity to store spring runoff waters, the impacts of depletions would likely be greatest during low-flow periods of the year, exacerbating potential low-flow impacts on fish during the months of August through October.

If the anticipated frequency of low instream flows do not provide adequate protection of endangered fish, it is incumbent upon the Recovery Implementation Program for the Recovery of the Endangered Fishes of the Upper Colorado River Basin (RIP) to provide alternatives that promote recovery of affected listed species. Several options exist to provide adequate low flow protection including purchasing and converting existing senior water rights to instream flow rights, and developing water storage to augment flows during the low flow period. In an effort to address the future water development and recovery options for endangered fishes in the Yampa Valley, the RIP initiated the Yampa River Basin Endangered Fish Recovery and Water Management Plan. The goal of this plan is "to provide water for existing and future human needs, to provide and protect the instream flows and habitat needed to maintain and recover the endangered fishes, [and] to protect other native fish and wildlife resources in the Yampa River Basin."

As a part of the NEPA process in developing the water management plan, this study was initiated to define low flow needs (i.e., August through October) of the endangered fishes in the Yampa River for use by the Yampa River Management team. Whereas the previous interim flow recommendations (USFWS 1990a, Modde and Smith 1995) were based largely on data summaries, this study was designed to collect data necessary to define flows needed by fish and determine whether water management was necessary to achieve those flows. Flow needs in this study were defined as those flows that insure habitat needed for survival of endangered fishes in the Yampa River, as well as those that would insure local and spawning related migratory movement. This study was not designed to define specific water management alternatives. In addition, this study relates only to the baseflow period and makes no recommendation as to the potential trade-offs of storing water during the spring runoff to provide augmentation during the months of August through October.

Approach

The goal of this study is to define the baseflow needs of endangered fish populations in the Yampa River to insure their recovery. The approach taken was to simulate habitat availability associated with several low flow scenarios and relate changes in habitat availability to the use of these habitats by endangered fishes. The specific objectives identified to accomplish this goal include:

1) Determine the composition, dimensions and characteristics of the riverine habitat at randomly selected sites in the Yampa River during the baseflow period (August – October) 1996 and 1997.
2) Determine the relationship between channel morphology characteristics and flow in the Yampa River, and relate them to passage criteria for endangered fishes.
3) Monitor movements of Colorado pikeminnow, humpback chub, channel catfish, and northern pike in the Yampa River during low flows to determine the range of movement and habitats occupied during the baseflow period.
4) Determine the relationship of riffle characteristics at various flows to passage requirements of endangered fishes
5) Using the data collected above and from previous studies in the Yampa River, determine whether a low flow management plan for the Yampa River Basin is necessary.

Our approach to defining flow needs was to identify the relationship of habitat availability as a function of discharge and relate availability to habitat needed by endangered fishes. Initially the study area of the Yampa River was stratified into the lower gradient reach above Yampa Canyon and the higher gradient reach in Yampa Canyon. River channel variables were used to identify similarities and differences between reaches. Three approaches were used to identify flows that will provide habitat for recovery of endangered fishes; 1) identifying the greatest rate of change (i.e., curve break) in the stream morphology as flows decline, 2) estimating available habitat based on suitability curves, and 3) defining barriers to fish passage. The first approach is a general, holistic approach that defined the flow at which the greatest rate of change in major features of the channel, as well as potential for instream productivity (wetted perimeter) by estimating river channel variables at various flows using hydraulic simulation (RHABSIM). The second approach was an based on the Instream Flow Incremental Methodology (IFIM) RHABSIM that integrated suitability curves of depth, velocity and substrate from fish capture or telemetry observations together with hydraulic simulation to generate a set of weighted useable area estimates for simulated flows. Estimates of the flow needs for fish passage over riffles was determined using an element of the RHABSIM. The rate of habitat loss or habitat isolation due to flow reductions (flow/habitat relationship) can be accurately predicted using hydraulic simulation models (Bovee 1982). However, due to several concerns related to estimation of suitability curves (i.e., few observations, life stage dependency, concerns regarding whether observations truly reflect suitable habitat [Tyus 1992], and other criticisms of the PHABSIM approach [Stanford 1994], etc.), the primary means for determining the impacts of low flows was based on estimates of change in river channel characteristics (curve break analysis). In our approach, the use of weighted useable areas estimates for RHABSIM was used only as a comparison to the stream profile approach.

The curve break analysis is a threshold approach using hydraulic simulation that was used to estimate channel characteristics (mesohabitat availability) at various baseflow scenarios. The application of this approach assumes that the Yampa River channel is in equilibrium. Telemetry data was used to identify which mesohabitat types (runs, riffles, or pools) were important to Colorado pikeminnow *Ptychocheilus lucius* and humpback chub *Gila cypha*. In addition, riffles were emphasized in the analysis because of their importance to invertebrate production (Brown and Brussock 1991) as well as habitat use (as discussed in Chapter 4). Guidance from the RIP expert panel (Drs. Stephen Ross, University of Southern Mississippi; Robert White, Montana Cooperative Fish and Wildlife Research Unit, and William Trush, McBain and Trush, Inc. and Humboldt State University) during two meetings in March 1997 and January 1998 emphasized the importance of riffles in the analysis because they are the most sensitive mesohabitat to reductions in discharge. The curve break analysis was used to define the flow below which the greatest loss in habitat availability occurred for each mesohabitat type (i.e. maximum degradation in stream profile of the mesohabitat type). The rationale behind the curve break analysis is: 1) native fishes, including listed species, in the Yampa River are adapted to local channel characteristics as they have existed historically, and 2) that baseflows below the curve break flow represent the greatest loss of habitat and is, therefore, detrimental to recovery of the fishes. However, because variability in low flows as well as high flows is recognized as essential in maintaining native fish communities (Poff et al. 1997), we recognize that endangered fishes have maintained persistent populations in the Yampa River despite periods of very low flow. Therefore, the recommendation of this report is to maintain flows above levels that were identified by habitat availability simulations integrated with an understanding of variability within the context of the historical flow record.

The format for this report is set up by chapter to address the specific objectives of the study. This chapter describes the purpose and approach taken in this study and the next chapter provides a description of the hydrology and physical characteristics of the Yampa River study area. Chapter 3 presents analysis of the physical characteristics of the Yampa River study area and provides simulations of channel features for various flows as well as weighted useable areas estimates for Colorado pikeminnow and humpback chub. Chapter 4 discusses the findings of the radio telemetry efforts, both the aerial surveys and the intensive ground surveys, for Colorado pikeminnow, humpback chub, northern pike and channel catfish, and the telemetry component of the Colorado pikeminnow passage study. The last chapter presents a baseflow management recommendation in context to the historical flow pattern.

CHAPTER 2: HISTORICAL HYDROLOGY AND BIOLOGICAL COMPONENTS OF THE STUDY AREA

Historic Hydrology

The Yampa River Basin drains approximately 7,660 square miles. Most runoff is produced by melting snowpack in higher elevations at the eastern and southern edge of the basin (Hydrosphere 1993). The Yampa River is 180 miles long and varies in elevation from over 10,000 feet above sea level (fasl) at its headwaters to 5,100 fasl at its confluence with the Green River. Natural flows in the Yampa River are seasonally variable and typically reach a peak in late spring and decline by late summer to minimal levels in late fall. Peak to baseflow ratios for annual hydrographs on the Yampa River can exceed 100 to 1. Nearly two thirds of the annual discharge in the Yampa River near Maybell occurs in May and June. Runoff typically occurs between April and July with peak flows usually occurring in mid May to early June. Baseflows typically occur in late August and early September (Figure 2.1). The hydrographs in Figure 2.1 represent the 90%, 80%, 50%, 20% and 10% exceedance flows for 82 years of flow records for the Maybell gage and are an indication of the magnitude and frequency of historical flows.

From 1916 to 1997, mean total annual runoff for the Maybell gage is 1.13 million-acre feet (MAF). The minimum flow for the 82 years of record at the Maybell gage was 3 cfs in 1934, followed by 7.9 cfs in 1994. Half the years had a minimum flow exceeding 128 cfs, and 20% had minimum flows exceeding 235 cfs (Figure 2.2). The year with lowest summer flows was 1934 and the wettest year was 1997 (Figure 2.3). The median flow year, based on total water volume between August 1 and October 30, was 1967. The minimum flow in 1967 was 118 cfs and the number of days flow was below 128, 150 and 200 cfs were 1, 7 and 18 respectively (Figure 2.3). Exceedance flows of 90%, 80%, 70%, 60% and 50% for the baseflow period are shown in Figure 2.4. The annual runoff for 1996 and 1997 was 1.57 MAF and 1.88 MAF, respectively (USGS records CO-96-2 page 358, CO-97-2 page 396). Bankfull flow, defined as the 1.5 year recurrence channel forming flow (Gordon et al 1992), at the Maybell gage is 8,463 cfs. The median, 50% exceedance, or 2-year peak flow recorded on the Maybell gage is 10,000 cfs and the 10-year flood is 14,634 cfs. In both 1996 and 1997 annual runoff volumes were above average with peak flows of 14,700 cfs and 16,400 cfs, respectively.

According to the Colorado River Decision Support System (CRDSS) (information provided by the Colorado Water Conservation Board), during the 17 year period between 1975 and 1991, about 57% of

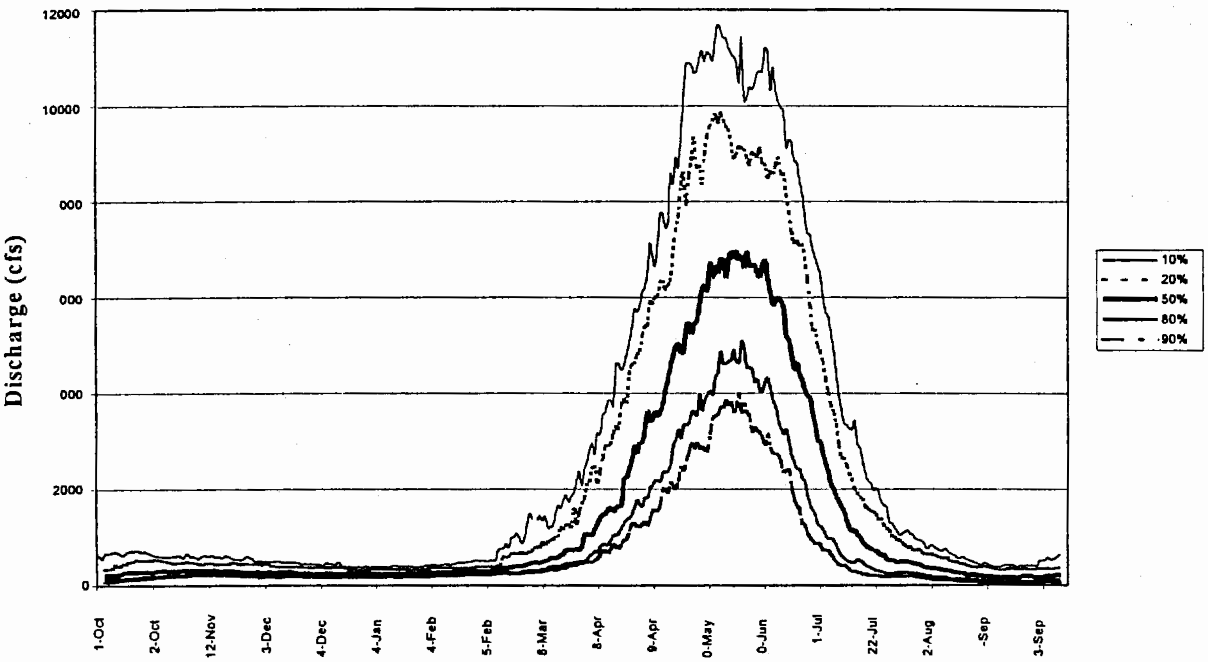


Figure 2.1. Annual hydrograph for the Yampa River, Maybell gage for 10%, 20%, 50%, 80% and 90% exceedance flows.

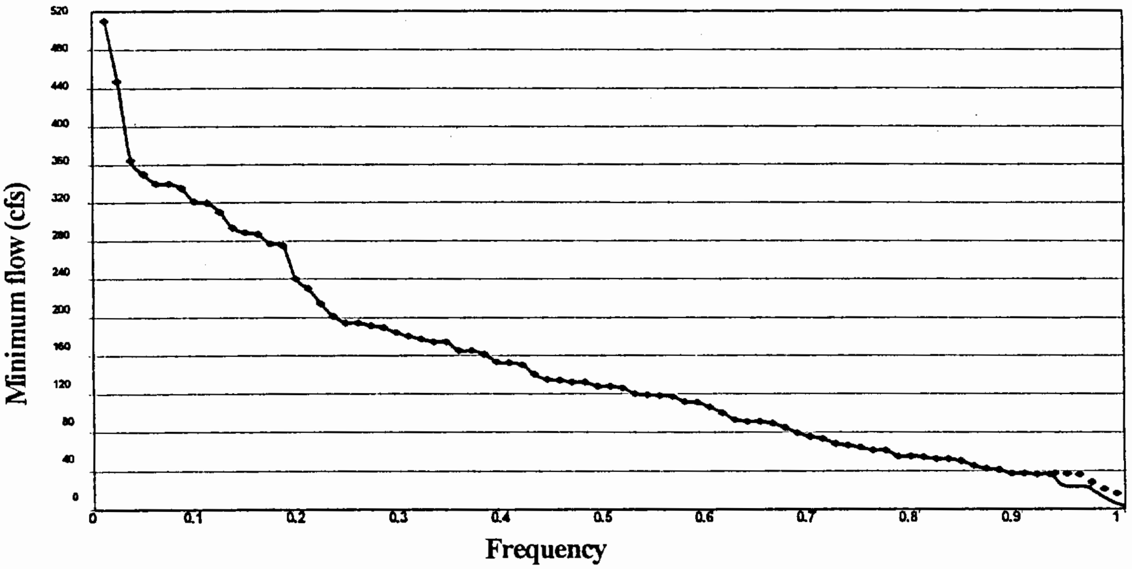


Figure 2.2. Flow frequency curve for average daily flow for 82 years for the Maybell gage.

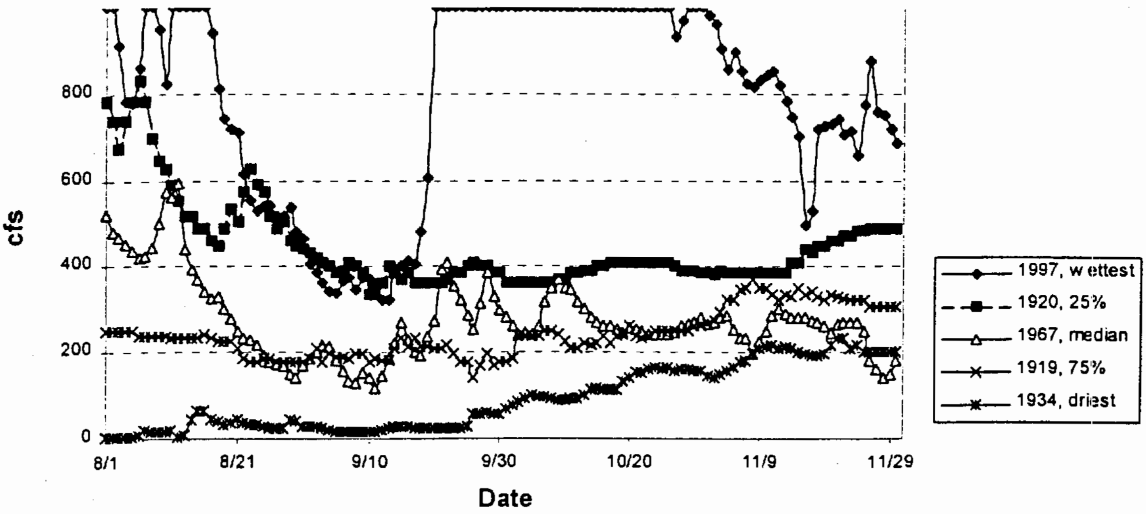


Figure 2.3. Seasonal hydrographs for the driest (1934), 75% exceedance (1919), median (1967), 25% exceedance (1920), and wettest (1997) years recorded on the Yampa River, Maybell gage.

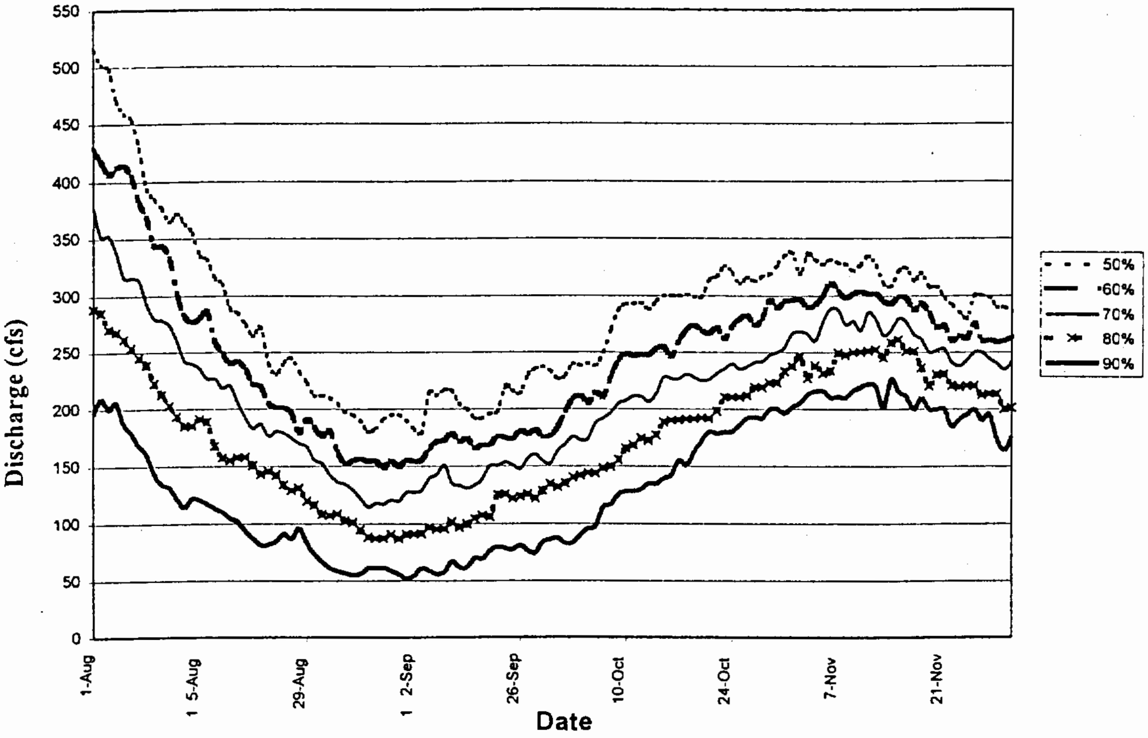


Figure 2.4. Fall hydrograph for the Yampa River, Maybell gage showing percentile flows.

total annual depletions occur in the months of April, May and June. Natural flow was reduced by an average of only 6% for those three months. The fall and winter months of October through March accounted for 8% of the annual water diversions and natural flow was reduced by about 6%. Depletions had the greatest impact during August and September, when natural flows for the 17-year period were reduced by 28% and 33%, respectively. The CRDSS modeled data showed that in 6 of the 17 years natural flow in August and September was depleted by 50% or more.

Description of Study Area and River Strata

The study area encompasses the Yampa River from its confluence with the Green River at Echo Park in Dinosaur National Monument upstream to Craig, Colorado (Figure 2.5). This area of the Yampa River was stratified by Miller et al. (1982) into 8 strata based upon geomorphology, gradient, tributary input, etc. These same strata were used in our study area. Strata 1 through 4 were located downstream of Cross Mountain Canyon and the remaining strata were located between Cross Mountain Canyon and Craig, Colorado. Strata 5 and 7 were not included in the study because they were relatively short river reaches. Brief descriptions of the strata sampled in this study are found below and in Table 2.1.

Stratum 1 extends upstream from RM 0 at the Green River confluence to RM 20 at Harding Hole. The river is bedrock confined in the canyon channel with frequent hydraulic controls provided by debris fans from local side channels. Substrate ranged from sand and cobble to large colluvium depending on local sources and hydraulic conditions (i.e. smaller substrate above Warm Springs Rapid and larger substrate below). Wider areas in the canyon have provided opportunities for formation of Pleistocene Era alluvial terraces.

Stratum 2 extends from RM 20 upstream to RM 45 in the upper Yampa Canyon and contains the greatest slope of all strata studied. This reach is less sinuous than Stratum 1. The higher gradient of the Yampa River is masked somewhat by the backwaters formed by tributary debris fans responsible for the many steep rapids in this reach. Substrate is larger consisting of cobble and small boulder as well as large colluvium.

Stratum 3 extends from RM 45 upstream to the confluence of the Little Snake. This is a lower gradient reach in a wider alluvial valley dominated by sand transported from the Little Snake River.

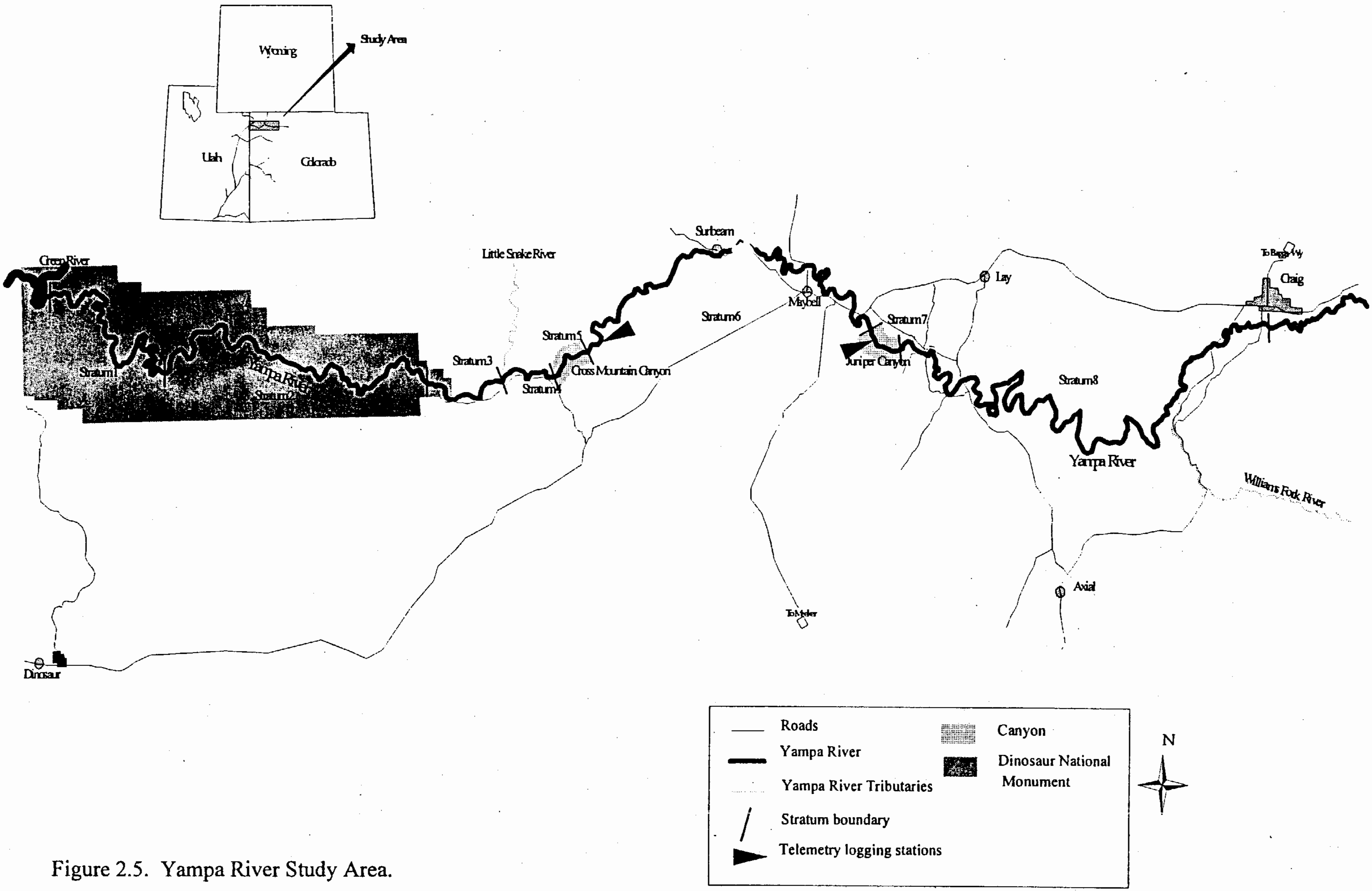


Figure 2.5. Yampa River Study Area.

Table 2.1. Descriptions of river strata in the Yampa River, Colorado study area 1996 and 1997.

Strata	River Mile Location (Kilometer)	Total Miles (km)	Description
1	0-20.0 (0-32.2)	20 (32.2)	Echo Park to Harding Hole: A medium-gradient canyon-bound reach, consisting of run, riffle and pool habitat, with boulder, gravel and sand substrate. Located in Dinosaur National Monument.
2	20.0-45.0 (32.2-72.4)	25 (40.2)	Harding Hole to Deerlodge Park: A high-gradient canyon-bound reach, consisting of run, riffle and pool habitat, with boulder and gravel substrate. Located in Dinosaur National Monument.
3	45.0-51.0 (72.4-82.1)	6 (9.7)	Deerlodge Park to Little Snake River confluence: A low-gradient open-valley reach, consisting of run and riffle habitat, with gravel and sand substrate. A small portion in Dinosaur National Monument, but mostly bordered by private land.
4	51.0-55.6 (82.1-89.5)	4.6 (7.4)	Little Snake River confluence to Cross Mountain: A low-gradient open-valley reach, consisting of run, riffle and pool habitat, with gravel and sand substrate. Mostly bordered by private land.
6	58.8-88.7 (94.6-142.7)	29.9 (48.1)	Cross Mountain to Juniper Canyon: A low-gradient open-valley reach, consisting of run and riffle habitat, with gravel and sand substrate. Mostly bordered by private land. Most of the floodplain is grazed and is adjacent to irrigated agricultural land. Only a small percentage of the riverbank is stabilized by shrubby vegetation. The Maybell gage is located near the upper edge of this Stratum at RM 85.8.
8	91.0-135.0 (146.5-217.3)	44.0 (70.8)	Juniper Canyon to Craig: A medium-gradient open-canyon reach, consisting of run, riffle and pool habitat, with gravel and sand substrate. The river reach between RM 105 and RM 126 is the Little Yampa Canyon management unit. The Williams Fork and Milk Creek are the only major tributaries to enter the river above Cross Mountain and its confluence is at RM 129. Bordered by BLM and private land.

Stratum 4 extends from the Little Snake River confluence at RM 51 upstream to RM 55.6, the lower end of Cross Mountain Canyon. Substrate consists mainly of cobble and gravel that is washed out of Cross Mountain Canyon. Riffles, eddies and side channels are common and there is a large deep pool in the section where Colorado pikeminnow were previously collected by Seethaler (1978). Average gradient is 8 feet/mile and average depth is about 3 feet during post runoff (Miller et al. 1982).

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

Stratum 8 extends from RM 91.6 to RM 135 at the town of Craig, Colorado. In this stratum the valley tends to be more confined than in Stratum 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 Bureau of Land Management (BLM) Little Yampa Canyon Management Unit. Most of the river bottom in this reach is owned by the BLM. The canyon walls are not as confined as Yampa Canyon and a flood plain is typically associated with at least one side of the river.

Description of Yampa River Biotic System

The influence of seasonal changes in hydrology on movement and reproduction of large river fishes in the Upper Colorado River Basin is well documented (e.g. Tyus and Karp 1989, Stanford 1994). Hydrology is important in initiating movement to spawning areas (Nesler et al. 1988, Tyus 1990, Karp and Tyus 1990, Modde and Irving 1998) and determining both the formation (Ligon et al. 1995, Rakowski 1997) and availability (Orchard and Schmidt 1998) of habitat for fishes in large rivers . Much of our knowledge of hydrological effects on fish in the Colorado River Basin are linked to responses from high and receding flows on fish and habitat (Stanford 1994). Relatively little is known about the importance of low flows to the maintenance of native fishes in southwestern rivers.

Several studies have shown that native fishes tolerate higher flow events than nonnative fishes in arid streams and rivers in the southwest (Meffe and Minckley 1987, Minckley and Meffe 1987, Deacon 1988, Hoffnagle et al. In review, Muth and Nesler 1993). Hawkins and Nesler (1991) reported that nonnative fishes declined following years with high spring discharge in the Upper Colorado River Basin. In general, fishes native to the southwest have shown a greater tolerance to environmental variability. Given that native fish tolerate a more highly variable flow regime, seasonal as well as annual variability was an important element in the modified flow recommendation for the Yampa River by Modde and Smith (1995). Poff et al. (1997) suggested that the natural flow regime of all rivers is inherently variable and that this variability is critical to ecosystem function and native biodiversity. Studies in Midwestern (Poff and Allan 1995), Californian (Baltz and Moyle 1993), and Australian streams (Closs and Lake 1996) have suggested that maintaining natural flows regimes, including baseflow variation, is important in maintaining native fish assemblages. This rationale suggests that if environmental variation is reduced, dominant nonnative species could displace or eliminate tolerant, less competitive native species. Because abiotic factors are more influential on ecological processes in highly variable systems such as the Yampa

River, and, biotic factors such as competition are more directive in relatively benign and predictable systems (Poff and Ward 1990), maintaining natural variability is important in maintaining the native fish fauna in the Yampa River.

Macroinvertebrate community structure is a product of the physical and biological influences in the environment. Gordon et al. (1992) described a number of elements that interact to give rise to the general character of a stream. These elements include elevation, stream order, length, discharge, slope, and substrate type. Macroinvertebrates have evolved anatomical, behavioral, and physiological characteristics to adapt to the conditions of their environment (Poff and Ward 1989; Poff and Ward 1990).

Macroinvertebrate community structure is then limited by the physical and biological constraints of each species and the disturbances existing in their environment. The dominant force contributing to the structure of aquatic macroinvertebrate communities is dependent upon the time of year, adaptations of the given macroinvertebrates, and magnitude of the disturbance (Poff and Ward 1989). The flow regime of a stream is usually considered to be one of the most important factors that influence aquatic communities (Poff et al. 1997).

Flow is particularly important because it is often correlated with numerous other factors that influence the aquatic community (Poff and Ward 1990). These factors include: depth, velocity, thermal changes, renewal of resources, etc. Floods or high flows have been shown to be beneficial to disturbance dependent species, whereas other species thrive in a more stable environment (Poff and Ward 1989). Invertebrate communities in streams with a high degree of flow variation are typically dominated by species that can efficiently colonize new areas or can behaviorally avoid adverse conditions (e.g., invertebrates adapted for swimming). Streams with a low frequency of natural disturbance are generally inhabited by more diverse populations of invertebrates that often are larger, more specialized, and long-lived (Poff and Ward 1989). The macroinvertebrate community composition of a given stream is adapted to, and dependent on, the flow regime (as well as other variables) existing in that stream. Changes in the natural flow regime of a system will result in changes to the aquatic communities (Poff et al. 1997).

Some behavior of aquatic invertebrates has been shown to be dependent on flow. Manipulation of flow has been associated with an increase in drift of many species (White et al. 1981; Poff and Ward 1991). Poff and Ward (1991) indicated that the drift patterns of several species of macroinvertebrates in the upper Colorado River were influenced by increasing or decreasing stream flow. Several taxa responded positively (increased drift) to artificially lowering the flow. These taxa included *Baetis* sp., *Triznaka* *signata*, Simuliidae, and other species during certain seasons. White et al. (1981) indicated that an 85% reduction from normal flow during the fall would cause the genus *Baetis* to increase drift to the point that would significantly decrease their densities in riffles. Poff and Ward (1991) reported that several species representing four different orders responded to high flows with increased drift. Most of the species found to be influenced by a change in flow in the upper Colorado River are represented by members of the same taxonomic families in the Yampa River. These include: *Ephemerella* sp., *Baetis* sp., *Paraleptophlebia* sp., *Isoperla* sp., *Brachycentrus* sp., *Lepidostoma* sp., and *Hydropsyche* sp.

White et al. (1981) found no significant change in total abundance of benthic invertebrates as a result of reductions in discharge (up to 95%), however, certain species were significantly depleted. This research indicates that the density of invertebrates in the wetted area of the stream channel before dewatering was not significantly different from the density of invertebrates in the stream channel after flow reductions. However, if the wetted area is reduced by 50%, half of the invertebrate community and biomass is lost. White et al. (1981) suggested that a reduction in discharge results in a change in the hydraulic characteristics of a stream thus affecting the factors responsible for microhabitat selection and invertebrate distribution. The increased drift observed as a response to flow reductions may be an evolutionary adaptation to insure survival in response to natural flow fluctuations. For many species this may be an attempt to relocate to an area of more suitable habitat (White et al. 1981).
Within a week or two after flow reductions, White et al. (1981) found that drift rates returned to normal densities (at flow reductions between 50 and 85%). Even when drift densities were within the range considered "normal", the rate of drift was far less (about 50% less when flow was reduced by 50%) than that observed in the control channel (because of the reduction in wetted area in the test stream). White et al. (1981) found that during 95% flow reductions in the fall, invertebrate drift densities did not increase and were reduced by 50% or more and remained below normal throughout the study period. This information is important because many fish species rely on invertebrate drift as a food supply. Assuming no mortality, flow reductions will cause fish densities to increase. Chapman (1966) suggests that the availability of food is an important factor in determining the density of fish. The increase in fish density combined with the observed decrease in invertebrate drift rate should result in a negative impact to some fish species at low flows. White et al. (1981) suggested that fish may be adversely affected by the decrease in drift density at flows less than 85% of normal.

Ames (1977) provided a species list for macroinvertebrates occurring in the Yampa River. Most of the species on this list have physical or behavioral adaptations specific to the habitat (and velocity) where they reside. The macroinvertebrate communities in the Yampa River exhibit longitudinal changes in structure that can be correlated to longitudinal changes in habitat and other physical parameters (Ames 1977). Many of the changes in community structure among stations can be directly or indirectly attributed to the flow regime at each site. It is likely that flow (primarily velocity and depth) exerts a major influence on macroinvertebrate community structure in the Yampa River by: 1) imposing physical, behavioral or life history constraints on species in the community, 2) by influencing biological interactions such as regulating the availability of food supply, and influencing algal species composition and rate of growth, and 3) by controlling and limiting the availability of specific habitat.

Native Fishes

Colorado Pikeminnow

Colorado pikeminnow are piscivorous, long-lived, large-river fish that utilize a variety of substrates, depths, and velocities. Juveniles up to 50 mm (2 in) in length consume zooplankton and insect larvae. Colorado pikeminnow from 50-100 mm (2-4 in) in length feed on insects, and individuals larger than 200 mm (7.9 in) are primarily piscivorous (Vanicek and Kramer 1969). During spring and early summer, adult fish use areas inundated by spring flooding. Colorado pikeminnow usually become sexually mature within 5-7 years (Vanicek and Kramer 1969). Sexually mature Colorado pikeminnow can migrate long distances (up to 322 km [200 miles]). This behavior is important to this species' reproductive cycle. Adult Colorado pikeminnow are known to migrate long distances for spawning (Tyus and McAda 1984; Wick et al. 1983; Wick et al. 1986; Tyus 1990). Tyus (1990) notes that physical conditions such as high spring flows and increasing river temperatures are important migratory cues. He reported that Colorado pikeminnow spawning migrations were initiated at water temperatures of 14-20°C (57.2-68°F), while spawning occurred at an average temperature of 22°C (71.6°F). Colorado pikeminnow demonstrate a fidelity to spawning locations (Tyus 1985; Tyus 1990; Wick et al. 1983; Irving and Modde 1999), with reproduction occurring in whitewater canyons. Once larval pikeminnow emerge, they undergo a period of drift to reach suitable nursery habitats. During the larval drift, they may be transported up to 161 km (100 miles) downstream (Tyus and Haines 1991). Nursery areas consist of ephemeral backwaters and shoreline embayments with little or no current (Tyus and Haines 1991).

Wick et al. (1983) reported migration from the Upper Yampa to the Lower 32km (19.9 mi) of the Yampa Canyon during late June and early July. Tyus (1990) reported migrations occurring between late May and mid June on the Yampa River and late May and late June on the Green River. Miller et al. (1982) reported migrations between late June to early July. Osmundson and Kaeding (1989) reported increased movement of Colorado pikeminnow from late June and early July to late August on the Colorado River near Grand Junction, Colorado.

Migration to spawning areas roughly coincides with the decrease of spring runoff and an increase in water temperatures. Tyus (1990) reported migration beginning approximately 28 days (d) after peak spring flows when mean water temperatures were approximately 14°C. Wick et al. (1983) observed migration in radio-tagged pikeminnow after temperatures rose to 16°C. Tyus (1990) noted the midpoint of migration coincided with the summer solstice and suggested photoperiod may be important in initiating migration. Tyus (1990) reported spawning migrations occurring earlier in low water years and later in high water years. Wick et al. (1983) suggested other environmental factors besides flow may be important in initiating migrations. Spawning migrations may be an important adaptation to a highly variable environment (Smith 1981; Tyus 1986). Migration to suitable spawning habitat may have some advantages in widely fluctuating environmental conditions (Tyus 1986).

Although adult Colorado pikeminnow may migrate long distances, movement within their home range is relatively limited. In the Yampa River, Wick and Hawkins (1989) found that pikeminnow were often active within a particular habitat but rarely moved outside the reach (average of 0.3 miles) selected for overwintering. Valdez and Masslich (1991) also found that Colorado pikeminnow generally overwinter in localized Green River regions (3-5 km or 1.9-3.1 mi long).

Tyus and McAda (1984) reported that adult Colorado pikeminnow predominately utilized shoreline habitats and were mostly associated with sandy substrate. They also used eddy, run, backwater, and pool habitats and silt, boulder, rubble, and gravel substrates. Habitat and substrate use varied between river systems and time of year. Fish occupied significantly different water depths and velocities between rivers. It is not known whether Colorado pikeminnow select different conditions between river systems, or simply tolerate the wide range of conditions existing between the Green River mainstream and its two upstream tributaries. In the '15 mile reach' near Grand Junction, Colorado, Colorado pikeminnow used run habitats most during the summer (Osmundson and Kaeding 1989, Osmundson et al. 1995). They noted that Colorado pikeminnow seek deep water when water clarity is high. Tyus and Karp (1989) reported that adult Colorado pikeminnow occupied a variety of habitats in mid-to-late summer, but were most common in eddies, pools, runs, and shoreline backwaters. In the Yampa River, Wick et al. (1983) noted a high use of runs during the summer.

Wick et al. (1983) reported high use of pool habitat during October and November on the Yampa River. During the winter, Wick and Hawkins (1989) and Valdez and Masslich (1991) observed Colorado pikeminnow using embayments, backwaters, and runs in the Yampa and Green rivers. Valdez and Masslich

(1991) noted wintering pikeminnow were often associated with an instream cover element (e.g. sand shoals, sand ridges, cobble jetties, or ice jams). They reported that Colorado pikeminnow preferred areas of low velocity (0.0-0.15 m/sec) and moderate depths (0.6-1.1 m).

ISMP data indicates that number of Colorado pikeminnow CPUE sampled in the Yampa River by electrofishing over the last nine years has been fairly consistent, ranging from 17 to 23 fish from three sites totaling 25 miles (McAda 1997). The percent composition of Colorado pikeminnow, for all fish over 15 cm, was estimated to be 0.3% downstream of Sunbeam (RM 60-64) and 1.8% 50 miles upstream near Duffy Tunnel (Anderson, in press).

Humpback Chub.

The humpback chub is a specialized morph of the *Gila robusta* complex (Minckley et al. 1989, Dowling and DeMarias 1993) that exists almost entirely in high gradient canyon reaches of large rivers in the Colorado River Basin (USFWS 1990b). Because of the difficulty in sampling these remote locations large gaps exist in our knowledge of the ecology of this species. Currently only six, isolated reproducing populations of humpback chub exist in the Colorado River Basin (Gorman and Stone in press). Much of the information that is known of this species relates to spawning chronology and habitat use and movements of adult fishes. In the Little Colorado River (Gorman and Stone in press) and Yampa River (Tyus and Karp 1989, Karp and Tyus 1990) humpback chub spawned on the descending limb of the hydrograph. In the current study, both roundtail chub and humpback chub were observed in spawning coloration (reddish orange ventral surface) during the descending limb of the hydrograph. Movement of spawning humpback chub into the Little Colorado River from the Grand Canyon was coincidental with declines in peak flows (Valdez and Ryel 1995). Karp and Tyus (1990) recaptured several individuals at the same location during the spawning season suggesting fidelity to spawning sites.

Little is known of the habitat needs of early life stages (larval, age-0, and juvenile) humpback chub other than they occupy the same reaches of the river as adults and probably utilize large substrate (Valdez et al. 1990). The Little Colorado River is the only location in which young humpback chub are readily collected, and juveniles appear to stay in this tributary for more than a year before they recruit to the Colorado River in the Grand Canyon (Valdez and Ryel 1995). Despite having a narrow caudal peduncle and forked caudal fin characteristic of fast moving swimmers (Moyle and Cech 1988), adult and subadult humpback chub occupy slow velocity, deep-water habitats (Valdez et al. 1990, Valdez and Ryel 1995, Gorman 1994). In the Grand Canyon of the Colorado River adult humpback chub were abundant in large eddies formed downstream of debris fans (Valdez and Ryel 1995). In larger rivers of the Upper Colorado River Basin humpback chub were found in relatively deep (mean =10.3 ft) and slow velocity (mean =0.6ft/sec) water. Karp and Tyus (1990) and additional data presented in this study suggested that humpback chub in the Yampa River use low velocity habitats near shore. Humpback chub used deeper habitats when available, however, during baseflow periods the abundance of deep-water habitat declines, fish are capable of using shallower habitats.

Colorado pikeminnow and humpback chub are members of the native fish community of the Colorado River Basin. The following sections describe other members of the Yampa River fish community, both native and nonnative. These fishes are dependent on the primary and secondary production present in the river. The remainder of the this chapter describes habitat associations and diet of select native and nonnative fishes to provide a context for interpreting radio telemetry data for the Colorado pikeminnow and humpback chub.

Other native fishes

Native fish species present in the potamon reaches of the Yampa River include flannelmouth sucker *Catostomus latipinnis*, bluehead sucker *Catostomus discobolus*, roundtail chub *Gila robusta*, and speckled dace *Rhinichthys osculus*. All of these species are potential prey for the Colorado pikeminnow. In a recent study, the Colorado Division of Wildlife made population estimates at two sites on the Yampa River in September 1998. The native fish component comprised 71% of the fish over 15 cm caught downstream of Sunbeam (RN60-64), but were only 14% of the catch at Duffy Tunnel (RM 104.5-110.0) (Anderson, in press).

Historic distribution of the flannelmouth sucker included medium to large streams throughout the upper and lower Colorado River basin (Joseph et al. 1977; Arizona Game and Fish 1996). Currently flannelmouth sucker populations in the lower basin have been reduced and restricted to areas of suitable habitat (Minckley 1985). In the upper basin this species still persists in much of its original range (Holden and Stalnaker 1975); however, flannelmouth sucker populations have become lost or depleted in areas that are influenced by impoundments (Chart and Bergesen 1992). Flannelmouth suckers remain common in the upper basin in medium to large streams with natural temperature and flow regimes. Carlson et al. (1979) reported that flannelmouth suckers composed between 12.5% and 53.7% of the total fish captured from July 1975 through October 1977 at six sites on the Yampa River between Dinosaur National Monument and the town of Hayden, Colorado. The percent composition of flannelmouth sucker, for all fish over 15 cm, was estimated to be 37% downstream of Sunbeam (RM 60-64) and 7 percent 50 miles upstream near Duffy Tunnel (Anderson, in press). Flannelmouth suckers in the Yampa River are known to hybridize with bluehead sucker and white sucker (Carlson et al. 1979). Determining age by scale analysis indicated that flannelmouth sucker can reach at least 10 years of age in the Yampa River (Carlson et al. 1979).

Flannelmouth suckers utilize several different habitats and feeding strategies during various life stages. Young flannelmouth suckers are often associated with backwaters, slow runs or pools (Holden and Stalnaker 1975; Joseph et al. 1977). Adults occupy pools and eddies in larger streams, but will often move into shallow riffles to feed between rocks (Joseph et al. 1977). Carlson et al. (1979) found flannelmouth suckers using a wide range of habitat and substrate types on the Yampa River; however, these fish seemed to prefer relatively shallow water with sand or small cobble substrates. Joseph et al. (1977) suggested that larvae of flannelmouth suckers feed primarily on crustaceans and other small aquatic invertebrates. As these fish get older their diet consists primarily of bottom materials including organic debris, algae, and invertebrates (Joseph et al. 1977; Arizona Game and Fish 1996). Gut samples from flannelmouth suckers collected from the Yampa River during August and September 1975 contained mostly periphyton (algae) and a few invertebrates (Carlson et al. 1979).

The bluehead sucker is native to streams in the Upper Colorado River basin (Joseph et al. 1977). Vanicek et al. (1970) reported that the bluehead sucker was common within the canyon section of the Green River in Dinosaur National Monument. Holden and Stalnaker (1975) found the bluehead sucker "common" to "abundant" at sample locations at the Yampa, Gunnison, and middle to upper Green and Colorado Rivers. Between July 1975 and October 1977 bluehead suckers composed 7.8% to 28.0% of the fish collections in the Yampa River between Dinosaur National Monument and the town of Hayden, Colorado (Carlson et al. 1979). The bluehead sucker also hybridized with white and flannelmouth suckers in the Yampa River.

Adult bluehead suckers exhibit a strong use of specific habitat types (Holden and Stalnaker 1975). This species typically occurs in runs or riffles with rock or gravel substrates (Vanicek 1967; Holden and Stalnaker 1975; Carlson et al. 1979). Juvenile bluehead suckers occur in slower water than adults, and juveniles have been collected from shallow riffles, backwaters, and eddies with silt or gravel substrates (Vanicek 1967). The percent composition of bluehead sucker, for all fish over 15 dm, was estimated to be 27% downstream of Sunbeam (RM 60-64) and 5 percent 50 miles upstream near Duffy Tunnel (Anderson, in press).

Bluehead suckers feed by scraping periphyton from rocks (Joseph et al. 1977). The mouthparts of the bluehead sucker and other sucker species in the subgenus *Pantosteus* are specifically adapted for scraping algae from rocks (Sigler and Miller 1963; Joseph et al. 1977). Vanicek (1967) found that gut samples from bluehead suckers from the Green River contained mud, filamentous algae, and chironomid larvae. Carlson et al. (1979) reported that gut samples from bluehead suckers in the Yampa River contained mostly periphyton and a few invertebrates during August and September 1975.

Young bluehead suckers are eaten by piscivorous species. Piscivorous fishes that feed on bluehead suckers primarily include roundtail chub and several introduced nonnative species (Joseph et al. 1977). Most populations of bluehead suckers occur in smaller streams and at higher elevations than those inhabited by Colorado pikeminnow, so bluehead suckers in most systems do not constitute a major food source for Colorado pikeminnow (Joseph et al. 1977).

The roundtail chub is endemic to the Colorado River drainage. Historically, roundtail chub commonly occurred in most tributaries of the upper Colorado River Basin (Vanicek 1967; Holden and Stalnaker 1975; Joseph et al. 1977). Holden and Stalnaker (1975) reported that roundtail chub were abundant or common at all sites sampled at the Yampa River, and most sites in the Dolores River. Carlson et al. (1979) found that roundtail chub composed between 2.8% and 14.3% of the total fish captured from July 1975 through October 1977 at five sites on the Yampa River between Dinosaur National Monument and the town of Craig, Colorado. The percent composition of roundtail chub, for all fish over 15 cm, was estimated to be 6.7% downstream of Sunbeam (RM 60-64) and 3.8 percent 50 miles upstream near Duffy Tunnel (Anderson, in press). In the Yampa River most roundtail chubs collected by Carlson et al. (1979) were in eddy or pool habitat. McNatt and Skates (1985) found roundtail chub common at most sites in the Green River and Yampa River in Dinosaur National Monument. Olson (1967) stated that roundtail chub were common in collections in Navajo Reservoir during 1965.

Feeding habits of roundtail chub are described as “opportunistic” and “sporadic” (Vanicek 1967). Joseph et al. (1977) reported that roundtail chubs of all age classes are primarily carnivorous. Young roundtail chub typically inhabit the slower, shallower water along the shoreline of the stream (Sigler and Miller 1963). Young chubs in the Green River consumed primarily aquatic insects (particularly chironomid larvae and ephemeropteran nymphs) (Vanicek 1967; Vanicek and Kramer 1969). Joseph et al. (1977) provided additional evidence of young roundtail chub feeding mostly on aquatic invertebrates found at the bottom of pools and eddies. Most growth in young fish occurs between late May and October (Vanicek 1967).

Roundtail chub over 200mm in length consume a greater variety of prey items. Adult roundtail chub have been reported to feed on filamentous algae, aquatic invertebrates, terrestrial invertebrates (especially grasshoppers and ants), fish, and plant debris (Vanicek and Kramer 1969; Joseph et al. 1977). Minckley (1973) indicates that adult roundtail chub may also consume their own eggs as well as eggs of other fish species. Olson (1967) reported that the diet of roundtail chub in Navajo Reservoir was primarily plankton with some aquatic insects. Greger and Deacon (1988) determined that the diet of Virgin River roundtail chubs consists mostly of filamentous algae with some macroinvertebrates. Macroinvertebrates were consumed primarily during December.

At present, there is concern regarding the status of roundtail chub in the Colorado River drainage. Historically, the roundtail chub may have been the most abundant carnivore in the upper Colorado River Basin (Holden and Stalnaker 1975). Recently, a decrease in distribution and abundance has been documented at several locations (Vanicek et al. 1970; Joseph et al. 1977; Kaeding et al. 1990). Joseph et al. (1977) suggested that roundtail chub populations often declined after predatory nonnative fish became established in roundtail chub habitat. It is likely that both native and nonnative predators prey on roundtail chub. Joseph et al (1977) speculated that before the introduction of nonnative fish the roundtail was probably a major prey item for Colorado pikeminnow.

The speckled dace is native to the Colorado River Basin and its tributaries. This species occurs in the mainstem and most medium to small tributaries. Holden and Stalnaker (1975) found the speckled dace common at most sites in the upper Colorado River Basin; however, this species was absent or rare in slower moving sections of the warmer, large rivers. This fish does, however, occur in larger rivers in areas of suitable habitat. Vanicek and Kramer (1969) found speckled dace common in collections from the Green River in Dinosaur National Monument. In medium to small tributaries, speckled dace occur in most habitats, but are usually most abundant in areas of current or riffle habitat (Holden and Stalnaker 1975). Carlson et al. (1979) indicated that speckled dace in the Yampa River were found in a variety of habitats including pools, backwaters and near shore habitat. During periods of low flow in the Yampa River, speckled dace survived for several days in stranded pools where temperatures exceeded 30° C.

The speckled dace feeds primarily along the bottom, but will occasionally consume items in the drift. The diet of specked dace is almost entirely aquatic invertebrates; however, they may also rarely consume algae and detritus (Sublette et al. 1990). Speckled dace feed mostly at night.

Nonnative fishes

Numerous nonnative fish species have been introduced in the Yampa River basin. Three species are of particular concern because of possible competition with and predation on endangered fishes include channel catfish *Ictalurus punctatus*, northern pike *Esox lucius*, and smallmouth bass *Micropterus dolomieui*. The entire nonnative species component of the fish population was found to be 29% downstream of Sunbeam (RM 6-64) but 86% near Duffy Tunnel (RM 104.5 – 110.0) (Anderson, in press). White sucker was found to progressively increase in numbers in an upstream direction and represented 67% or the fish caught at Duffy Tunnel.

Channel catfish habitat use is life stage specific. Aadland (1993) used habitat preference guilds to define habitat selection by channel catfish. He assigned age-0 channel catfish to the slow-riffle guild (velocity 30-59 cm/s, depth <60 cm), and juvenile and adult catfish to the medium-pool guild (velocity <30 cm/s, depth 60-149 cm). Although Aadland (1993) assigned juvenile catfish to the medium-pool guild, he reported that they appeared to be habitat generalists at this lifestage. In the Green and Yampa Rivers, Colorado and Utah, Tyus and Nikirk (1990) found the highest concentrations of channel catfish in rocky, high gradient areas. Carlson et al. (1979) collected channel catfish in the Yampa River from a variety of habitat types and associated velocities; however, these fish were often associated with at least some boulder size substrate. Results of sampling the Yampa River from July 1975 through October 1977 indicated that channel catfish decreased upstream from Cross Mountain Canyon (Carlson et al. 1979). The percent composition of channel catfish, for all fish over 15 cm, was estimated to be 6.6% downstream of Sunbeam (RM 60-64) and 3.9 percent 50 miles upstream near Duffy Tunnel (Anderson, in press).

Channel catfish are generally nocturnal feeders, with peak activity occurring from sunset until midnight (Sublette et al. 1990). Juvenile channel catfish usually feed on plankton and small aquatic insects. As adults, channel catfish become omnivorous. Tyus and Nikirk (1990) found aquatic invertebrates, vascular plants, terrestrial insects, algae, fish, and mice in channel catfish stomachs, although only the largest of catfish (mean TL=392 mm) had consumed fish. Carlson et al. (1979) found that gut samples from 17 channel catfish collected in the Yampa River near Cross Mountain during September contained only filamentous algae and diatoms. The optimal temperature for growth of juvenile channel catfish is between 27° – 29°C (Memahon and Terrell 1982); however, growth rates may decrease as a result of overcrowding or stress caused by low dissolved oxygen levels (Carlander 1969).

The northern pike is a large (>1300 mm) member of the family Esocidae. Juvenile and adult northern pike are strongly piscivorous; however, young pike (<50 mm) feed primarily on insects and crustaceans (Hunt and Carbine 1951; Frost 1954). Although northern pike become strongly piscivorous as they mature, Chapman et al. (1989) and Chapman and Mackay (1990) reported that invertebrates may be important food items seasonally. Because northern pike feed by sight, their growth rates may be hindered by high turbidity—a physical characteristic common to many western rivers. Male northern pike become sexually mature around ages 2 or 3 and most females reach maturity by age 3 (Carlander 1969). Crossman (1979) reported life expectancy of northern pike to be at least 24 years.

Northern pike are typically found in small lakes, vegetated portions of larger lakes, and rivers (Crossman 1979). Miller and Rees (1997) found that northern pike in the Yampa River, selected pools as habitat, although they also documented use of backwaters. Carlson et al. (1979) did not obtain northern pike in fish collections from July 1975 to October 1977 in the Yampa River between Dinosaur National Monument and the town of Hayden, Colorado. Nesler (1995) found that northern pike occupied the same pool habitats as Colorado pikeminnow. The percent composition of northern pike, for all fish over 15 cm, was estimated to be 1.5% downstream of Sunbeam (RM 60-64) and 4.1 percent 50 miles upstream near Duffy Tunnel (Anderson, in press).

Smallmouth bass are sight dependent carnivores during all life stages. At an early age they feed on plankton and aquatic invertebrates, but eventually switch to small fishes (sometimes other small bass) and crayfish (Carlander 1977; Stephenson and Momot 1991). Lachner (1950) found that smallmouth bass over 60 mm consumed primarily crayfish and fish, while bass smaller than 40 mm consumed only crayfish. Females become sexually mature between ages 4 to 6, at which time they are usually able to produce one brood per year. Males become sexually mature at ages 3 to 5 (Cross and Collins 1975; Pflieger 1975). Carlander (1977) listed the maximum life span for smallmouth bass as about 18 years.

Smallmouth bass of all ages occur in rocky habitat, but they also use log jams and root wads. Rankin (1986) reported that smallmouth bass habitat selection in the Flat River, Michigan, was influenced by abiotic factors such as depth, velocity and substrate, but he also hypothesized that prey distribution was important to habitat selection. Probst et al. (1984) demonstrated that habitat use by smallmouth bass is life stage specific. Smallmouth bass smaller than 350 mm were found associated with faster water velocities, vegetation, and boulders more often than larger smallmouth bass, which chose log jams and slower current velocities. Smallmouth bass avoid water with a pH less than 6.0, and require dissolved oxygen concentrations of greater than 0.96 ppm at a water temperature of 21°C (Carlander 1977).

Smallmouth bass often benefit from the stabilization in temperature and discharge below dams in rivers (Beckman 1974; Cross and Collins 1975). Smallmouth bass tend to be inactive during the winter when water temperatures are less than 10°C (Carlander 1977). Funk (1955) and Todd and Rabeni (1989) classified smallmouth bass as a sedentary species, although some movement between pools during certain times of the year has been documented. No smallmouth bass were present in fish collections from July 1975 to October 1977 at the Yampa River between Dinosaur National Monument and the town of Hayden (Carlson et al. 1979). The percent composition of smallmouth bass, for all fish over 15 cm, was estimated to be 1.1% downstream of Sunbeam (RM 60-64) and 11 percent 50 miles upstream near Duffy Tunnel (Anderson, in press).

CHAPTER 3: HABITAT AVAILABILITY AND HYDRAULIC SIMULATION

Introduction

In riverine ecosystems the physical habitat and biotic communities are inextricably linked. Peak flows form and maintain channel morphology, which significantly affects the quality and quantity of aquatic habitats during the baseflow period. The integrity of the aquatic community is a function of habitat quality and availability. By identifying relationships between channel characteristics and flow we can estimate the influence of flow reduction on habitat quality and quantity. Many instream flow methodologies are based on relationships between flow and channel configuration. These methods rely on the assumption that reliable and stable riffle habitats maintain biological integrity. The approach taken by this study was to determine curve breaks in the relationship between flow and channel variables and to use them as indicators of the point at which flow reduction most impacts habitat availability and production in the Yampa River.

While there is some lower flow that maintains a healthy, functioning river community, methods to identify this flow are controversial. Instream Flow Incremental Methodology (IFIM) (Bovee 1982) generates a prediction of the amount of usable habitat for fish as a function of discharge by combining habitat suitability curves with a hydraulic model. The habitat component of the model has received much criticism because of assumptions concerning positive relationships between habitat availability and fish abundance. When habitat availability is not limiting, biological interactions primarily determine community structure and carrying capacity (Allan 1995). Even when environmental factors are stressful, the correlation between habitat availability and fish abundance may not be readily apparent. However, at some reduced flow, lack of habitat can become a limiting factor and maintenance of normally stable habitats is necessary for maintaining community structure. IFIM is a useful tool for identifying habitat stability over a range of low flows.

Even though IFIM is capable of integrating two to three variables, the weighted useable area (WUA)/flow relationship only applies to individual life stages of a single species, in this study adult Colorado pikeminnow and humpback chub. Flows that appear to be adequate for maintaining Colorado pikeminnow and humpback chub habitat may not necessarily be adequate for other members of the aquatic community. Conversely, flows adequate to protect the aquatic community should be inclusive for adult pikeminnow and humpback chub. In this respect, IFIM analysis was included as supplementary information to the curve break analysis.

The objective of this chapter is to describe the characteristics of the channel morphology with changes in flow within the designated critical habitat of the Yampa River and quantify habitat/flow relationships for adult Colorado pikeminnow and humpback chub.

Methods

Cross Section Profiles

Channel cross section profile methodology is frequently used to determine minimum flows needed to maintain habitats for the aquatic community (Allan 1995). These methods use a stage-discharge relationship to simulate depths and velocities for a desired range of flows. Because of its greater slope, riffle habitat is influenced more by reduced flows than other mesohabitats such as runs and pools. Therefore, riffles were the focus of our low flow analysis.

This study was designed to determine habitat availability during the baseflow period (August 1 to October 31), when flows typically range below 300 cfs (approximately 50% exceedance during baseflow period). All measurements were taken at flows between 300 and 800 cfs during the baseflow period in August and September 1996 and in September and October 1997. During this period flows ranged from less than 100 cfs to as much as 6,770 cfs (Figure 3.1). Sample sites, called habitat clusters, were identified and numbered sequentially along the Yampa River in the study area. Habitat clusters were long enough to contain at least two representative riffle-pool-run-riffle habitat sequences. The length of a habitat cluster was ten times the average river channel width (Leopold et al. 1964). The average channel width of the Yampa River was estimated to be 102 ft in Yampa Canyon and 250 ft above Cross Mountain Canyon based on aerial photographs taken on 18 September 1990 when baseflows were 74 cfs at the USGS gage at Maybell, Colorado. The number of habitat clusters per stratum was determined by dividing the stratum length by the cluster length. For example, Stratum 1 had approximately 104 habitat sample clusters and was based on the following equation:

$$Number\ of\ Habitat\ Clusters = \left[\frac{20\ miles * \left(\frac{5280\ feet}{1\ mile}\right)}{(10 * 102\ feet)}\right] = 104$$

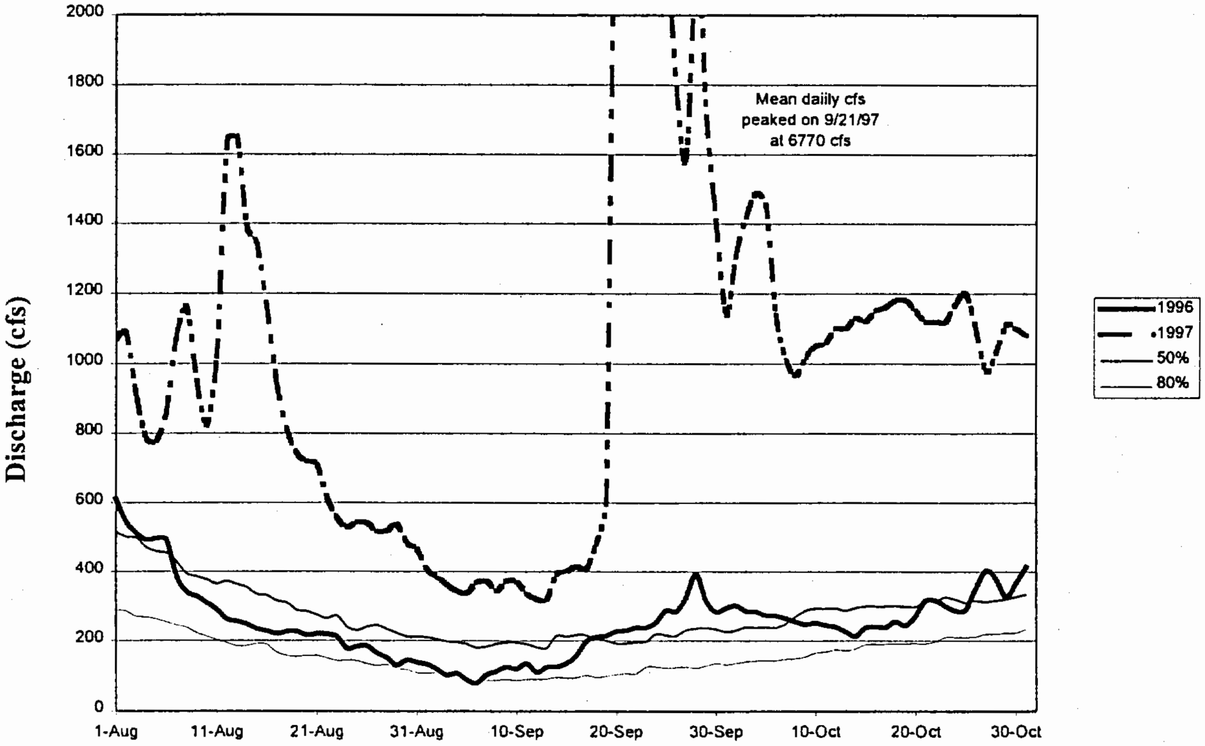


Figure 3.1. Fall flows for 1996 and 1997 with reference flows for 50% and 80% daily exceedance.

Over 500 habitat clusters were delineated on the Yampa River between Echo Park and Craig, Colorado. Cross section data were collected from 43 randomly selected habitat clusters (8.6% of the study reach). Habitat sequences were surveyed in 17 habitat clusters in the lower river reach (5 in Stratum 1, 8 in Stratum 2, and 2 each in Strata 3 and 4) and 26 clusters in the upper river reach (9 in Stratum 6 and 17 in Stratum 8).

Within the 43 habitat clusters, 220 cross section profiles were measured in the Yampa River study area. At each cross section, a measuring tape was stretched between head pins set at or above the grassline on both sides of the river channel. The channel slope and water surface elevation were determined using a stadia rod and standard surveying level. Distance between cross sections and differences in water surface elevations were used to determine the slope of the channel (Bovee and Milhous 1978).

The first cross section was placed at the most suitable hydraulic control in the cluster, just above a riffle at the downstream terminus of each cluster. The next cross section was placed upstream of the control, across the lower end of the adjoining mesohabitat. Cross sections through the middle and upper run, and the bottom, middle, and top portions of the upper riffle completed the habitat cluster. One of the three cross sections on the upper riffle was located in the shallowest or widest part of the riffle.

Because depth, velocity, and wetted perimeter are more sensitive to flow changes in riffle habitats than other habitat types, the analysis focused on riffles (per advice of the RIP selected expert panel). Accordingly, during the extraordinarily high baseflows in 1997, priority was assigned to sampling riffles, and in some clusters only the riffles were surveyed. Between one and three cross sections were completed in the clusters where only riffles were sampled.

Data were collected at 25 to 30 points along each cross section. These data included habitat type and substrate type (defined by Bisson et al. 1982 and Modde et al. 1991) depth and mean water velocity at each point. Only one stage-discharge measurement was made at each cross section. The predictability of only one stage-discharge measurement was tested by running multiple simulations and increasing the Manning's n at low flow since roughness increases as flow decreases (Gordon et al. 1992). Increasing Manning's n at flows of less than or equal to 40% and less of the measured flow did not change results compared to using the calculated Manning's value.

Hydraulic Simulation

The conveyance channel module of the RHABSIM computer program (Payne 1995) was used to develop the stage-discharge relationship for cross sections in the Yampa River. The model predicted changes in channel variables at flows of 1, 10, 20, 40, 60, 80, 100, 125, 150, 200, 250, and 300 cfs by mesohabitat type (run, riffle, and pool). Seven flow and/or channel variables were estimated by the hydraulic model for each cross section by habitat type. The seven variables are defined as:

a) Wetted width: width of the stream at the water surface.
b) Percent wetted perimeter: The distance along the streambed in contact with the water divided by the distance along the streambed between the grassline of each bank.
c) Depth: The vertical distance between the water surface and measured points 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 unit-less 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 by average depth.

g) Velocity: Linear distance water moves per second.

Curve Break Analysis

Curve breaks are defined as the rate of greatest change in a variable with declining flow and were determined for all seven variables from all selected cross sections. Rate of maximum change was calculated by fitting a line to the x and y coordinates (Figure 3.2) and selecting the largest regression residual (the largest difference between the curve and the line). Curve breaks were calculated by mesohabitat type (runs, riffles, and pools) in all strata. To prevent over-representation of any given riffle among clusters, a single cross section was selected from riffles where more than one cross section was measured. Typically the cross section selected was the widest or shallowest part of the riffle measured. For each riffle cross section, the values for each of the seven variables were plotted against a range of flows from 1 to 300 cfs. The maximum range of 300 cfs was selected because it represents the median flow during the baseflow period for the period of record.

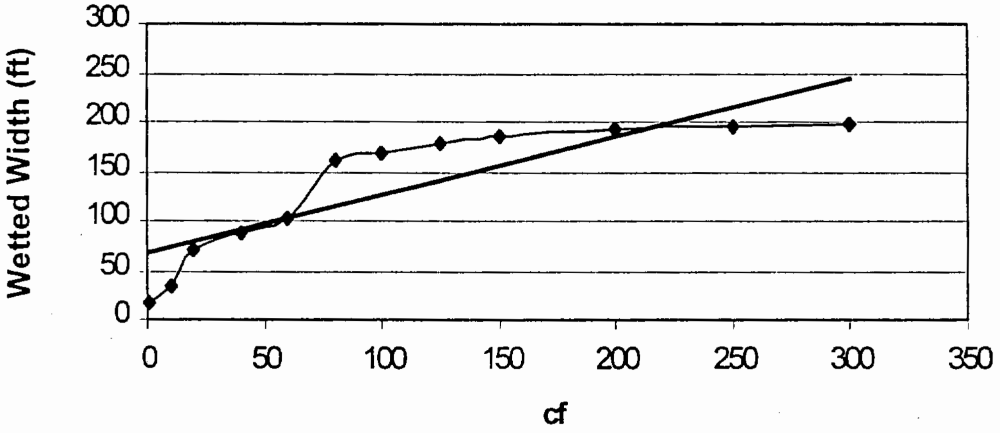


Figure 3.2. Example of curve break flow (i.e., approximately 80 cfs) representing the point at which flows decline at the greatest rate relative to the decrease in a given stream profile variable (i.e., wetted width).

In most cases there were multiple cross sections for each run. In general, cross sections through run mesohabitats were placed above the riffle/run transition (tail), at the narrowest and at the widest part of the run. This placement was used to represent different habitat qualities of each run. For example, the tail of a run may have characteristics more similar to riffles while the upper reach may have characteristics more similar to pools. Typically, only one pool cross section was surveyed per cluster.

Curve breaks for all cross sections were grouped by mesohabitat-type, i.e. riffle, run, and pool and compared between variables and between habitats for differences.

Physical Habitat Simulation

Calculation of WUA for multiple cross sections was modeled using the step-back module of RHABSIM (Bovee 1982). Cross sections were placed to represent an entire run/riffle sequence with the downstream cross section in each cluster on a hydraulic control. Habitat criteria for adult Colorado pikeminnow and humpback chub were used for modeling WUA. Depth and velocity habitat criteria were used for Colorado pikeminnow and shoreline habitat (20 feet outward from each shoreline) criteria were used for humpback chub. Only shoreline habitat was used for humpback chub because the majority (71%) of these fish have been caught in shoreline eddy habitats with most fish being collected adjacent to large shoreline substrate (unpublished data, Colorado River Fish Project, Vernal , UT). Habitat suitability criteria for Colorado pikeminnow are presented in Appendix 2. The frequency distribution developed from these observations represented the likelihood that fish would select a specific habitat type. Diurnal Colorado pikeminnow habitat was restricted to pools over 2 ft deep, while nocturnal Colorado pikeminnow habitat and includes shallower swifter areas. Humpback chub were found in habitat associated with large cobble and boulder substrate in shoreline eddy habitat.

Passage

The hydraulic equation (stage-discharge relationship) was used to define minimum passage criteria. The minimum passage depth of a riffle is considered to be the maximum body depth of the largest fish in the community. Body depth is defined as the distance from the tip of the extended dorsal fin to the lowest portion of the body cavity. A large Colorado pikeminnow in the Yampa River is 32 inches (80cm) long and weighs about 11 pounds (2.4 kg) (Interagency Standardized Monitoring Program data) with a body depth of about 9 inches, of which the dorsal fin is about 3 inches. Using this logic, average depth of riffles need to be at least 0.75 ft to allow passage. We also used the depth criteria defined by Burdick (1996), who felt that a maximum depth of one foot would satisfy unrestricted movement of adult Colorado pikeminnow.

Statistical Testing.

Tests for significant differences between means of the seven parameters were used to determine if the physical properties of aquatic habitats varied between strata. Data from riffles were tested at flows of 80, 150 and 300 cfs. Eighty cfs represented minimum flows that infrequently have occurred (<25%), 150 cfs represents the minimum flow that commonly occurs (<50%), and 300 cfs represents median flows that typically occur during the baseflow period. A complete block design analysis of variance (ANOVA) (Sokal and Rohlf 1981) was used to detect differences in simulated channel variables and curve break values among all variables and strata. Simulated values of channel variables were blocked by flow (80, 150 and 300 cfs). Variables included in the ANOVA were selected following correlation analysis, with those variables showing independence being tested. All variables and strata were included in the ANOVA of curve break data. A Tukeys Multiple Comparison Test (Ott 1977) was used to determine where differences occurred. Statistical significance was set at the 0.05 alpha level. In addition, curve breaks were also generated for WUA estimates, which is a deviation from the intended use of the methodology, but they provided an opportunity to compare PHABSIM estimates to the channel variable curve break estimates.

Results

Flows During the Study Period

In 1996, Yampa River flow averaged 252 cfs at the Maybell gage between August and October and was less than 100 cfs for 2 days. The minimum flow of 79 cfs occurred on September 6, and the next lowest daily mean flow was 88 cfs on September 5. Flow was under 128 cfs (50th percentile) for 12 days. In 1997, flows during August, September and October were exceptionally high (Figure 3.1), averaging 1,135 cfs. Flows were above 10% exceedance for much of the summer and fall, except between September 1 and 18, when flows were near the 20% exceedance level. On September 21, the mean daily flow rose to 6,770 cfs, following an intensive rain event in the basin. The very high flows of September and October 1997 were an obstacle to cross section data collection, and some of the field work was modified or abandoned because of the short window when flows were below 600.

Cross Section analysis

The strata, cluster location, date, and numbers of cross sections measured during this study are listed in Table 3.1. Curve break data for all cross sections are summarized and presented in Appendix 1, Tables 1.1 to 1.6. The data in Appendix 1 are grouped by riffles (Appendix 1, Tables 1.1 & 1.2), runs (Appendix 1, Tables 1. 3 & 1.4), and pools (Appendix 1, Tables 1.5 & 1.6). Within each mesohabitat group are the results of the curve break analysis for the six variables of interest (i.e., percent wetted perimeter; wetted width; average depth; stage; width/depth ratio; velocity; and cross sectional area).

Table 3.1. Cross-section sampling dates, locations, and flow measurements from the Yampa River during the 1996-1997 study period.

Strata	River Mile	No. of Cross-Sections	Date of Survey	Field measured Flow (cfs)	Deer Lodge Flow (cfs)	Maybell Flow (cfs)	Craig Flow (cfs)
1	4.0	6	9/9/97	483	494		
1	11.3	6	8/29/97	631	666		
1	16.6	6	9/8/97	514	494		
1	17.8	6	8/28/97	639	646		
1	19.9	6	8/27/97	662	675		
2	23.9	6	11/6/96	323	358		
2	26.2	6	9/7/97	510	515		
2	34.1	6	9/20/97	860	857		
2	36.0	6	9/6/97	514	517		
2	37.5	6	8/26/97	684	699		
2	41.8	6	9/19/97	852	857		
2	42.2	6	9/5/97	474	488		
2	44.1	6	9/18/97	531	597		
3	45.5	6	10/22/96	399	433		
3	51.5	4	8/22/96	209	184		
4	53.5	6	10/16/96	236	215		
4	54.0	6	10/17/96	243	215		
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

Sixty-two riffles were surveyed with single or multiple cross sections. Table 1.7 in Appendix 1 lists the river mile and simulated width, depth, velocity, % wetted perimeter, stage, width-depth ratio, and cross sectional area for each riffle cross section at 80, 150 and 300 cfs. The results of the correlation analysis were used to reduce the number of variables in the analysis by eliminating those that were highly correlated with others. A comparison of the association among variables indicated that depth, wetted width and velocity accounted for most of the observed variation. The remaining channel variables were significantly correlated with one or more of these variables or with another variable (e.g., cross sectional area) which was correlated with one of the three (e.g. depth wetted width) (Table 3.2). Relative to curve break flows, depth, wetted width, stage and width/depth ratio showed the greatest independence among variables (Table 3.3). Analysis of variance for depth, width, and velocity indicated significant differences among strata. Tukey's multiple comparison tests among strata showed no geographical pattern for depth and velocity, but indicated differences in width between strata above and below Cross Mountain Canyon (Table 3.4). Analysis of variance of curve break data indicated no differences among variables ($P > 0.05$) or among strata ($P > 0.12$) (Table 3.5). Thus, because no differences could be detected among variables or strata, all data can be combined to provide a single estimate applicable to both Yampa Canyon and the river above Yampa Canyon.

Curve Break Analysis

The means of curve break flows for riffles were similar for all six variables (wetted width, depth, velocity, stage, width-depth ratio, % wetted perimeter, and cross sectional area). The lowest was 83 cfs (width/depth ratio) and the highest was 113 cfs (cross sectional area)(Table 3.6). The grand mean curve break flow of all six variables for all 62 cross sections was 93 cfs. The mean of the curve break flows was greater than the median (50% percentile) for wetted width, stage, width/depth ratio and cross sectional area, but less than the median for depth and velocity.

There were 69 run cross sections in the study area: 9 in Stratum 1, 9 in Stratum 2, 7 in Stratum 3, 4 in Stratum 4, 18 in Stratum 6, and 22 in Stratum 8 (Appendix 1, Table 1.3). The mean of the curve break

Table 3.2. Pearson correlation matrix of the field collected data for seven habitat variables among 62 riffle cross sections in the Yampa River. Bold represents significant differences (r>0.5)

Variable	Depth	Wetted Width	Velocity	% Wetted Perimeter	Stage	Cross Sectional Area	Width/ Depth Ratio
Depth	1.000						
Wetted Width	0.034	1.000					
Velocity	0.319	-0.070	1.000				
% Wetted Perimeter	0.035	**1.000**	-0.067	1.000			
Stage	**0.954**	-0.137	0.477	-0.135	1.000		
Cross Sectional Area	-0.405	0.443	-0.349	0.440	-0.458	1.000	
Width/Depth Ratio	**-0.635**	**0.644**	-0.320	**0.643**	**-0.699**	**0.537**	1.000

Table 3.3. Pearson Correlation Matrix of the curve breaks (cfs) for the seven habitat variables. Bold represents significant differences (r>0.5)

Variable	Depth	Wetted Width	Velocity	% Wetted Perimeter	Stage	Cross Sectional Area	Width/ Depth Ratio
Depth	1.000						
Width	-0.332	1.000					
Velocity	**0.887**	-0.301	1.000				
%Wetted Perimeter	-0.328	**0.998**	-0.300	1.000			
Stage	-0.043	0.482	-0.012	0.488	1.000		
Cross Sectional Area	-0.392	**0.811**	-0.351	**0.814**	0.454	1.000	
Width/Depth Ratio	-0.123	0.238	-0.074	0.263	0.250	0.234	1.000

Table 3.4. The results of the complete block (flows of 80, 150,and 300 cfs) design ANOVA and Tukeys Multiple Comparison tests for the macrohabitat data collected for riffle habitat on the Yampa River, Colorado, 1996 and 1997. I in each column represent sets of comparisons without significant differences.

Strata	ANOVA *P*-Value	Mean Depth (ft)	Tukeys Comparison				Group Relationships
2	<0.001	1.09	I				Stratum 2: > Strata 4, 1, 3, 6 and 8 Stratum 4: < Stratum 2; = Strata 1 and 3; > Strata 6 and 8 Stratum 1: < Stratum 2; = Strata 4, 3 and 6; > Stratum 8 Stratum 3: < Stratum 2; = Strata 4, 1, 6 and 8 Stratum 6: < Strata 2 and 4; = 1, 3 and 8
4		0.80		I			
1		0.72		I	I		
3		0.71		I	I	I	
6		0.61			I	I	
8		0.60				I	
						I	

Strata	ANOVA *P*-Value	Mean Width (ft)	Tukeys Comparisons				Group Relationships
8	<0.001	189.38	I				Stratum 8: = Strata 4 and 6; > Strata 1, 2 and 3 Stratum 4: = Strata 8 and 6; > Strata 1, 2 and 3 Stratum 6: = Strata 8 and 4; > Strata 1, 2 and 3 Stratum 1: < Strata 8, 4 and 6; = Strata 2 and 3 Stratum 2: < Strata 8, 4 and 6; = Strata 1 and 3 Stratum 3: < Strata 8, 4 and 6; = Strata 2 and 3
4		189.03	I				
6		179.74					
1		123.91		I			
2		108.34		I			
3		105.31		I			

Strata	ANOVA *P*-Value	Mean Velocity (ft/s)	Tukeys Comparisons				Group Relationships
1	<0.001	1.99	I				Stratum 1: = Stratum 3; > Strata 6, 2, 8 and 4 Stratum 3: = Stratum 1; > Strata 6, 2, 8 and 4 Stratum 6: < Strata 1 and 3; = Strata 2 and 8; > Stratum 4 Stratum 2: < Strata 1 and 3; = Strata 6 and 8; > Stratum 4 Stratum 8: < Strata 1 and 3; = Strata 6 and 2; > Stratum 4 Stratum 4: < Strata 1, 3, 6, 2 and 8
3		1.90	I				
6		1.73		I			
2		1.59		I			
8		1.58		I			
4		1.13			I		

Table 3.5. The results of the complete block (flows of 80, 150, and 300 cfs) design ANOVA tests for the curve break cfs data for riffle habitat on the Yampa River, Colorado, 1996 and 1997.

Strata	ANOVA *P*-Value	Mean Curve Break (CFS)
2	>0.12	106.2
6		98.1
3		92.9
4		91.3
1		88.9
8		87.8
Variable	ANOVA *P*-Value	Mean Curve Break (CFS)
Cross Sectional Area	> 0.07	111.6
% Wet Perimeter		93.2
Wetted Width		93.0
Stage		62.6
Depth		91.1
Width/Depth Ratio		91.1
Velocity		86.8

Table 3.6. Comparison of mean and standard deviation of curve-break flows (cfs) of six channel variables collected from 62 cross sections sampled in riffles in the Yampa River with 50, 75 and 100 percentile flows.

			Percentile		**Flows**
Variable	**Mean Curve-Break Flow**	**Std. Dev.**	**50**	**75**	**100**
Wetted Width (ft)	91.5	43.0	80	125	200
Average Depth (ft)	92.6	36.7	100	125	150
Change in Stage (ft)	93.6	24.8	80	100	150
Width/Depth Ratio	82.6	62.8	60	125	250
Cross Sectional Area (sq ft)	113.1	30.1	100	125	200
Average Velocity (ft/s)	86.5	29.7	100	100	150
Grand Mean	93.3	40.8	100	125	250

flows for all 69 cross sections ranged from 76 cfs (width/depth ratio) to 94 cfs (cross sectional area) (Table 3.7). Variability between runs was high for wetted width, depth, width/depth ratio parameters, but was low for stage and cross sectional area as indicated by the standard deviations (Table 3.7). The means of the curve break flows for five of the six variables were found to be somewhat less for runs than riffles. Velocity was the only variable with a higher curve break flow for the run mesohabitat, and it was 92 cfs compared to 87 cfs for riffles. The grand mean curve break flow for all runs was 87 cfs compared to 93 cfs for riffles.

Table 3.7. Comparison of mean and standard deviation of curve-break flows (cfs) of six channel variables collected from 69 cross sections sampled in runs in the Yampa River with 50, 75 and 100 percentile flows.

			Percentile	Flows	
Variable	**Mean Curve-Break Flow**	**Std. Dev.**	**50**	**75**	**100**
Wetted Width (ft)	86.1	51.9	80	125	250
Average Depth (ft)	87.3	43.7	80	125	250
Change in Stage (ft)	83.7	22.5	80	100	150
Width/Depth Ratio	75.7	61.1	60	100	250
Cross Sectional Area (sq ft)	93.9	28.3	100	100	200
Average Velocity (ft/s)	91.5	35.1	100	125	150
Grand Mean	86.4	42.7	80	100	250

Thirty cross sections were surveyed through pools in the study area, 5 in Stratum 1, 12 in Stratum 2, 0 in Stratum 3, 0 in Stratum 4, 8 in Stratum 6 and 5 in Stratum 8 (Appendix 1, Table 1.5). The mean of curve break flows for pools, 87.1 cfs, was very similar to that found for runs, 86.4 cfs. The velocity curve break was higher in pools, 112 cfs, (Table 3.8), than in runs, 92 cfs, and riffles, 87 cfs. Velocity is very low in pools and fastest in riffles. In pool and run habitats, stream width was fairly stable at low flows, which meant velocity typically did not have a dramatic curve rate break as flows decreased to zero in pools.

Table 3.8 Comparison of mean and standard deviation of curve-break flows (cfs) of six channel variables collected from 30 cross sections sampled in pools in the Yampa River with 50, 75, and 100 percentile flows.

Variable	Mean Curve-Break Flow	Std. Dev.	50%	75%	100%
Wetted Width (ft)	82.8	52.3	60	100	250
Average Depth (ft)	87.3	31.2	80	100	150
Change in Stage (ft)	86.7	24.6	80	100	125
Width/Depth Ratio	61.0	54.3	20	80	250
Cross Sectional Area (sq ft)	92.7	28.2	100	100	150
Average Velocity (ft/s)	111.8	32.9	125	125	200
Grand Mean	87.1	42.9	80	100	250

Curve break flows for riffles, runs, and pools are found in Tables 3.9, 3.10, and 3.11, respectively. Wetted width at curve break flows was narrower for all three mesohabitats in Yampa Canyon than in the upstream strata. The mean wetted widths at curve break flows for riffles, runs, and pools in Yampa Canyon were 105 ft, 132 ft and 110 ft, respectively, while mean wetted widths for these mesohabitats in the upper three strata were 166 ft, 174 ft, and 166 ft, respectively. Curve breaks for wetted width were the most similar of any variable among habitat types. At flows between 80 and 100 cfs, wetted widths for the three mesohabitat types were similar, however, the width/flow relationship was much different between habitat types at flow below 80 cfs. Wetted width decreases rapidly in riffles and typically approaches zero at zero flow. In runs, wetted width decreases, but typically not to zero, while wetted width is maintained at low flows in pools (Appendix 1, Figure 1.1). In addition, riffles display the highest variation in wetted width among the three mesohabitats (Appendix 1, Figure 1.2)

Even though mean curve breaks for wetted widths were similar for the three mesohabitat types, the means for percent wetted perimeter showed greater variability. The mean curve break for percent wetted perimeter was 37% in Yampa Canyon (Strata 1, 2, & 3) and 48% above the canyon (Strata 4, 6, & 8) for riffles. For runs, wetted perimeter was 40% and 54%, and for pools it was 50% and 72% for Yampa Canyon and the upstream strata, respectively. The percent wetted perimeter was larger for all habitat types in the upper strata where the river channel is wider (Tables 3.9, 3.10, and 3.11).

The average velocity curve break for all riffles was 1.5 ft/sec and was similar for all strata (Table 3.9), indicating that channel changes respond similarly to low flows. However, average velocity curve breaks were higher for runs and pools in Yampa Canyon (1.2 ft/sec & 0.7 ft/sec) compared to the upper river (0.6 ft/sec and 0.2 ft/sec. This suggested higher gradients in the canyon for both runs and pools and that the habitat characteristics of pools and runs also were different between the reaches.

Average depth curve break flows were deeper for riffles in Yampa Canyon than the upstream strata (0.8 ft and 0.5 ft, respectively), the same for runs (1.18 ft and 1.18 ft, respectively), and shallower for pools (1.9 ft and 3.2 ft respectively)(Tables 3.9, 3.10, and 3.11). The narrower channel in Yampa Canyon may explain the deeper riffles. Average depths are the same on runs due to narrower and higher gradient conditions in the canyon. The shallower pools in Yampa Canyon are a result of higher pool velocity. These data imply that pools sampled in Yampa Canyon were generally shallower and faster, and therefore, pool characteristics may not be the same between the two reaches.

Table 3.9. Comparison of channel variable means and standard deviations for curve-break points from riffles for strata in Yampa Canyon (strata 1,2, and 3) and above Yampa Canyon (strata 4,6, and 8) and all strata combined (total mean). N=62.

Variable	Total Mean	Total Std. Dev.	Strata 1,2,&3 Mean	Strata 1,2,&3 Std. Dev.	Strata 4,6,&8 Mean	Strata 4,6,&8 Std. Dev.
% Wetted Perimeter	43%	15%	37%	16%	48%	12%
Wetted Width (ft)	138	55.7	105	41.2	166	51.3
Average Depth (ft)	0.64	0.32	0.80	0.40	0.52	0.15
Change in Stage (ft)	1.10	0.55	1.41	0.65	0.85	0.27
Width/Depth Ratio	332	255	194	105	445	286
Cross Sectional Area (sq ft)	82	29.7	79	30.2	84	29.4
Average Velocity (ft/s)	1.47	0.50	1.55	0.49	1.41	0.50

Table 3.10. Comparison of channel variable means and standard deviations for curve-break points from runs for strata in Yampa Canyon (strata 1,2, and 3) and above Yampa Canyon (strata 4,6, and 8) and all strata combined (total mean). N=69.

Variable	Total Mean	Total Std. Dev.	Strata 1,2,&3 Mean	Strata 1,2,&3 Std. Dev.	Strata 4,6,&8 Mean	Strata 4,6,&8 Std. Dev.
% Wetted Perimeter	49%	19%	40%	18%	54%	19%
Wetted Width (ft)	159	65.2	132	74.7	174	54.4
Average Depth (ft)	1.18	0.63	1.18	0.87	1.18	0.44
Change in Stage (ft)	1.27	0.54	1.44	0.66	1.17	0.44
Width/Depth Ratio	215	170	206	159	220	178
Cross Sectional Area (sq ft)	180	118	138	146	203	93
Average Velocity (ft/s)	0.81	0.53	1.18	0.63	0.60	0.31

Table 3.11. Comparison of channel variable means and standard deviations for curve-break points from pools for strata in Yampa Canyon (strata 1,2, and 3) and above Yampa Canyon (strata 4,6, and 8) and all strata combined (total mean). N=30.

Variable	Total Mean	Total Std. Dev.	Strata 1,2,&3 Mean	Strata 1,2,&3 Std. Dev.	Strata 4,6,&8 Mean	Strata 4,6,&8 Std. Dev.
% Wetted Perimeter	60%	19%	50%	15%	72%	17%
Wetted Width (ft)	134	43.7	110	38	166	28
Average Depth (ft)	2.50	1.11	1.94	1.02	3.22	0.76
Change in Stage (ft)	1.28	0.71	1.51	0.84	0.97	0.28
Width/Depth Ratio	74	50.2	89	61.4	57	21.8
Cross Sectional Area (sq ft)	359	212	234	177	522	125
Average Velocity (ft/s)	0.49	0.31	0.67	0.30	0.24	0.08

The curve breaks for the stage/flow relationship were similar among habitat types and about 0.4 ft higher in the canyon. The stage/flow relationship is related to wetted width. Stage increases more quickly in parts of the channel where wetted width increases more slowly. Stage is an expression of water depth. In riffles, stage is measured at the deepest part of the channel (thalweg), and therefore stage is equivalent to maximum depth. In runs and pools the stage of zero flow is dependent on a downstream control point. In the upstream strata (4, 6 and 8), width/depth ratios were much higher for riffles, similar in runs, but were lower for pools compared to Yampa Canyon (Tables 3.9, 3.10, and 3.11).

Habitat Availability

Colorado pikeminnow Diurnal Weighted Useable Area.

Diurnal habitat use of Colorado pikeminnow was restricted to pools/runs in depths exceeding 1.5 ft and half the observations were in pools/runs in depths over 3.8 ft (Chapter 4). Curve break flows for each cluster are in Appendix 1, Table 1.8. The mean of the curve breaks for diurnal habitat was 111 cfs (Table 3.12). The amount of diurnal habitat for Colorado pikeminnow habitat was low (<10%) to very low (<2%) in 23 of the 31 clusters, moderate in 4, and common or abundant in only 4 clusters (Appendix 1, Table 1.8).

Table 3.12. Mean curve break flows for Colorado pikeminnow nocturnal and diurnal WUA, and humpback chub shoreline WUA for each stratum in the study area.

	Colorado pikeminnow				***Humpback chub***	
	Diurnal		**Nocturnal**		**Shoreline**	
Strata	**(cfs)**	**%**	**(cfs)**	**%**	**(cfs)**	**%**
Stratum 1	130	11%	172	46%	116	16.8%
Stratum 2	111	1%	143	35%	144	18.2%
Stratum 3	93	0%	145	12%	130	14.5%
Stratum 4	135	1%	110	24%		
Stratum 6	98	12%	91	33%		
Stratum 8	110	11%	79	30%		
Strata 1,2,3	115	5%	153	34%	121	16.6%
Strata 4,6,8	108	10%	88	31%		
All Strata	111	8%	119	32%		

Colorado Pikeminnow Nocturnal Weighted Useable Area

Colorado pikeminnow were active nocturnally and occupied run and riffle habitats (Chapter 4). Curve breaks for nocturnal WUA averaged 119 cfs for all 31 clusters (Table 3.12). Colorado pikeminnow nocturnal WUA was similar between clusters. As was found in diurnal pikeminnow WUA, the curve break for nocturnal pikeminnow WUA was at a higher flow in Yampa Canyon (153 cfs) than in the upper three strata (88 cfs)(Appendix 1, Table 1.8).

The mean curve break flows for pikeminnow diurnal and nocturnal WUA were higher in Yampa Canyon than in the upper three strata, where the habitat observations were made. Comparison of cross sections in Yampa Canyon to the upper three strata showed that the canyon had shallower and faster runs and pools compared to strata 6 and 8, the telemetry study area. The habitat data indicated that slow deep runs and pools were not as common in the canyon, and therefore, it took higher flows were needed in the canyon to produce the estimated depths that pikeminnow occupied in the upper reaches.

Variability between clusters was low for pikeminnow nocturnal WUA, but high for diurnal WUA (Appendix 1, Table 1.8). Examination of individual clusters indicates that most have a relatively high amount of foraging habitat, but that two-thirds of the clusters sampled lacked available pool habitat. Since most clusters did not have large pool areas (diurnal WUA), pikeminnow may have to move between clusters to locate those with adequate pool habitat.

Humpback Chub Habitat Availability.

Weighted useable area for humpback chub was determined for five habitat clusters in Stratum 1, eight in Stratum 2, two in Stratum 3, and two in Stratum 4. The curve break flows for shoreline useable area ranged from 20 to 250 cfs (Appendix 1, Table 1.8). The mean curve break flow for shoreline useable area was 121 cfs (Table 3.12). The shoreline useable area was 4,877 to 33,929 ft^2. The shoreline eddy habitat ranged in depth from 0.6 to 3.0 ft and water velocity ranged from 0-2.0 ft/s.

Passage

The passage criterion, a maximum depth of 1.0 ft in at least one point on a cross section, was achieved on 50% of the riffles surveyed at a flow of 111 cfs (above Cross Mountain Canyon). The mean flow for the 31 riffles needed to produce a maximum depth (thalweg) of at least 1.0 ft was 153 cfs (Appendix 1, Table1.4).

Discussion

Currently, there is no single reliable method capable of predicting the response of stream biota to changes in flow regime (Allan 1995). Lacking methods that have been rigorously tested against biological variables, we used the hydraulic model to examine channel morphology. Stream channel morphology is a function of streamflow duration and magnitude, size and type of transported sediment, the bed and bank materials of the channel, valley morphology, and basin relief. Wetted 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 interaction among all variables measured. The results of our cross section analysis provide a basic understanding of channel morphology of the study area in the Yampa River.

Cross Section Analysis

Typically, river morphology and structure differ with changes in flow regime, topography, or geology. Yampa Canyon differs from upstream reaches in all three of these aspects. The Little Snake River is a major tributary of the Yampa River, contributing about 25% of the total mean annual flow in Yampa Canyon. The Little Snake River also provides a large sediment load. The river in Yampa Canyon is high gradient, confined by narrow canyon walls with a high proportion of large rocks in the substrate. These factors suggest that Yampa Canyon has habitat characteristics different from those of the upstream reach. The cross section analysis of this study found significant differences in wetted width, depth and other related parameters between Yampa Canyon and upstream areas.

Statistical testing was conducted to determine differences among strata; if no significant differences were found, data from different strata were combined into larger subsets. Strong evidence warranted at least two distinct groups; Yampa Canyon (1,2 and 3) and the upper reach (4, 6, and 8).

Curve Break Points

In spite of physical differences between the river in and above Yampa Canyon, curve breaks were not significantly different. For example, the river in Yampa Canyon is significantly narrower and deeper than above the canyon, but the curve break flows for width and depth were not significantly different. Also, in spite of the fact that the river in Stratum 6 was much wider than in Yampa Canyon, its curve break flows were lower. These results appear to be somewhat contradictory. A wider channel suggests a higher flow or a less confined channel. However, higher curve break flows are found in Yampa Canyon because the channel in that reach must transport a higher volume of water and sediment compared to the river upstream of the Little Snake River. The river in Yampa Canyon is confined by canyon walls but there is evidence of channel widening upstream of the canyon due to bank erosion in grazed bottomlands.

Because this study addressed low flows during the baseflow period, we focused on flow magnitudes between August and October. The curve break analysis identified the relationships of channel characteristics to flow below the 50% exceedance flows in August (i.e., ~300 cfs). The Montana method for identifying minimum flows for fishes uses a curve break flow based on the entire channel, from grassline to grassline (Leathe and Nelson 1986). The Montana approach would have produced curve-break flows much higher if non-baseflow periods were included. For example, the channel begins to fill at flows around 1,200 cfs, and bankfull flow occurs at flows near 8,000 cfs in Stratum 6. Because we focused on the baseflow period (flows ranging from 1 to 300 cfs), curve break flows were restricted to a maximum of only 250 cfs. We believe this method identified flows necessary to avoid habitat degradation, rather than flows that maintain the morphology of riffle habitats.

The riffle grand mean for all curve break flows among all channel variables and strata was 93 cfs. We used this flow as the reference or target to compare flows derived from individual variables, other habitat types or those developed from PHABSIM. The basis for using riffles for identifying minimum stream flows is consistent with the critical riffle approach employed by the R2Cross method, i.e., if riffle habitats are maintained, other habitats will also be maintained. This appeared evident because curve break flows for riffles were slightly higher than for either runs or pools.

The curve breaks identify threshold flows where there are breaks in the energy dynamics of the channel. Riffles have the highest slope and, therefore, the highest energy. Fast currents flowing over large stable substrates create turbulent flow (Gordon et al. 1992). As depths and velocities are reduced the energy characteristic of riffles is reduced. As energy and wetted perimeter are lost, invertebrate populations in riffles may be negatively impacted. An underlying assumption of the curve break approach is that physical conditions that maintain desired mesohabitat (riffles) should be preserved. This is important because there is a strong relationship between a stable and predictable environment and stability and integrity of the aquatic community, a relationship well supported in the literature (Allan 1995, Brown and Brussock 1991, and Brusven et al 1990).

Flows identified by curve breaks were within a fairly narrow range both within, and among mesohabitat types. For all three mesohabitat types, the mean curve break flows fell within a range of 61 to 113 cfs. The mean of the individual curve breaks for riffle cross sections ranged from 83 to 113 cfs. Curve break flows for riffles were found to be at somewhat higher than for runs and pools. Flows of 125 cfs would be sufficient to meet or exceed 75% of the riffles surveyed and presumably maintain ecological integrity of riffle habitats.

Habitat diversity of the Yampa River above Cross Mountain appears to be very low. Runs were by far the dominant habitat type (> 80%) which may be enhanced by current land use practices. Runs have limited production potential for invertebrates in the Yampa River because these habitats are dominated by sand substrate. Because runs are generally poorer quality, efforts need to be directed to maintaining as many functioning riffle habitats as possible. This further suggests that riffles should be the habitat type for basing flow protection.

Habitat Availability

The mean curve break flows for adult Colorado pikeminnow diurnal WUA was 108 cfs in the strata where pikeminnow observations were made, while the mean was 111 cfs (diurnal) for the entire study area. These results suggested that baseflows modeled to maintain Colorado pikeminnow diurnal habitat are about 15 cfs higher than those determined by riffle curve break analysis (93 cfs). The distribution of pools was found to be very patchy and pools were often separated by long distances. The patchy nature of pools in the channel suggested that access to pools may be limited during periods of very low flow. 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. However, if pikeminnow movement between pools is not restricted by low flow, then pool habitat availability is probably not a concern.

During nocturnal periods, Colorado pikeminnow moved across shallow riffles taking temporary positions in the shallower/faster habitats (Chapter 4). The mean curve break flow for nocturnal habitat was 88 cfs in the strata where the telemetry observations were made. Eighty-eight cfs is similar to the mean curve break for runs (86 cfs) in the strata where telemetry observations were made. However, transferring suitability curves from strata 6 and 8 to the canyon strata does not appear to be appropriate, because they produced nocturnal WUA curve break flows (153 cfs) much higher than those for runs (89 cfs). The curve break for suspected foraging (i.e. nocturnal period) Colorado pikeminnow WUA in the upper strata (88 cfs) was somewhat less than found for riffles (93 cfs), and suggests that the 93 cfs baseflow will also maintain adequate habitat for endangered Colorado pikeminnow in the upper strata.

The mean curve break flow for estimated WUA for humpback chub was 121 cfs, which was 27 cfs over the riffle curve break estimates. Maintenance of fish passage supercedes the concerns about habitat availability for endangered fish because fish may need to move between diurnal and nocturnal activity sites. Colorado pikeminnow movement patterns were different between high and low flow years. Movements were longer and more dramatic in the high flow summer 1997 than in the low flow summer of 1996 (Chapter 4). In 1996, when low flows were between 100 and 125 cfs for 10 days in September, pikeminnow moved between a run/riffle sequence during the nocturnal period. During low flow events, larger and deeper pools will presumably offer more foraging potential because the depth of riffles and runs will be substantially reduced. Flows under 111 cfs appear to have greater potential for restricting pikeminnow movements to certain riffle/run sequences. At flows over 111 cfs, movement should not be a problem in at least half the riffles. Conversely, humpback chub moved substantially during the low flow year (Chapter 4). During lower flows and reduced shoreline habitat, fish would be forced to move to alternative habitat.

Passage

Results from riffle cross sections were emphasized for passage because this habitat type is likely to restrict movement at low flows. To achieve an average depth of 0.75 ft across riffles, flow had to be higher than that determined by curve break analysis. The riffle with the lowest flow that resulted in an average depth of 0.75 ft was 67 cfs. Eight riffles did not achieve a 0.75 average depth at flows of at least 500 cfs. The average flow of the riffles with an average depth of 0.75 ft was 342 cfs. Selection of an average depth criterion is important because a small change in average depth can mean large differences in concomitant flows. The average depth at a flow of 93 cfs was 0.52 ft. The passage criterion used for this study was a maximum depth of least 1.0 ft in the cross section. This criterion seems to be a more practical average depth since fish can pass a riffle through the thalweg. This was achieved on 50% of the riffles at a flow of 111 cfs (upper strata). The mean flow for riffles with a thalweg depth of at least 1.0 ft was 153 cfs.

CHAPTER 4: HABITAT USE

Introduction

This chapter presents the results of radio telemetry studies conducted during 1996 and 1997. The studies included both aerial and ground telemetry. The goal of the radio telemetry study was to determine movement, distribution , and seasonal habitat use of Colorado pikeminnow, humpback chub, northern pike and channel catfish for the purposes of developing flow management recommendations.

The specific objectives included:

1) Monitor movements of Colorado pikeminnow, humpback chub, northern pike and channel catfish in the Yampa River during the low flow periods (August through October) to determine the range of movement and habitats occupied during these months.

2) Monitor movements of migrating Colorado pikeminnow to determine the potential of low flow barriers that might prevent the return of postspawned fish.

Movements of Colorado pikeminnow and humpback chub were monitored using radio telemetry to determine: 1) the range of movement during the low flow period, and 2) summer habitat use. Northern pike and channel catfish also were monitored to determine the range of movement during the baseflow period. Colorado pikeminnow movement was monitored following spawning to determine when fish returned from the spawning reach and identify potential physical barriers to migration. In addition to the determination of movement patterns, telemetry data were used to compare sites occupied by Colorado pikeminnow to the availability of habitat during the summer low flow months.

Methods

Upstream of Cross Mountain Canyon

Ten adult Colorado pikeminnow, five adult channel catfish, and five adult northern pike were opportunistically implanted with radio transmitters in a cooperative effort by personnel from Miller Ecological Consultants, Colorado Division of Wildlife, and U.S. Fish and Wildlife Service (USFWS) in

1996 and 1997 (Table 4.1). Four Colorado pikeminnow and three northern pike were collected by angling. All other fish were collected by electrofishing. Radio transmitters were implanted using procedures developed by the USFWS. Fish were anesthetized with MS-222 and transmitters were surgically implanted into the body cavity. Fish were observed in a recovery tank for a minimum of 10 minutes. When fully recovered from the anesthetic, they were released at the location of capture.

Radio tracking was conducted on a biweekly basis from 22 July, 1996 through 26 October, 1996 and 20 July, 1997 through 26 September, 1997. Observations were made on five consecutive days each week that tracking was conducted. We attempted to locate all fish at least once each observation week. After a fish was located it was monitored for a minimum of 30 minutes (Colorado pikeminnow were monitored for a minimum of one hour). During this monitoring period, the date, time of day, weather conditions, water and ambient air temperature, length of time monitored, and any observations of local movement were recorded, along with a sketch of the surrounding habitat including fish locations. Other physical habitat data were collected whenever possible, including habitat type, total water column depth, water velocity (mean column and bottom), substrate type, proximity to cover, description of cover at the location, general description of the site, and measurements of the habitat including length, width, bank features, shoreline vegetation, dominant substrate and cover. Discharge was obtained from the USGS gaging station near Maybell, Colorado.

Twenty-four-hour observations were made in both 1996 and 1997 on Colorado pikeminnow. One Colorado pikeminnow was monitored for a continuous 24-hour period during each observation week. The fish was located and observed for movement approximately every hour except for some short periods when weather interfered. All observed activity, movement and habitat use by fish during this time was recorded.

Aerial surveys were conducted from fixed-wing aircraft using a wing-mounted antenna during each observation week to determine approximate fish locations within the river. Fish and Wildlife Service personnel obtained the fish locations from the air in 1996. Aerial surveys in 1996 were usually conducted on the second or third day of the observation week. The location procedure consisted of an upstream flight over the entire river reach followed by a downstream flight to obtain fish transmitter signals.

Table 4.1. **Species, radio frequencies, and capture locations for implanted fish in the Yampa River, Colorado.**

Species	Freq. (MHz)	Length (mm)	Weight (g)	Date (1996)	Capture Location (RM)
Colorado Pikeminnow	40:7810	522	965	25 Jul.	94.6
Colorado Pikeminnow	40:7410	676	--	27 Aug.	82.7
Colorado Pikeminnow	40:6840	569	1301	27 Aug.	82.7
Colorado Pikeminnow	40:6635	562	1437	29 Aug.	95.4
Colorado Pikeminnow	40:7143	573	1541	29 Aug.	95.4
Channel Catfish	40:5539	539	1768	25 Jul.	97.2
Channel Catfish	40:6732	657	--	25 Jul.	97.2
Channel Catfish	40:6532	535	1722	23 Jul.	79.5
Channel Catfish	40:7033	606	--	23 Jul.	79.5
Channel Catfish	40:7719	466	916	23 Jul.	78.5
Northern Pike	40:5834	635	1768	25 Jul.	95.1
Northern Pike	40:5440	525	979	26 Jul.	78.5
Northern Pike	40:7919	648	1722	23 Jul.	78.5
Northern Pike	40:6135	625	1541	29 Jul.	80.1
Northern Pike	40:5936	825	--	26 Jul.	77.2
Species	**Freq. (MHz)**	**Length (mm)**	**Weight (g)**	**Date (1997)**	**Capture Location (RM)**
Colorado Pikeminnow	40:8555	649	2400	8 May	99.6
Colorado Pikeminnow	40:8455	580	1614	8 May	99.6
Colorado Pikeminnow	40:5125	542	1456	8 May	98.0
Colorado Pikeminnow	40:5021	587	1656	8 May	97.5
Colorado Pikeminnow	40:8041	539	1358	8 May	103.2

Miller Ecological Consultants personnel located fish from the air in 1997. The 1997 aerial surveys were conducted on the first day of each observation week. In 1997, the suspected fish locations were confirmed by repeated circling of the aircraft over suspected fish locations to confirm the transmitter signal. Ground contact surveys began immediately after the aerial surveys to confirm fish locations.

Specific fish locations in the river were obtained during ground surveys by walking the shoreline or floating the river. After signal contact was made, the crew would locate the fish position using a triangulation method from positions along the shore. When possible, the crew would obtain a strong signal and a null at a location upstream of the fish location; then the crew would move to a position directly across from the fish and obtain a second null signal. The fish position was the intersection point on the lines from the two null signals. Usually this location was verified by obtaining third null signal at a downstream location. This exact procedure was precluded at times by fish position, topography, or private property restrictions. In those instances, fish position was estimated from at least one shore or boat position.

Downstream of Cross Mountain Canyon

Radio telemetry was designed to provide information on range of movement during the low flow period, specific habitat use during the low flow period, and daily habitat use and movement for Colorado pikeminnow and humpback chub. Channel catfish were also implanted to define the range of movement and distribution in Yampa Canyon. Five fish of each species (Colorado pikeminnow, humpback chub and channel catfish) were implanted with radio transmitters in July 1996 and five humpback chub and two channel catfish were implanted with transmitters in July 1997 (Table 4.2). All transmitters were equipped with internal antennas except the five humpback chub in 1997 that were implanted with external antenna transmitters to improve radio signal reception. Fish were collected by either angling or electroshocking. Weekly aerial surveys of all fish implanted were made between 5 August and 20 September 1996 (excluding the 2nd week of September due to conflicts with fire fighting activities in Dinosaur National Monument [DNM]) and between 24 July and 22 August 1997. In addition, other aerial flights were made on 29 October 1996 and 21 October 1997 in an attempt to determine if implanted fish migrated to different locations to overwinter. Seasonal movement of fish was compared with flow changes in the river.

Table 4.2. List of frequencies, dates, and locations of fish implanted with radio transmitters in the Yampa River Canyon during the baseflow periods of 1996 and 1997.

Species	Freq.	Date	TL (mm)	WT (g)	RM	Transmitter Duration	Antenna Type
Humpback chub	40.271	7/1/96	282	170	37.5	6 month	Internal
Humpback chub	40.262	7/3/96	302	216	23.8	6 month	Internal
Humpback chub	40.281	7/3/96	283	192	18.2	6 month	Internal
Humpback chub	40.241	7/4/96	287	180	16.8	6 month	Internal
Humpback chub	40.211	7/15/96	276	162	36.2	6 month	Internal
Humpback chub	40.461	7/8/97	259	186	26.4	6 month.	External
Humpback chub	40.451	7/10/97	336	445	20.5	6 month	External
Humpback chub	40.442	7/10/97	325	257	18.2	6 month	External
Humpback chub	40.481	7/15/97	286	193	37.5	6 month	External
Humpback chub	40.471	7/15/97	298	196	37.5	6 month	External
Channel catfish	40.644	7/2/96	435	740	36.0	24 month	Internal
Channel catfish	40.574	7/4/96	460	825	18.2	24 month	Internal
Channel catfish	40.694	7/4/96	476	844	16.8	24 month	Internal
Channel catfish	40.253	7/15/96	468	973	39.5	24 month	Internal
Channel catfish	40.604	7/15/96	531	6037	37.3	24 month	Internal
Channel catfish	40.162	7/7/97	645	2706	26.6	6 month	Internal
Channel catfish	40.152	7/8/97	570	1452	34.5	6 month	Internal
Colorado pikeminnow	40.724	7/3/96	543	--	23.8	24 month	Internal
Colorado pikeminnow	40.633	7/3/96	561	--	23.8	24 month	Internal
Colorado pikeminnow	40.623	7/3/96	530	1247	23.8	24 month	Internal
Colorado pikeminnow	40.563	7/3/96	535	--	23.8	24 month	Internal
Colorado pikeminnow	40.733	7/3/96	555	--	23.8	24 month	Internal

Sampling trips were made 1-5 July, and 15-19 July, 1996 to implant study fish and monitoring trips were made 3-6 September, and 30 September through 5 October, 1996. During the first trip five Colorado pikeminnow (all at RM 23.8), four humpback chub (RM 37.5, 23.8, 18.2, and 16.8), and three channel catfish (RM 36.0, 18.2, and 16.8) were implanted with transmitters (Table 4.2). During the second collection trip in 1996, one humpback (RM 36.2) and two channel catfish (RM 39.5 and 37.3) were collected. In 1997 three humpback chub (RM 26.4, 20.5, and 18.2) were implanted between 7 and 10 July and two more implanted on 15 July at river mile 37.5. Two channel catfish were implanted with radio transmitters on 8 July at river miles 26.6 and 34.5 in 1997.

Three trips in 1996 and two trips in 1997 were made in August and September in an effort to monitor 24-hour movement for humpback chub and Colorado pikeminnow. Boats or rafts equipped with whip antennas were used to locate fish and exact locations were determined using directional antennas. In 1996 no fish were located from the ground, and in 1997 only two humpback chub were monitored over a twenty-four hour period. Because limited information on habitat use of humpback chub was collected with telemetry, habitat use data collected by the Colorado River Fish Project from Yampa Canyon between 1981 and 1989 were compiled and used together with the telemetry data collected in this study.

Colorado pikeminnow migrational passage

The potential for low flow barriers to postspawning migrant Colorado pikeminnow in the Yampa River was evaluated in 1997 by monitoring movement through two potential barriers, Cross Mountain Canyon (RM 58.8) and the Maybell Diversion (RM 89.4). Six month transmitters were surgically implanted in five Colorado pikeminnow in the second week of May 1997 in the Yampa River between Government Bridge (RM 98.8) and Morgan Gulch (RM 103.7) (Table 4.1). Fish were collected by Colorado Division of Wildlife during ISMP monitoring, and transmitters were implanted by U.S. Fish and Wildlife Service personnel. Following implantation, two stationary telemetry logging stations were established. One was approximately 0.6 miles above Cross Mountain Canyon and the other directly above the Maybell Diversion. Location of the telemetry station directly at the mouth of the canyon was not possible because it was within the boundary of a wilderness study area. Telemetry logging stations were located in cooperation with the U.S. Bureau of Land Management.

Both stationary logging stations consisted of two, four filament Yagii antennas, one pointing upstream and one downstream. Antennas were connected to LOTEK model SRX 400 logging receivers, which continually scanned 11 Colorado pikeminnow frequencies (four fish implanted in 1996, five fish implanted in 1997 and two fish occupying Yampa Canyon in 1996). The Cross Mountain became operational on 2 June 1997 and the Maybell Diversion station on 23 June 1997. However, difficulty with compatibility of receiver to transmitters prevented efficient operation of the Cross Mountain and Maybell Diversion stations until 30 June and 4 July 1997, respectively. The logging receivers were powered by a photovoltaic panel equipped with a battery that stored electricity. Thus, movements of fish past logging stations were monitored continuously from late June - early July until the stations were dismantled in September 1997. Data from logging stations were retrieved on a weekly basis for the first 3 weeks following installation to monitor performance and potential vandalism, thereafter stations were monitored biweekly.

Results

Upstream of Cross Mountain Canyon

<u>Colorado Pikeminnow</u>.

In 1996, Colorado pikeminnow remained approximately at the locations they were tagged except for CS663 which moved approximately 7 miles upstream then 7 miles downstream at the end of the year's observations (Figure 4.1). In 1997, one Colorado pikeminnow from 1996 and five new fish were tagged in 1997 and monitored. Most fish remained within a short river reach as in 1996. In 1997, one fish, CS513, moved approximately 60 miles upstream from the point of initial contact in August until the end of tracking in September (Figure 4.2).

Colorado pikeminnow exhibited both local and long-distance movement patterns throughout the study. The 1996 flows did not prevent the upstream movement through shallow (<0.5 ft) riffles or the Patrick Sweeney Diversion structure. In 1996, flows were less than 95 cfs for 2 days and below 125 cfs for nine days (Figure 3.1). On most 24-hour observations, local movements of several hundred feet by the fish were being observed, with movement peaking after dusk. Movement activity increased after dark with fish moving either upstream or downstream to a probable feeding location and then returning to the original observation point (Figure 4.3a, 4.3b).

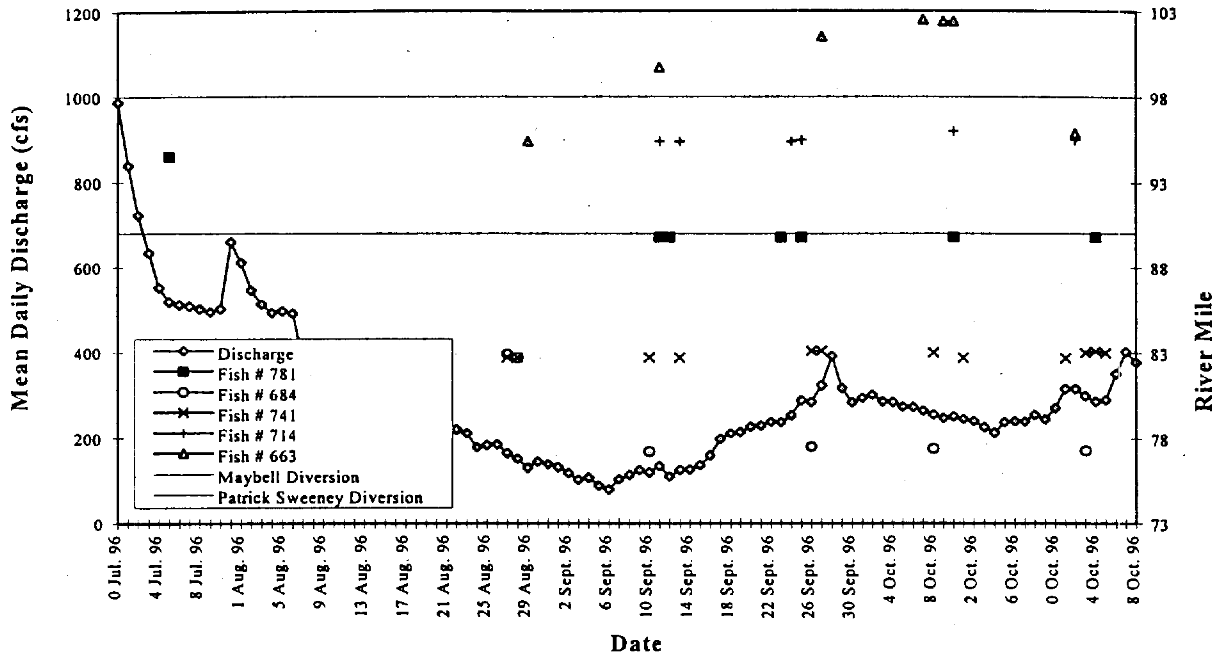


Figure 4.1. Colorado pikeminnow locations and mean daily discharge, 1996 study period.

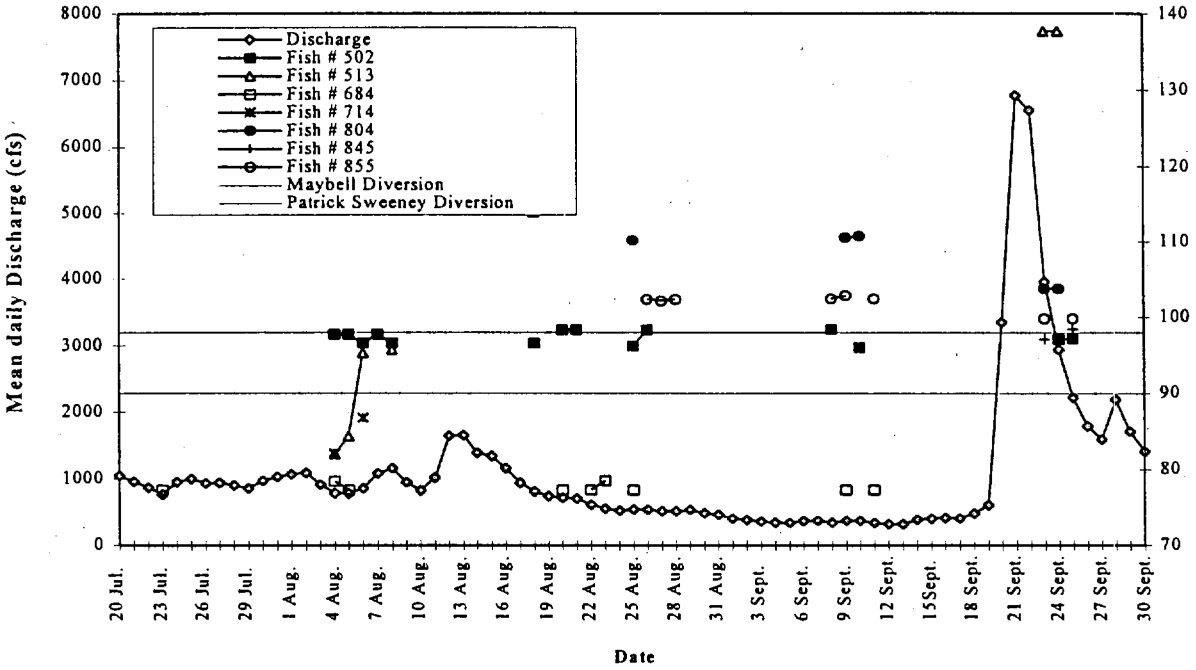


Figure 4.2. Colorado pikeminnow locations and mean daily discharge, 1997 study period.

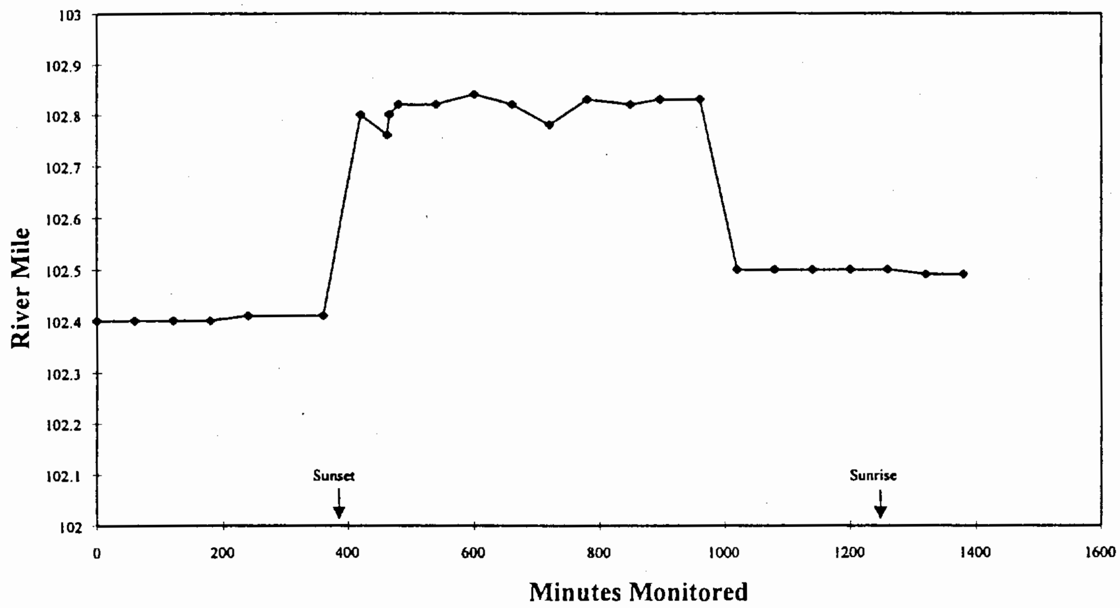


Figure 4.3a. Locations of Colorado pikeminnow CS855 in river miles during a 24-hour observation (September 9, 1997).

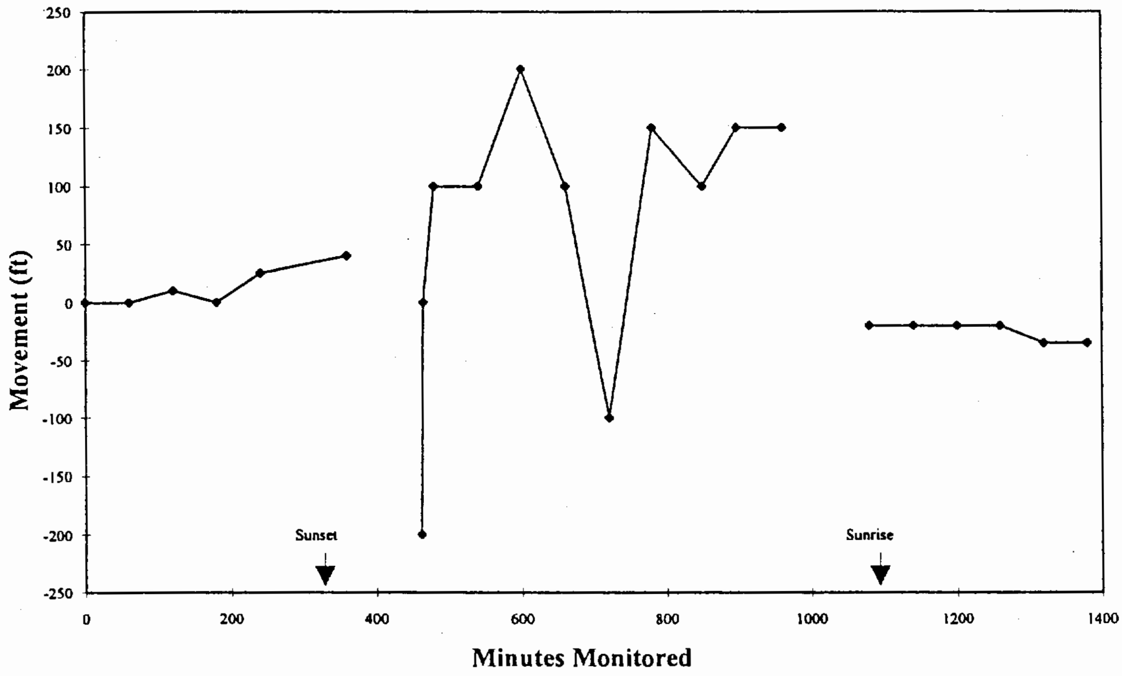


Figure 4.3b. Locations of Colorado Pikeminnow CS855 in feet during 24-hour observation (September 9, 1997).

At various times during 24-hour observations, Colorado pikeminnow occupied most of the available habitats in the Yampa River. The range of microhabitats, depths, and velocities used varied between day and night. During most environmental conditions (excluding events of high water and turbidity) pikeminnow occupied deep pools during the day where they remained mostly inactive. Results of 24-hour observations during the two study years showed that most movement between habitats and river locations occurred at night. Additionally, the observations suggested that foraging activity may also occur at night. The specific area used during "foraging activity" probably depends on a variety of environmental conditions as well as individual fish preference. The data suggested that the channel margins, and upper and lower ends of pools were used primarily during the low water conditions that prevailed during 1996. Observations during 1997 (a higher water year) indicate that most fish moved into shallow runs or riffles during the night and showed a presumed foraging type behavior similar to 1996. The depths of most habitats used at night were shallower than habitats used during the day. Colorado pikeminnow were located in, or observed moving through, a wide range of velocities at night.

Colorado pikeminnow almost exclusively used pools throughout the observation period from July through October in 1996 (Figures 4.4 and 4.5). Two of the five fish implanted used run habitat only occasionally during the eight weeks of observations conducted on the river. In addition, one fish used an eddy pool, but less than 5% of the time of observation. Observations in 1997 focused on 24-hour periods to develop a larger data set for specific diurnal and nocturnal habitat use patterns of Colorado pikeminnow. There was a distinct habitat use pattern over a 24-hour cycle for all of the pikeminnow observed. The fish showed what appeared to be a resting activity during daylight hours and a feeding activity after sunset, returning to a resting mode at sunrise. This pattern was exhibited in all of the 24-hour observations in 1996 and 1997.

The combined 24-hour observations show that pikeminnow predominantly used pool and eddy habitats in 1996 and pools and runs in 1997 based on the percentage of time monitored (Figure 4.4). The routine daily contacts were very similar to that of the combined 24-hour observations of 1997 and 1996 (Figure 4.5).

Colorado pikeminnow were found mostly at depths over 3 feet during daylight hours. Shallower depths were used at night when fish were active (Figure 4.6). During night observations, fish were located at depths as shallow as 1.2 feet with only a few contacts deeper than 3.2 feet. The deeper night locations were observed during the 1996 lower flow year.

Figure 4.4. Habitat use for Colorado pikeminnow during 24-hour observations in the Yampa River, Colorado.

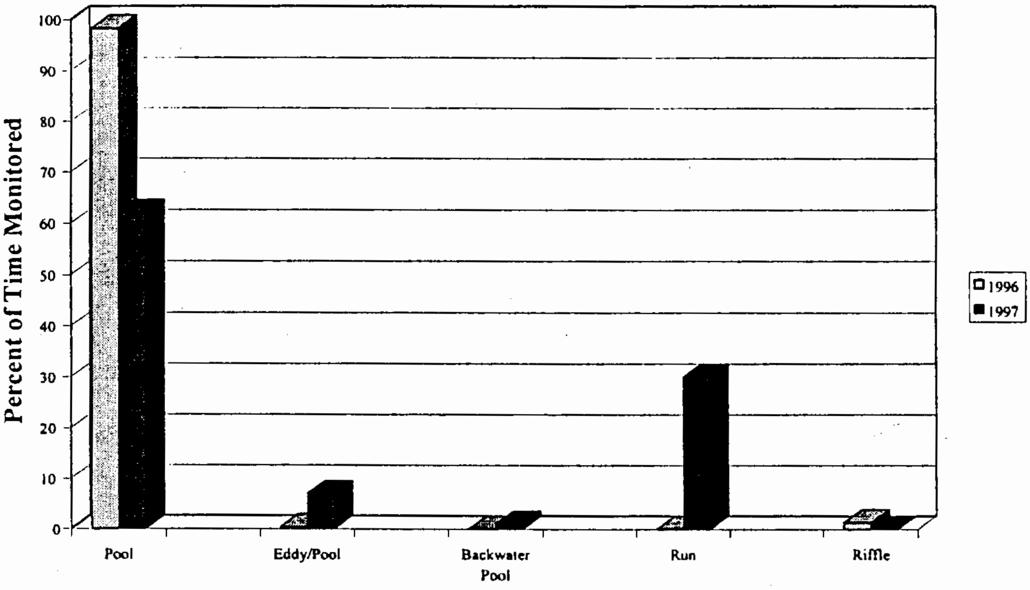


Figure 4.5. Habitat use for Colorado pikeminnow during daily contacts in the Yampa River, Colorado.

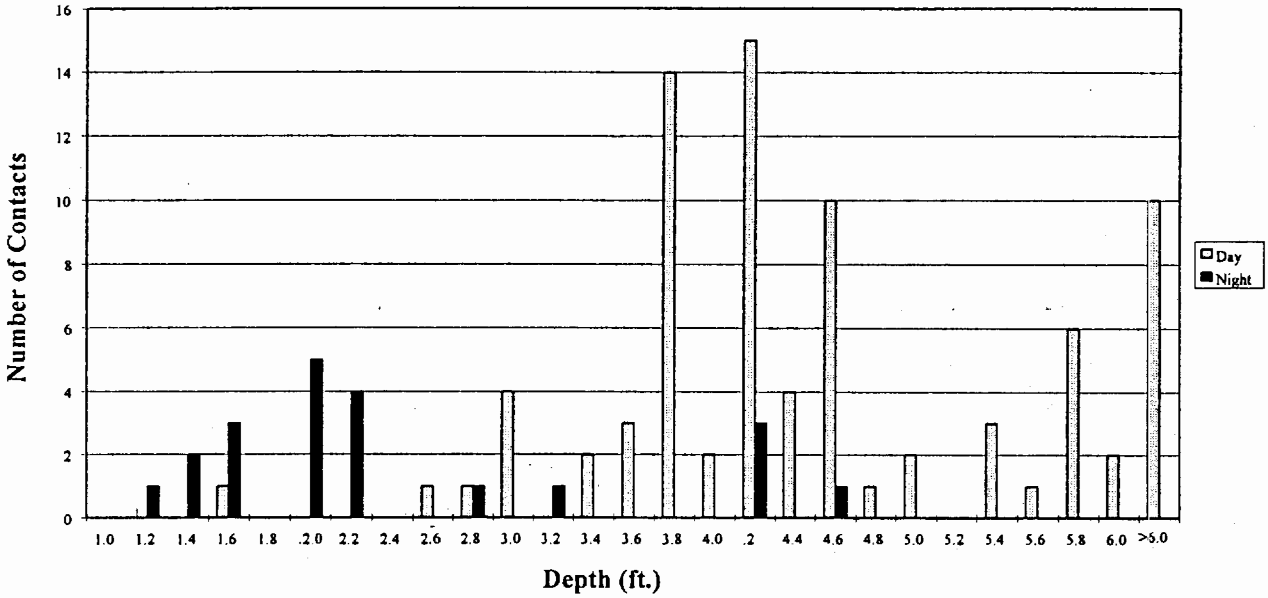


Figure 4.6. Depth of all habitats used by Colorado pikeminnow during day and night contacts.

Pikeminnow were found at different stream velocities between diurnal and nocturnal contacts. Daylight contacts show a use of lower velocity habitats. Nocturnal contacts show a wider range of velocities extending up to bottom velocity of almost 2 feet per second (Figure 4.7). Mean column velocity measured at daytime locations of pikeminnow ranged from 0 to 2.1 feet per second. Fish showed a wider range from 0 to over 2.5 feet at night (Figure 4.8). The fish were more sedentary during the day; therefore bottom velocity is probably a better indicator of the actual velocity experienced by the fish. During the portions of the night when the fish is moving across, up, and down the stream, the mean column velocity is probably more indicative of velocities experienced by the fish.

Habitat use by Colorado pikeminnow during 1996 and 1997 again showed a distinct pattern over the 24-hour observation period. Diurnal observations showed a distinct use of pool habitat, with some use of run habitat (Figure 4.9). Almost 80% of the time in 1997 and over 90% of the time in 1996, fish were observed in pool habitat during daylight hours. Nocturnal observations for 1997 showed a distinct use of higher velocity habitats over 50% of the time observed in runs and nearly 20% of the time spent in riffles (Figure 4.10). In 1996, pool habitat had been used almost 90% of the time during night observations, however, the activity level, even though it was within the pool, was higher than the daytime resting mode.

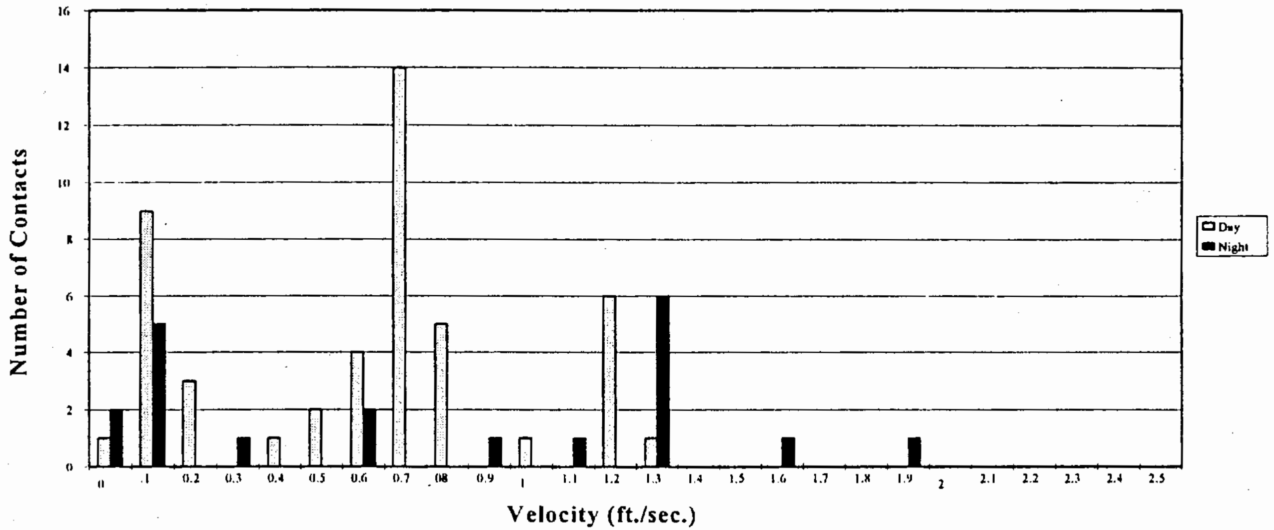


Figure 4.7. Bottom velocity of all habitats used by Colorado pikeminnow during day and night contacts.

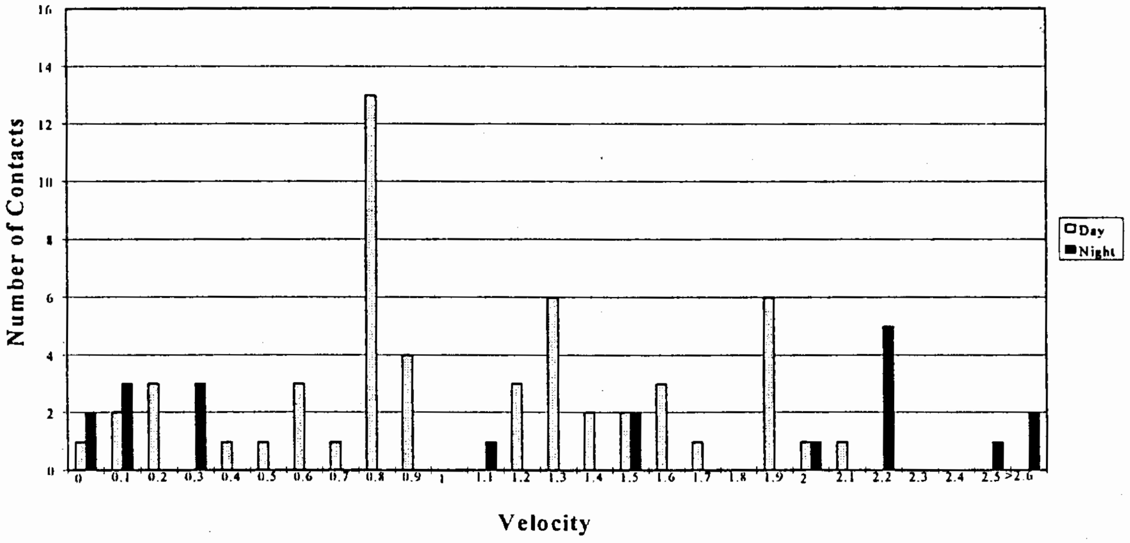


Figure 4.8. Mean column velocity of combined habitats used by Colorado pikeminnow during day and night contacts.

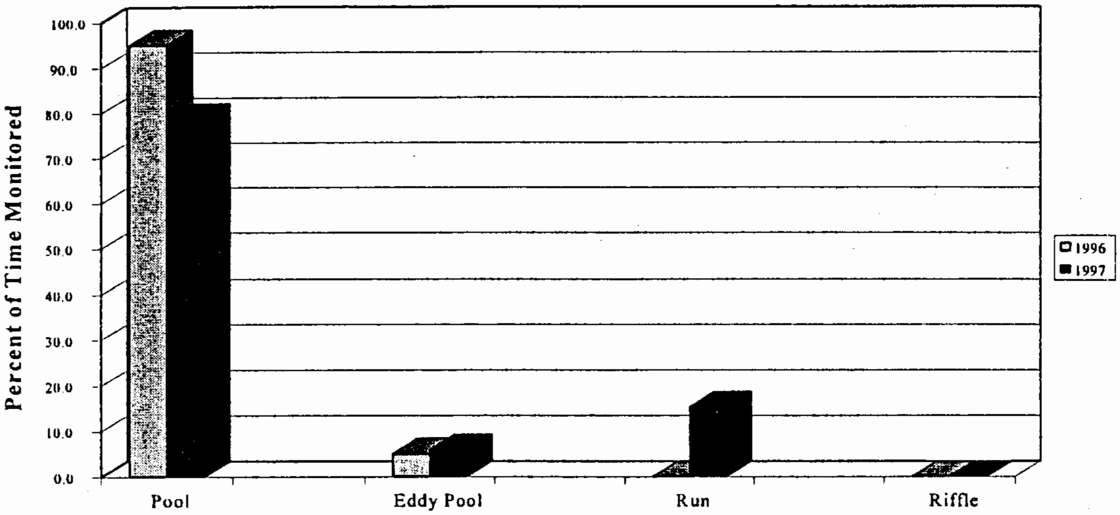


Figure 4.9. Habitat use during the day for Colorado pikeminnow in the Yampa River, Colorado.

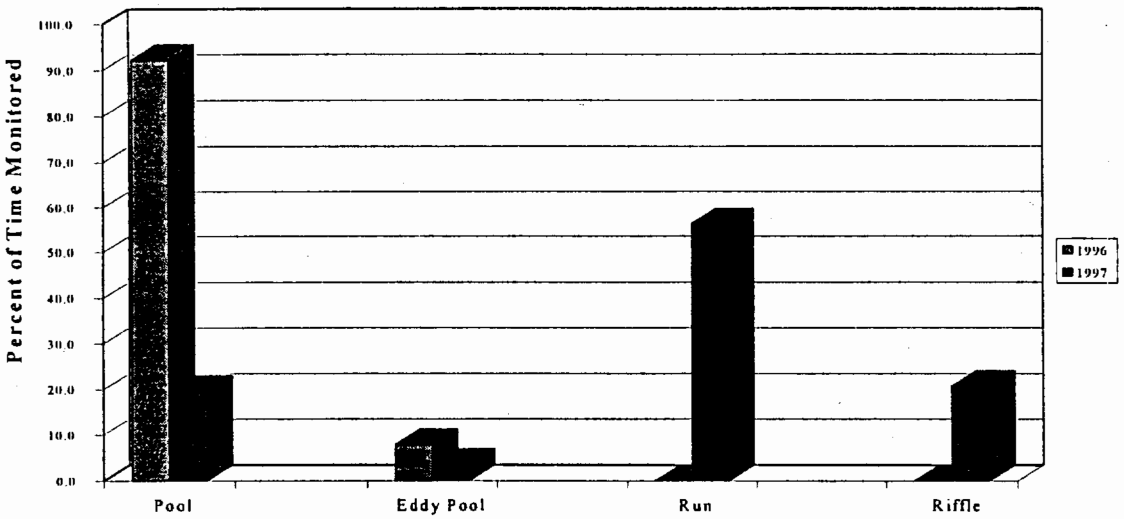


Figure 4.10. Habitat use during the night for Colorado pikeminnow in the Yampa River, Colorado.

Channel catfish and northern pike

Channel catfish and northern pike showed little movement during the study. Most of these fish remained in the same river mile where they were originally captured with the exception of two channel catfish that moved downstream approximately 4 miles by late October. One was located by the ground crew; the other was located only by aerial telemetry.

During the only 24-hour observation of a northern pike, local movement was similar to Colorado pikeminnow. Activity increased after dusk, when the fish moved upstream several hundred feet. Movement peaked just before midnight and the fish returned to its original location before dawn the next day.

Channel catfish used pools most of the time but also used runs (Figure 4.11). Catfish used run habitat more frequently than Colorado pikeminnow, which could be indicative of a difference in feeding behavior, general habitat use differences or intensity of observations.

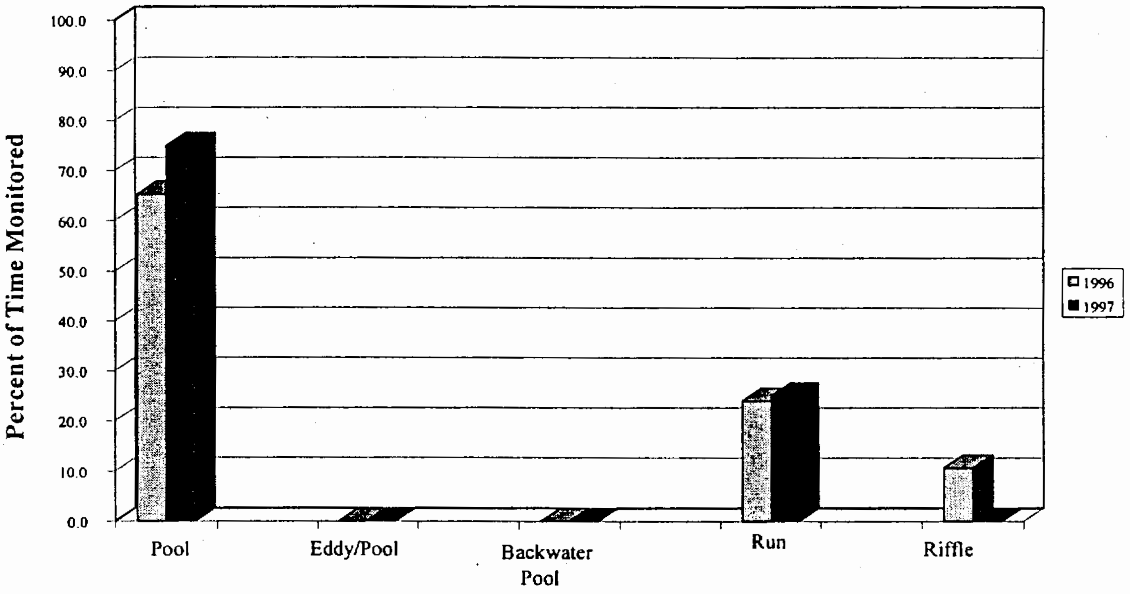


Figure 4.11. Habitat use for channel catfish during daily contacts in the Yampa River, Colorado.

Northern pike, like Colorado pikeminnow, mainly used pools during the study. However, these fish also used some backwater habitats. This was the only species observed using backwater habitat during the low flow period (Figure 4.12).

Habitat use by channel catfish and northern pike shows similar behavior to Colorado pikeminnow in the daytime contacts (Figures 4.13 and 4.14). Habitat use was almost identical for channel catfish and northern pike in both 1996 and 1997. In 1997, northern pike used predominantly backwater pools rather than main channel pools.

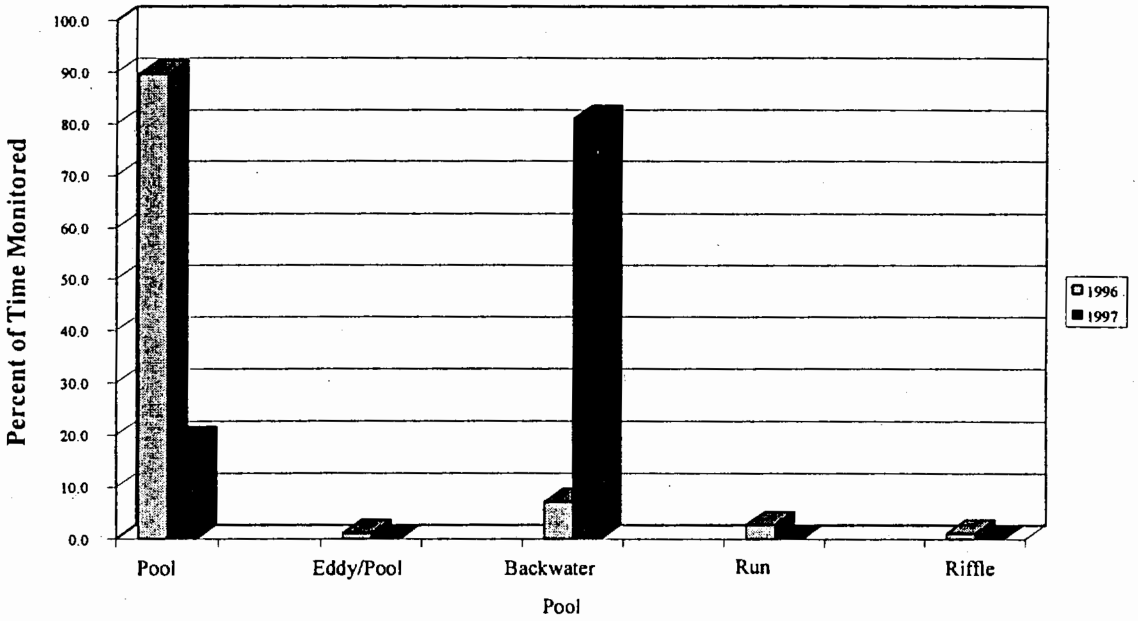
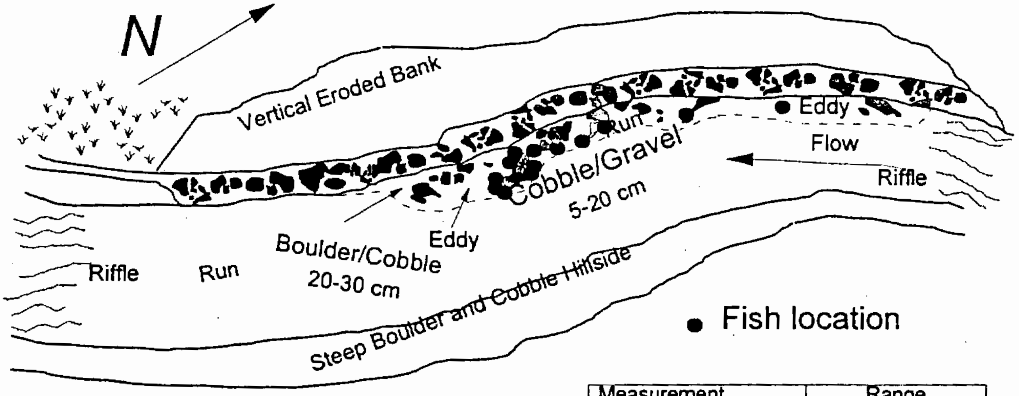


Figure 4.12. Habitat use for northern pike during daily contacts in the Yampa River, Colorado.

Downstream of Cross Mountain

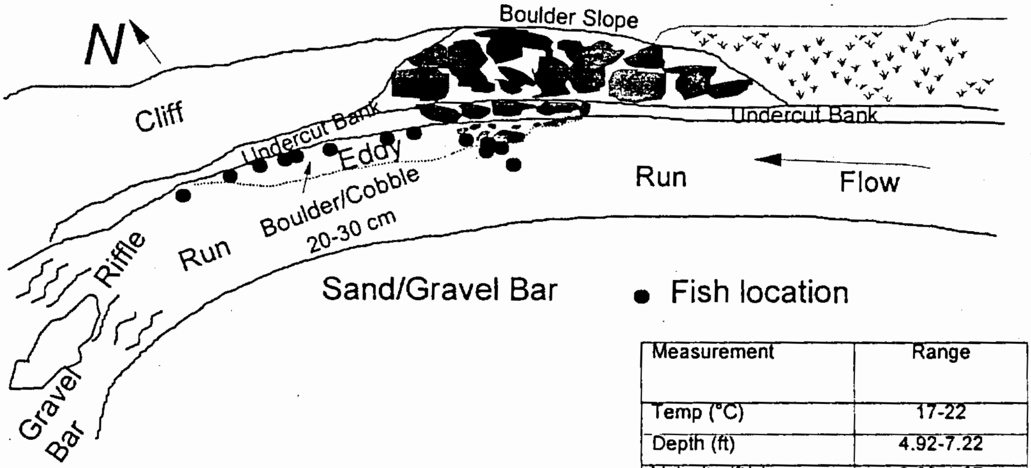
During three telemetry monitoring trips in 1996, ground contacts were made with only two fish, a Colorado pikeminnow (frequency 40.633 at RM 10.3) and a channel catfish (frequency 40.574 at RM 18.2), both during the 3-6 September trip. The Colorado pikeminnow transmitter indicated no apparent movement. The location of both fish with fixed-wing aircraft was recorded as river mile 10.7 (40.633) and 18.1 (40.574) on 4 September 1996. Thus, either the fish had shed the transmitter or died following implantation. No ground contact was made with any humpback chub in 1996. In an effort to increase the efficiency of finding fish in Yampa Canyon, a large 18-foot whip antenna was used during the second monitoring trip; however, no fish were contacted.

The two humpback chub (RM 18.1 and 35.3) monitored over a 24-hour period between 6-8 August 1997 showed only short local movements. Fish 40.471 was downstream of Teepee Rapid and remained in shallow, nearshore habitat throughout the 24 hours monitored (Figure 4.13). Average water column depth used was 1.34 ft, average water column velocity was 0.53 ft/s and the dominant substrate was boulder. Fish 40.451 was located at river mile 18.1, above Mathers Hole. It also remained in nearshore habitat and did not move outside of the eddy habitat it occupied (Figure 4.14). Unlike the fish below Teepee Rapid,



Measurement	Range
Temp (°C)	17-20
Depth (ft)	1.35-2.66
Velocity (ft/s)	0.03 - 1.28

Figure 4-13. Locations (dot) of humpback chub 40.471 recorded every two hours over a 24 hour period at river mile 35.3 in the Yampa River on 7 August 1997.



Measurement	Range
Temp (°C)	17-22
Depth (ft)	4.92-7.22
Velocity (ft/s)	0.03-1.67

Figure 4-14. Locations (dot) of humpback chub 40.442 recorded every two hours over a 24 hour period at river mile 18.1 in the Yampa River on 8 August 1997.

fish 40.451 was found in deeper water, exceeding 5.94 ft, but used nearly the same average water column velocity (0.56 ft/s) and was also found primarily in boulder habitat. Despite using different depths, both humpback chub used habitats adjacent to the shoreline. In the absence of a large telemetry database on habitat use, a summary of habitat use data from the humpback chub in Yampa Canyon (CRFP, unpublished data) was analyzed. A comparison of 153 humpback chub collected from Yampa Canyon between 1980 and 1997 indicated that most fish were collected in eddy or eddy-related habitats (Figure 4.15). The same database indicated that most fish collected were associated with shoreline structure rather than main channel or side channel habitats (Figure 4.16).

Of the five Colorado pikeminnow implanted in 1996, two left Yampa Canyon during the second week of August, 1 month following implantation. One fish either died or lost its transmitter and two fish remained in Yampa Canyon through the low flow period until at least 29 October 1996. Of the two Colorado pikeminnow that remained in Yampa Canyon, one remained in the upper canyon and the other in the mid to lower reach of the canyon. Both fish appeared to remain in the same general areas of the river following 15 August (Figure 4.17). Between mid-August and late September, one fish ranged from RM 12.1 to 20.1 (Freq. 40.733), and the other (Freq. 40. 623) from RM 39.1 to 43.3. On 29 October these fish were found at RM 21.6 (Freq. 40.733) and 29.7 (Freq. 40.623). On 22 April 1997, both pikeminnow were still in Yampa Canyon (Freq. 40.623 at river mile 33.7, and Freq. 40.733 at river mile 27.8) suggesting they may have spent the winter in the canyon. Both fish were located in the vicinity of the spawning area during the first aerial contact on 24 July 1997. They moved upstream afterward and remained in Yampa Canyon through 13 August 1997.

Considerable movement was observed among the five humpback chub implanted with transmitters (Figure 4.17, Appendix 2, Table 2.4) in 1996. Average distance traveled between aerial survey sightings was 6.2 river miles, and the average total distance traveled was 44.0 miles during the baseflow months between July and September. Greatest movement occurred prior to the third and fourth week of August and coincided with low discharge. During baseflows, the distance moved between location dates decreased. All humpback chub were observed to move upstream at some time during the low flow period, indicating that all fish survived. By the end of October 1996, all fish were found above RM 24.2. In 1997, they showed less movement, with an average distance between contacts of only 3.8 river miles and an average total distance of 30.3 river miles. However, there were fewer observations in 1997. When the total distance traveled is adjusted for an equivalent number of observations, the total distance traveled in 1997 was about 56% of that observed in 1996. Differences were also detected in the distance traveled

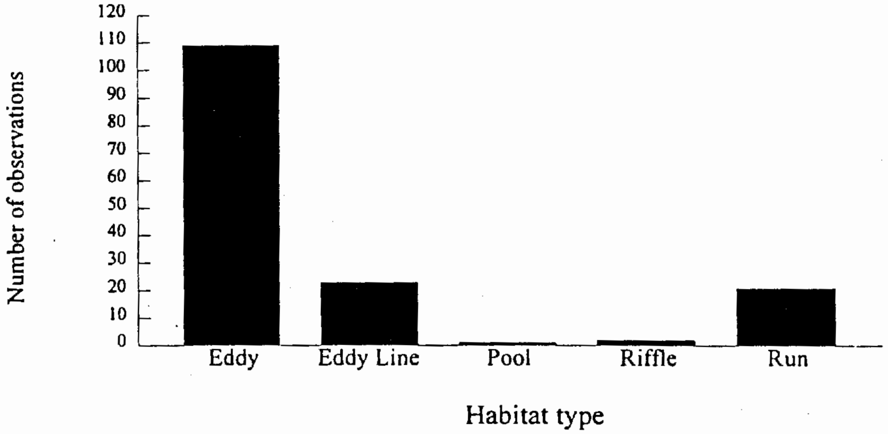


Figure 4-15. Macrohabitats used by humpback chub in the Yampa River (1986-96).

(1986-1993).

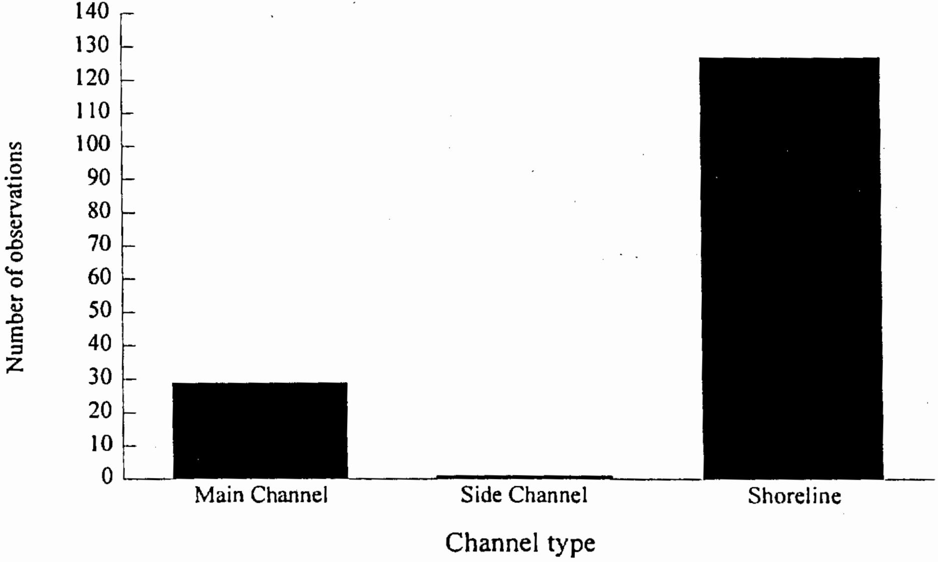


Figure 4-16. Channel location in which humpback chub were collected in the Yampa River

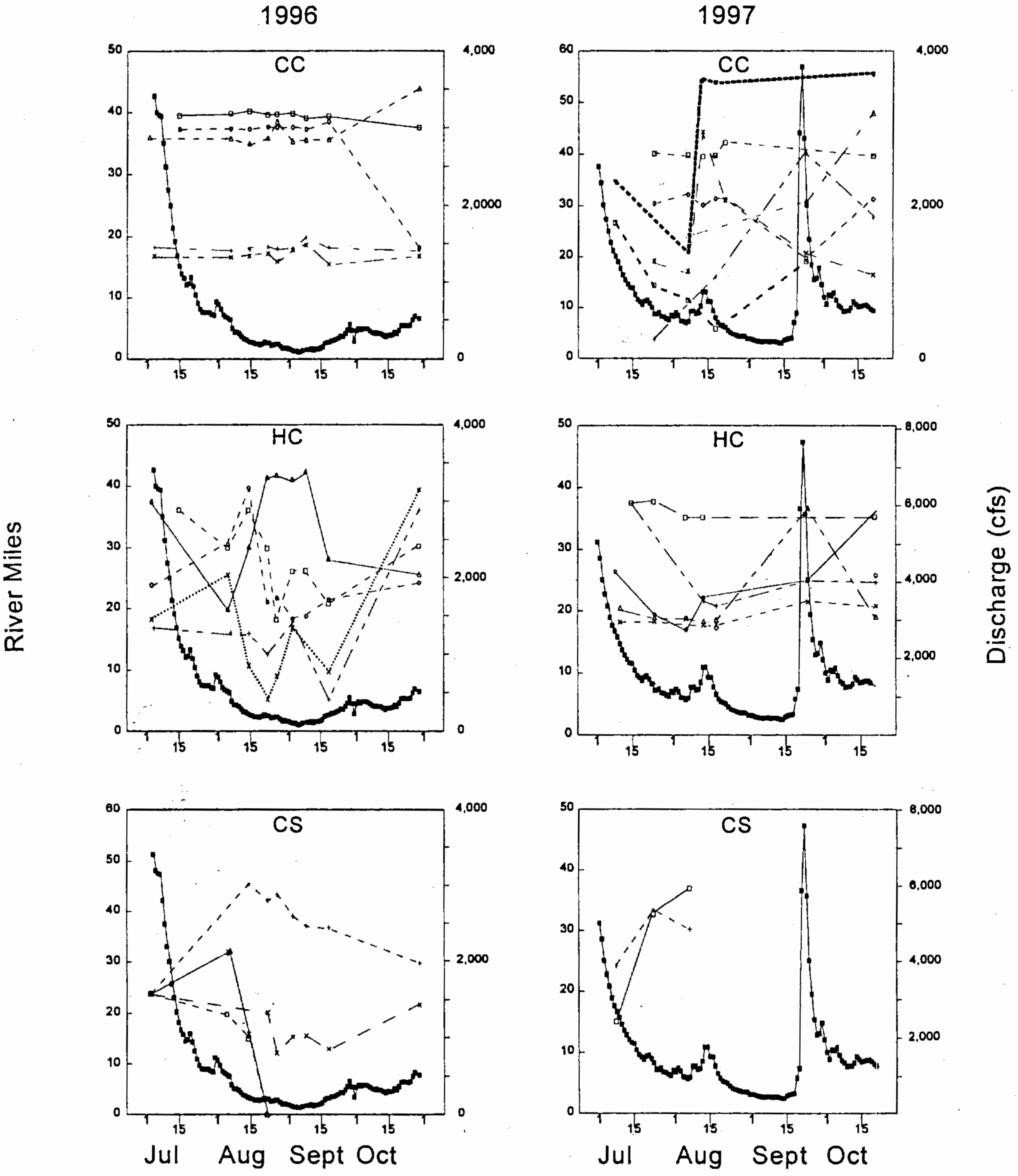


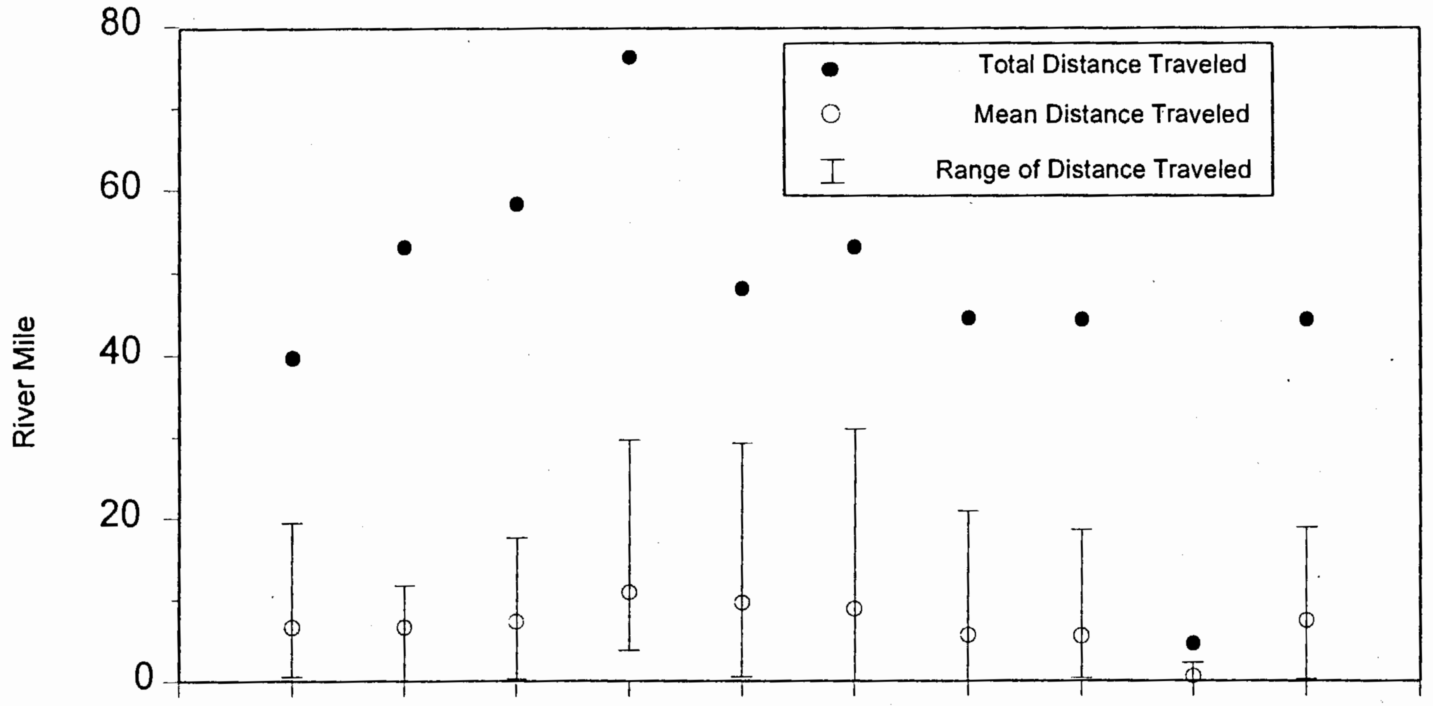
Figure 4-17. Flows and aerial contacts of channel catfish (CC), humpback chub (HC), and Colorado squawfish (CS) from the Yampa River during the baseflow period in 1996 and 1997.

following implantation. In 1996 the average distance between the initial collection site and last site located in late October was 11.7 miles, whereas in 1997 the average distance was only 5.4 miles. Although some differences existed in the size of fish implanted between years, no differences were observed in distance traveled by size (Figure 4.18).

Movement of humpback chub was determined almost entirely from observations from fixed-wing aircraft. Therefore, variation in the location of fish was not verified and distances traveled represent an estimate of actual mileage. Ground verification of aerial observations was made for two humpback chub on two occasions in 1997. On 6 August 1997, transmitter frequencies 40.442 and 40.471 were located at RM 18.7 and 35.3 with aircraft and were also located on the ground the same day at RM 18.1 and 35.3, respectively. These fish were located at RM 35.2 (Freq. 40.471) and 17.7 (Freq. 40.441) on 13 August 1997 and were found by ground observers at RM 35.2 and 18.3 on 13 August and 14 August 1997, respectively.

Channel catfish monitored showed minimal movement until the last aerial flight 29 October 1996 (Figure 4.17), when one fish moved 20.3 miles downstream (Freq. 40.604) and one 8.2 miles upstream (Freq. 40.644). Average movement between aerial locations in 1996 was 1.4 river miles, and average total movement through the summer baseflow period was 11.6 miles. Average total movement between implantation location and last location detected (net displacement) in 1996 was 5.9 river miles.

Aerial locations of all catfish varied in excess of one mile for all five channel catfish in 1996. In 1997, all five catfish implanted the previous year were detected and two additional transmitters (Freqs. 40.162 and 40.152) were implanted to provide a total of seven fish to monitor. Channel catfish implanted with transmitters moved much greater distances in 1997 than observed in 1996, with an average distance traveled of 7.5 river miles between aerial locations; the average total distance traveled was 30.0 river miles. In 1997, the average net displacement from initial implantation (Freqs. 40.162 and 40.152) or first location observed (22 April 1997 for fish implanted the previous year) during the summer baseflow period was 15.4 miles.



Fish #	8	2	1	4	7	5	6	3	10	9
Year	1997	1996	1996	1996	1997	1997	1997	1996	1997	1997
Length mm	259	276	282	283	286	287	298	302	325	336
Weight g	186	162	170	192	193	180	196	216	257	445

Figure 4-18. Distance traveled by radio implanted humpback chub in the Yampa River 1996-97.

Colorado pikeminnow migrational passage

Between 1 July and 12 August 1997, only 4 of 11 transmitter-implanted fish (including 2 fish in Yampa Canyon) were recorded passing the stationary telemetry logging stations. All four migrant fish were implanted above Yampa Canyon in May 1997. The first fish to move downstream passed the Maybell Diversion before the logging station was operating, but passed the Cross Mountain station on 1 July 1997. The remaining three fish passed downstream through the Cross Mountain station by 17 July 1997 (Table 4.3). During this period, flows ranged between 1,072 and 3,590 cfs on the Yampa River at the Maybell gage. The length of time for the fish to return to the Maybell Diversion ranged from 17 to 36 days following initial passage, averaging 27.8 days. The time required for the three pikeminnow to move downstream form the Maybell station to the Cross Mountain station ranged from 0.8 and 5.0 days, representing a rate of 38.3 to 6.1 miles per day (mean = 18.4). Postspawning (upstream) movement of four fish between logging stations ranged between 1.7 and 7.2 days or a rate of 4.2 to 18.3 miles per day (mean = 11.6). Using estimates of distance covered through time between the two telemetry logging stations, the slowest moving fish (4.2 miles per day) would take 17.4 days to move from the primary spawning area (RM 18) to the Maybell Diversion (RM 98.4). Using the same estimates of travel (computed separately for upstream and downstream movement), the time spent at the spawning site varied between 12 and 20 days (mean = 15.5) at the spawning area.

Table 4.3. Dates, flow, and time spent (Min = minutes) at each passage site by four Colorado pikeminnow implanted with transmitters as they migrated downstream and upstream of the Yampa River spawning site.

		Downstream			Upstream		
Site	**Freq.**	**Date**	**Flow**	**Min**	**Date**	**Flow**	**Min**
Cross Mountain	856	7/1/97	3,590	17	7/31/97	820	60
Cross Mountain	513	7/11/97	1,664	54	8/2/97	874	141
Cross Mountain	804	7/12/97	1,548	54	8/5/97	602	209
Cross Mountain	502	7/17/97	1,072	62	7/31/97	820	45
Mean				46.8			113.8
Maybell	856	Not	logged		8/2/97	874	213
Maybell	804	7/7/97	2,269	17	8/12/97	1,366	543
Maybell	513	7/8/97	2,193	9	8/5/97	602	186
Maybell	502	7/16/97	1,161	980	8/2/97	874	48
Mean			335.3				247.5

Most fish readily moved past logging stations; however, one fish (Freq. 40.502) remained at the Maybell diversion site for 16.3 hours before moving downstream on its spawning migration. Although most migratory fish passed beyond the reception range of both sites within 60 minutes, this fish remained at the Maybell site for 980 minutes. Upstream movement during postspawning migration was slower, averaging between 1.9 hours and 4.1 hours to move beyond the range of reception from the Cross Mountain and Maybell Diversion sites, respectively.

Discussion

Upstream of Cross Mountain Canyon

Radio telemetry observations showed that Colorado pikeminnow in the Yampa River exhibited different behaviors during day and night. The fish appeared to be foraging after sunset and moved actively within a discrete mesohabitat (e.g. pool, run or riffle) or moved to a suspected foraging location in another discrete mesohabitat. In 1996, an extremely low baseflow year, each fish remained within the habitat unit (pool or run), where it was observed during the daylight hours. After sunset, each fish either actively moved over the entire habitat or moved to the upstream or downstream interface with the adjoining habitat. Fish that moved to the area adjoining the next habitat moved laterally across the river in what appeared to be a feeding pattern. There was no attempt by the fish to leave the habitat.

In 1997, an extremely high baseflow year, the fish showed similar behavior as in 1996. Fish were most active after sunset and exhibited what appeared to be a foraging behavior. Some of the fish remained within a discrete habitat, while other fish were observed to move to another habitat during this apparent foraging behavior. Two of the fish observed in 1997 moved through several discrete habitats during the 24-hour observations. On these occasions each fish returned to its starting location within the 24-hour period.

It is not known if the fish observed in 1996 moved to an adjoining mesohabitat due to low flows or remained in the discrete habitat in response to forage availability. Fish were observed moving between mesohabitats during the lowest flows in 1996 (approximately 70 cfs), but fish were not observed moving between discrete mesohabitats during the 24-hour observations. The movement between adjoining habitats in 1997 may have been in response to several factors: Higher baseflows (> 320 cfs) could have more readily allowed movement between mesohabitats. Movement also could have been in response to location and abundance of the forage species.

These data show that the Colorado pikeminnow have distinctly different habitat use patterns between day and night (Figure 4.19). Therefore, any flow management scenario for the baseflow period should address the habitat use requirements for both resting and active behaviors and rely on the most limiting flow for habitat needs. Determination of the cause of movement (e.g., feeding) could help refine the flow recommendations. If the movement is due to feeding behavior, an understanding of the response of the forage species to flows would be important.

An example of 24-hour movement and habitat use is seen with Colorado pikeminnow Freq. 40.855). This fish remained at RM 102.3 for most of the summer observations. Two 24-hour observations were conducted on this fish (Figure 4.3a). During daylight, it remained in a pool approximately 3.5 feet deep, with velocities near 0 feet per second and sand substrate. It had a very specific location that it used repeatedly day after day. During the 24-hour observations, this fish moved at sunset from that location either downstream or upstream to an apparent feeding area. For most of the night, it moved actively throughout the riffle or within the riffle/pool interface in what appeared to be a feeding behavior (Figure 4-19). At sunrise the fish moved back to almost the exact location in the river where it had been the previous evening. This fish displayed a fidelity to a location within the river reach over the course of the study. During the week of 22 September, it was located downstream approximately two miles downstream from its usual location, apparently in response to flows produced by very high rainfall. The fish was located in very deep water in what appeared to be a refuge from the high stream velocities.

Downstream of Cross Mountain

Radio telemetry did not provide sufficient data to describe local movements or habitat use of humpback chub or Colorado pikeminnow in Yampa Canyon. The data collected were primarily the result of aerial observations, and therefore, distances traveled by fishes are only estimates of actual distances traveled. Nonetheless, the few (six) ground observations were consistent with fixed-wing locations on similar dates, and the methodology was consistent between years, providing important insight on seasonal movement patterns of these two species as well as channel catfish. Perhaps the most noteworthy information gained for humpback chub was the magnitude of observed movement. Valdez and Ryel (1995) monitored 69 radio-tagged adult humpback chub in the Grand Canyon and noted that net displacement (movement from original site) averaged only 0.93 river mile and gross displacement

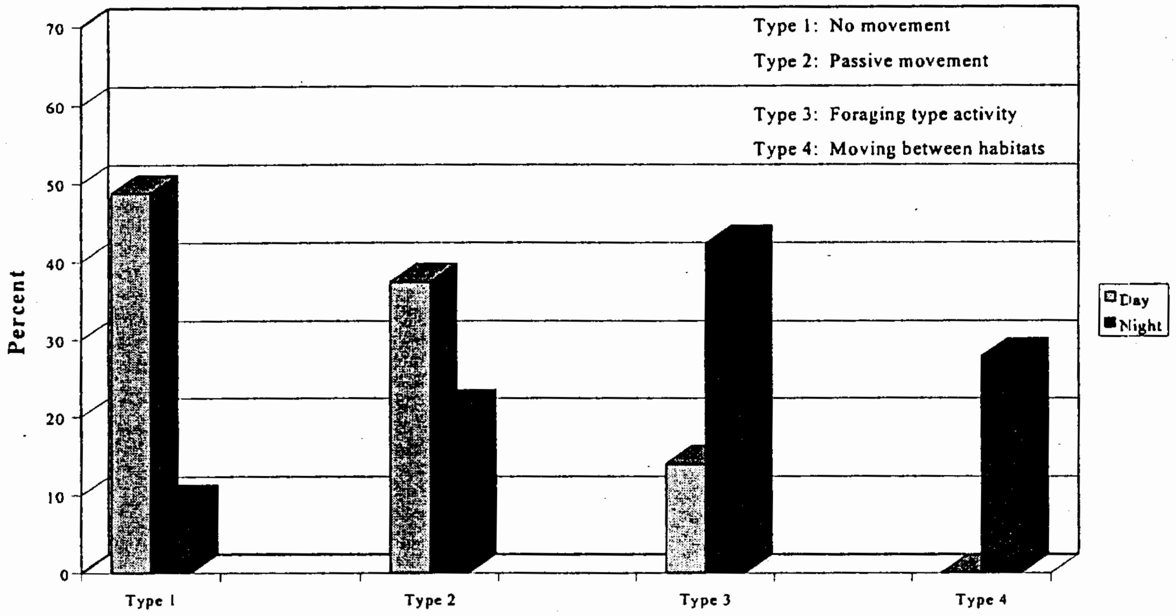


Figure 4.19. Type of activity exhibited by Colorado pikeminnow expressed as percent of time monitored during day and night contacts.

(cumulative distance traveled) averaged only 3.17 river miles. Movement of radio-tagged humpback chub in the Grand Canyon averaged only 0.19 river mile between radio contacts (Valdez and Ryel 1995). Grand Canyon humpback chub movement (net displacement) exceeded that observed in Black Rocks Canyon which averaged only 0.5 river mile (Valdez and Clemmer 1982, Kaeding and Zimmerman 1983). Net movement of ten fish monitored during our study in Yampa Canyon averaged 6.65 river miles. Humpback chub movement in the Yampa River far exceeded that observed in the larger Colorado River. Valdez et al. (1992) suggested that the greatest gross displacement of humpback chub in the Grand Canyon was associated with its migration into the Little Colorado River, and that migrating fish showed greater movement (gross displacement =3.54 river miles) than nonmigrating fish (gross displacement =1.73 mi). However, net displacement of migrating and nonmigrating fishes in the Grand Canyon were not significantly different, suggesting fish do not move far to spawning sites. Humpback chub movement in the Yampa Canyon during July may have been related to movement from spawning areas; at least one fish (Freq. 40.261) caught at Big Joe Rapid in 1996 appeared in spawning coloration. However, extensive movement in 1996 appeared after spawning activity and was probably related to changes in the hydrograph. The greatest movement by an individual fish in 1997 was 21.19 river miles downstream immediately after surgical implantation; this fish gradually moved upstream to within 12.92 river miles of its original collection site by 21 October 1997. Valdez and Ryel (1995) reported that humpback chub did not show long-range movements between research and interim flows in the Grand Canyon. However, they also noted that relatively stable geomorphic features and similarities in gross habitat complexes were observed between flows. Humpback chub in Yampa Canyon showed least movement during the summer of 1997, when flows were higher and presumably occupied habitat did not change as much as during the previous summer, when distances traveled were greater, and lower flows reduced the useable habitat of eddies in Yampa Canyon.

In Yampa Canyon, humpback chub were most often associated with large, rocky substrate (boulders) adjacent to the shoreline as described by Karp and Tyus (1990). Most fish were associated with eddy habitats. Valdez and Ryel (1995) observed that juvenile (>100 mm) and subadult (> 300 mm) humpback chub used shoreline habitat but adults tended to use large, closely-spaced, recirculating eddy complexes. Adult humpback chub in the Little Colorado River also used deeper habitats associated with large substrate but showed diel movements, occupying shallower habitats during the night (Gorman 1994). Valdez et al. (1990) reported that the most suitable depths used by humpback chub in the Upper Colorado River Basin exceeded 7.22 ft., and that boulders were the most utilized substrate type. However, only 7 of the 260 observations used in determining suitability curves were collected from the Yampa River. During the baseflow period, few areas in the Yampa Canyon exceed 7.22 ft. in depth. Whereas humpback chub in larger rivers tend to occupy deeper habitats, the Yampa Canyon does not provide these habitats. Deeper eddy habitats in the Yampa River are ephemeral, disappearing with declining summer flows (Karp and Tyus 1990) and forcing fish to move to other useable sites. When discharge in the Yampa River decreases to baseflow, much of the large boulder substrate along the shoreline in the canyon is disconnected from the river; the wetted channel consists largely of smaller boulders in the upper canyon and cobble and gravel in the middle reaches of the canyon. As deeper habitats associated with substrate decline in abundance, availability of habitats suitable for humpback chub declines, resulting in humpback movement to the fewer useable sites remaining. Nonetheless, fish show distinct distribution patterns in the Yampa River, and several fish have been recaptured near or in the same locations in subsequent years. Karp and Tyus (1990) observed fidelity among humpback chub to spawning sites in the Yampa River, and Tyus (1998) suggested that fish show fidelity to specific locations during non-spawning periods. Thus, humpback chub show a tendency for fidelity to certain sites or areas (Valdez and Ryel 1995, Kaeding and Zimmerman 1983), but in Yampa Canyon seem to move readily if habitat availability is limiting.

Because only two Colorado pikeminnow were observed moving in Yampa Canyon during the study, little information on habitat use was obtained. However, aerial identification of these two fish confirmed that both remained in Yampa Canyon through late October 1996 and were found in the canyon during the first flight in April 1997, suggesting that both pikeminnow could have over-wintered there. While attempting to locate radio-implanted fish in the canyon in late September, CRFP personnel (D. Beers and M. Toner) captured 10 Colorado pikeminnow with angling gear (7 at RM 19.4, 2 at RM 18.8, and 1 at RM 9.4), indicating that several Colorado pikeminnow remain in Yampa Canyon during the baseflow period well after postspawning migration. During the low-flow year of 1996 neither transmitter-implanted fish remained in the same location, as was observed in fish collected above the canyon (Miller and Rees 1997). During 1997, contact with both fish was lost after 13 August, at which time both fish were in the canyon. Neither fish was recorded passing by the stationary telemetry logging stations above Cross Mountain Canyon or the Maybell Diversion. At the same time, all four Colorado pikeminnow implanted above Yampa Canyon in May 1997 had migrated upstream through both Cross Mountain and Juniper canyons between 2 August and 12 August 1997. Thus, it is probable that both fish remained in Yampa Canyon during the baseflow period in both 1996 and 1997.

Channel catfish showed little movement during the low-flow year of 1996, but considerable movement during the higher flow summer of 1997. Substantial movements were observed in four of seven fish during or immediately after the flow spike that occurred in mid-August; most movement was upstream. During the relatively low baseflow year of 1991 in the Yampa River, six channel catfish similarly showed very little movement (Irving and Karp 1995). Extensive migratory movement of channel catfish has been documented in many streams and rivers (Hubert in press). Van Eeckhout (1974) reported that channel catfish movements are related to 1) seasonal movement to secure suitable habitat chronologically, 2) food, and 3) reproduction. Movements of most channel catfish in the Yampa River in 1997 were probably associated more with searching for food because they occurred after spawning and prior to seasonal weather changes. The greater flows in 1997 provided greater area for fish to move and may have increased food availability. In 1996, two fish moved in excess of 5 river miles between mid- September and late October, which may have been related to securing suitable winter habitat. Because of the extensive movement of most fish during the baseflow period in 1997, it was difficult to determine whether the movement of fish in October was related to searching for available winter habitat or other factors.

Colorado pikeminnow migrational passage

Unusually high summer baseflows and the observation of only four fish limited the direct information gained by this study regarding potential barriers to upstream movement of postspawned, migratory Colorado pikeminnow. Despite these limitations, this study provided information on travel times of pikeminnow through the Maybell Diversion site, and allowed estimation of the time spent in the spawning area as well as upstream and downstream migratory speeds of individual fish. Movement of fish in this study showed the same relationship of migratory movement to flow patterns as defined by Tyus (1990) and Tyus and Karp (1991), with fish moving to the spawning area on the descending limb of the hydrograph and leaving prior to the onset of baseflows. However, using evidence of spawning derived from larval fish presence, Bestgen et al. (1997) determined that the onset of spawning of Colorado pikeminnow over a 7-year period (1990-1996) occurred within a 14-day period between 13 June and 1 July, regardless of flows. The only environmental factor correlated with the onset of spawning by Bestgen et al. (1997) was degree days. Although spawning was initiated on similar dates, the duration of spawning was longer during higher flow years. By estimating the dates of spawning and travel time of migratory Colorado pikeminnow, it is possible to estimate when and at what flows fish passed through suspected barriers, i.e., Cross Mountain Canyon and the Maybell Irrigation Diversion. Comparing USGS gage records from the Maybell gage with estimated spawning dates (from Bestgen et al. 1997) between 1990 and 1996, postspawning migration of Colorado pikeminnow through Cross Mountain or the Maybell Diversion would have been problematic only in 1994. During the low baseflow years of 1990 through 1992, sufficient flows existed following the last day of reproduction for the slowest postspawning migrant to reach the Maybell Diversion prior to passage limiting flows (177 cfs, Modde and Smith 1995). During 1994, Colorado pikeminnow were estimated to spawn until 21 July when Yampa River flow at the Maybell gage was only 98 cfs. Thus, low flows were problematic for postspawning migration above Cross Mountain Canyon and the Maybell Diversion even while some fish were still spawning. Of interest in the low-flow year of 1994 was that very few larvae were collected in the Yampa River in 1994 and the majority of those were collected early in the reproductive period (Bestgen et al. 1997).

It is unclear whether the poor reproductive year in 1994 was the result of a lack of reproducing adults present or mass mortality of eggs spawned. Adult Colorado pikeminnow may have left the spawning site as flows receded, and low reproduction during low flows could have been the product of pikeminnow resident in Yampa Canyon. Travel times estimated in this study indicated that individual fish only occupy the spawning area for a portion of the entire spawning period. Bestgen et al. (1997) estimated the duration of Colorado pikeminnow spawning in Yampa River to range between 24 and 38 days (mean =

29.5) between 1990 and 1996. Similarly, Tyus (1990) estimated pikeminnow spawning to range between 31 and 39 days (mean = 35.6) between 1981 and 1988. Average estimated time spent near the spawning area in 1997, a high-flow year, was only 15.5 days. Although it is likely that individual fish do not remain in the spawning area for the duration of the spawning period, factors triggering fish to leave the spawning area are unknown. In summary, evidence suggested low flows in early to mid-July may be detrimental to spawning, however it is unlikely low baseflows are a factor in preventing passage of postspawning migrant adults.

CHAPTER 5: CONCLUSIONS AND INTEGRATED FLOW MANAGEMENT RECOMMENDATIONS

The late summer baseflow management recommendation for the Yampa River includes both magnitude and temporal components. We recommend that flows below 93 cfs, not occur at a greater frequency than the historical record. This reference flow, determined from the relationship of channel characteristics, represents the flow below which habitat loss is maximized in the lower Yampa River between August and October. The 93 cfs reference flow was determined by defining the curve break in flow/habitat relationships that identifies the maximum change in habitat variables across riffle transects. This approach is commonly used by natural resource agencies to identify minimum instream flow recommendations. However, the intent of this study was not to present a minimum instream flow recommendation, but to identify when base flows in the Yampa River become a deterrent to recovery of endangered fishes. Therefore, the 93 cfs should only be used as a reference flow that identifies the threshold at which greatest habitat degradation occurs. In addition, the recommendation in this chapter does not prioritize the importance of baseflow needs over spring peak flow (channel forming) needs. When water is limiting and a prioritization between spring flow needs and baseflow is required, then a separate process outside the scope of this project is necessary.

The 93 cfs reference flow was contrasted to flows determined by traditional methods (PHABSIM) that estimated weighted useable area for both Colorado squawfish and humpback chub. The 93 cfs flow was less than flows predicted to maintain pool and run habitat availability used by those species. Also, the 93 cfs was found to be less than flows identified to avoid a 50% risk of riffles becoming a potential barrier for local movement of Colorado pikeminnow because of shallow depths. However, we feel that flows over 93 cfs flow would be sufficient to maintain riffle habitat critical for instream primary and secondary production during the summer. Also, flows near 93 cfs are not expected to be long term, only experienced during the late summer. The historic hydrograph shows that flows usually drop to the lowest in early September but increase to about 300 cfs by November. If we assume the shape of future annual hydrographs will remain similar to historic conditions (1917 to 1997), then flows will increase in October to well above 93 cfs. Therefore, habitat availability and passage flow return to favorable conditions during fall and winter periods.

It is important to place the 93 cfs reference flow in context with the historic hydrograph. Figure 5.1 identifies the number of days and years during which flows were less than 93 cfs at the Maybell gage. Between 1916 and 1997, flows have been below 93 cfs in 31 of 82 years. The effects these low flows had on the biota of the Yampa River were not determined. However, it appears that the Colorado pikeminnow population has persisted in the Yampa River through time. Over the last 15 years, the population of pikeminnow in the Yampa River has been relatively stable as measured by ISMP (McAda 1998), in spite of several years with flows under 93 cfs in that period. This report is reluctant to interpret population status of endangered fishes, but no changes in population status of Colorado pikeminnow or humpback chub have been documented.

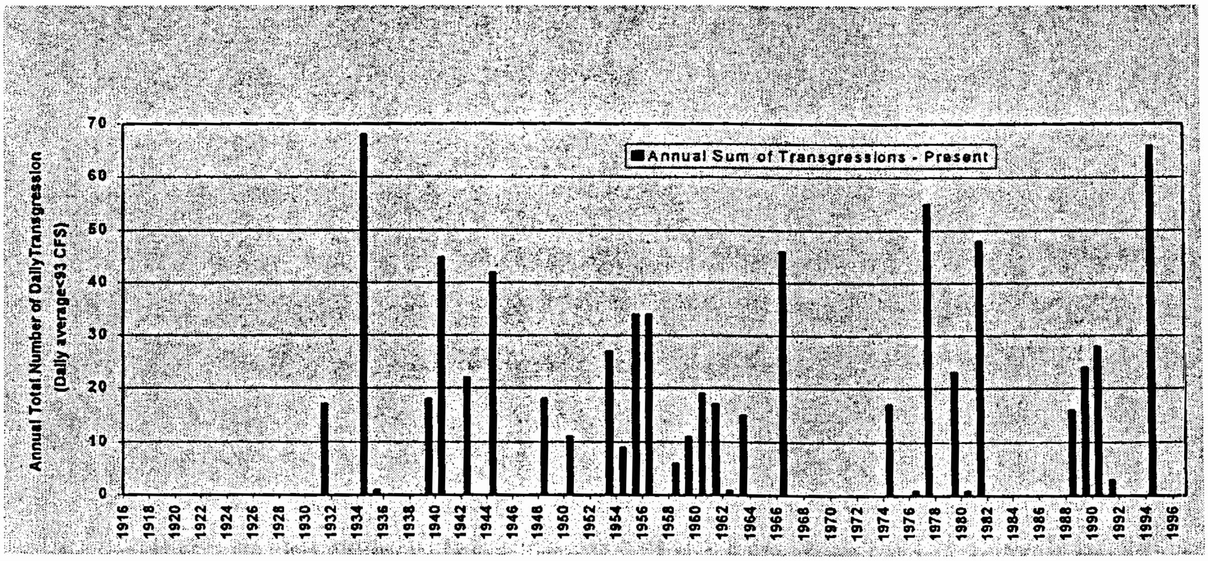


Figure 5.1. Histogram of annual total transgressions (flows below target of 93.0 cfs) based on flows in the Yampa River near Maybell, 1916 - 1995.

Without a strong empirical biological database, perhaps the soundest approach to flow management is one that uses the natural hydrograph as the ideal condition (Stanford 1994). The role of seasonal variation in flows has been reported to have particular significance to the ecology of lotic fishes (Poff et al. 1997). On the Yampa River, spring runoff flows are still relatively natural and have been reduced on average by approximately five to six percent. In contrast, base flows have been reduced by an average of 30% and up to 80% in dry years.

In order to include a variation component in flow recommendations, the virgin flow history needs to be determined. Typically, this is accomplished by adding depletions back to the stream flow and adjusting for return flows. This study strongly recommends that such an analysis be undertaken as part of a Yampa River water management plan. This exercise would provide useful information about native, historical and future flows. Two studies of the potential increase of human demands within the Yampa river basin (Yampa River Alternatives Feasibility Study -Hydrosphere 1993 and Yampa Valley Water Demand study -BBC research and Consulting 1998) have suggested that water depletions will grow by approximately 49,000 acre feet over the next 50 years. These studies infer that magnitude and duration of lower flows during the late summer period are likely to continue to increase over natural conditions.

This report recommends that the frequency of flow events under 93 cfs should not increase in the future. Thus, we believe that any increase in the number of years and the duration days with flows under 93 cfs is expected to have adverse impacts on stream productivity and habitat available to support populations of endangered fishes. The frequency criterion of this recommendation is simple to calculate from the historic record based on the frequency with which 93 cfs has been violated in the past. Since this study was not set up for flow modeling, we suggest that future modeling and planning efforts be directed to quantify frequency and duration criteria for native, historical and projected flows during the August to October period.

In addition to concerns about an increase in the frequency of years with low flows, as a result of future increases in water demand, we also have concerns about decreases in the frequency of years with optimal base flows. During the historic record (current level of depletions), the median flow for August, September and October was 264 cfs and the mean flow for this period was 322 cfs. Under natural flows, the median flow would have been higher than 264 cfs and we expect the median flow to be even less in the future. It would be desirable for the Yampa River flow modeling effort to create a frequency of occurrence that compares historic versus natural flow for years with favorable base flows (defined as average flow range in Modde and Smith 1994). This analysis will allow for a clearer understanding of seasonal (runoff, base, and winter) hydrograph alterations, which would be very useful reference for future decisions concerning habitat and flow on the Yampa River.

Recommendations

1. Develop a water management plan for the Yampa River that identifies and compares options for meeting the baseflow recommendation.

2. The frequency of daily flow events under 93 cfs should not increase above the historic record.

3. Quantify future low flow conditions in developing the Yampa River water management plan:

    a. The CRDSS Yampa River flow modeling effort should include frequency analysis of future "low flow" events. This could be accomplished by calculating the frequency and duration that flows were less than 93 cfs on the Maybell gage records (completed, March 4, 1999 memo from Yampa Management Team).

    b. Based on frequency analysis of "low flow" events during the natural flow and the historic flow categories, identify the flow volume shortage expected under planned development (completed, March 4, 1999 memo from Yampa Management Team).

4. In developing the water management plan, the variation in the baseflow hydrograph should be maintained such that both optimal and drought conditions be represented at historical frequencies.

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APPENDIX 1. HYDRAULIC RESULTS

Appendix Table 1.1. Flows (in cfs) at the curve breaks for the six variables for all riffles surveyed in the study area.

Riffle	Strata	XSEC	Wetted	Mean	Mean Velo	Rise in	W-D	S-C	Riffle	Strata	XSEC	Wetted	Mean	Mean Velo	Rise in	W-D	S-C
Num ber		ID	Width	Depth	city (cfs)	Stage	Ratio	Area	number		ID	Width	Depth	city (cfs)	Stage	Ratio	Area
1	1	**401**	40	100	125	60	20	80	37	6	**7331**	80	150	125	80	150	80
2	1	**404**	150	80	80	125	20	150	38	6	**7336**	60	150	125	60	60	80
3	1	**1131**	60	10	10	60	60	80	39	6	**7452**	60	125	100	100	125	80
4	1	**1136**	80	150	125	80	20	100	40	6	**7456**	150	100	100	150	125	150
5	1	**1661**	100	20	40	80	80	100	41	6	**7531**	40	100	100	125	20	125
6	1	**1666**	40	100	80	125	20	100	42	6	**7781**	20	125	100	100	125	80
7	1	**1781**	60	100	100	100	40	80	43	6	**7785**	80	125	125	80	40	100
8	1	**1786**	100	20	60	100	125	125	44	8	**9201**	60	150	150	60	150	60
9	1	**1991**	125	100	100	125	125	125	45	8	**9401**	150	60	60	100	150	150
10	1	**1996**	125	60	60	100	200	125	46	8	**9404**	20	125	100	80	20	100
11	2	**2391**	60	125	100	100	250	100	47	8	**9408**	20	100	80	125	80	125
12	2	**2396**	100	60	80	100	250	150	48	8	**9902**	40	125	100	80	125	80
13	2	**2621**	125	100	100	80	125	125	49	8	**10251**	80	40	40	80	40	80
14	2	**2626**	100	125	80	80	20	100	50	8	**10451**	125	60	60	100	80	125
15	2	**3411**	60	40	40	80	60	125	51	8	**10551**	200	40	40	80	80	200
16	2	**3415**	100	80	80	100	100	100	52	8	**10801**	60	125	100	80	20	100
17	2	**3601**	60	150	125	60	40	60	53	8	**10981**	80	80	100	100	40	150
18	2	**3605**	150	125	100	80	20	150	54	8	**11131**	40	125	100	80	60	80
19	2	**3751**	150	40	40	100	150	150	55	8	**11551**	100	100	80	100	20	100
20	2	**3756**	100	40	40	100	250	100	56	8	**11553**	150	100	100	150	150	150
21	2	**4181**	60	125	100	60	60	100	57	8	**11751**	60	125	150	60	60	100
22	2	**4186**	150	100	100	150	150	150	58	8	**11756**	80	40	40	80	80	100
23	2	**4221**	150	100	100	125	40	150	59	8	**11901**	40	100	100	125	20	80
24	2	**4225**	125	60	60	80	125	125	60	8	**12041**	125	100	100	80	40	125
25	2	**4411**	125	100	80	125	20	125	61	8	**12082**	125	40	40	80	40	125
26	2	**4416**	125	80	80	100	20	125	62	8	**12151**	60	40	40	60	60	125
27	3	**4551**	60	100	100	60	60	100				**Width**	**Depth**	**Velocity**	**Stage**	**Ratio**	**Area**
28	3	**4556**	125	80	80	100	125	125	MEAN FOR STRATUM 1			88	74	78	96	71	107
29	4	**5351**	125	100	100	125	20	125	MEAN FOR STRATUM 2			109	91	82	95	105	121
30	4	**5355**	80	125	100	100	40	80	MEAN FOR STRATUM 3			93	90	90	80	93	113
31	4	**5401**	80	60	60	80	20	150	MEAN FOR STRATUM 4			96	86	80	101	45	114
32	4	**5406**	100	60	60	100	100	100	MEAN FOR STRATUM 6			79	123	109	97	95	107
33	6	**6282**	60	125	125	60	125	100	MEAN FOR STRATUM 8			85	88	83	89	69	113
34	6	**6287**	200	100	100	150	200	200	MEAN FOR STRATA 1,2,3			100	85	81	94	92	115
35	6	**6983**	80	125	100	80	40	80	MEAN FOR STRATA 4,6,8			84	99	91	93	75	111
36	6	7081	40	125	100	80	40	100	MEAN FOR ALL			92	93	87	94	83	113

Appendix Table 1.2. Values at the curve breaks for the six variables for all riffles surveyed in the study.

Riffle Num ber	Strat a	XSEC ID	Wetted Width (ft)	Mean Depth (ft)	Mean Velocity (f/s)	Rise in Stage (ft)	W-D Ratio	S-C Area (sq ft)	% Wet. Perm.	Riffle Num ber	Strata	XSEC ID	Wetted Width (ft)	Mean Depth(ft)	Mean Velo City (f/s)	Rise in Stage (ft)	W-D Ratio	S-C Area (Sq ft)	% Wet. Perm.
1	1	401	90	0.71	1.43	1.17	252	65	23%	37	6	7331	105	0.56	2.28	0.61	200	42	40%
2	1	404	185	0.71	0.83	1.30	274	159	79%	38	6	7336	194	0.46	1.45	0.74	691	65	51%
3	1	1131	79	0.51	2.03	1.27	194	39	16%	39	6	7452	153	0.46	1.33	0.79	426	64	45%
4	1	1136	146	0.52	1.72	0.80	505	63	53%	40	6	7456	129	0.56	2.53	1.20	149	64	33%
5	1	1661	157	0.30	1.18	0.79	358	71	27%	41	6	7531	60	0.92	1.55	1.41	130	78	20%
6	1	1666	99	0.63	1.37	0.94	302	68	29%	42	6	7781	166	0.61	1.00	0.65	312	87	54%
7	1	1781	102	0.57	1.61	0.75	267	54	31%	43	6	7785	197	0.35	1.74	0.58	764	63	76%
8	1	1786	86	0.66	2.45	1.84	166	56	25%	44	8	9201	145	0.69	1.24	0.86	255	64	32%
9	1	1991	77	0.57	2.81	0.96	136	44	23%	45	8	9401	158	0.51	1.15	1.08	232	108	58%
10	1	1996	104	0.52	1.74	1.07	183	65	20%	46	8	9404	150	0.56	1.26	0.55	749	80	55%
11	2	2391	18	2.54	1.56	3.82	18	60	15%	47	8	9408	96	0.57	1.26	0.89	235	93	29%
12	2	2396	69	1.15	1.57	2.36	129	94	20%	48	8	9902	80	0.76	1.72	0.78	116	50	37%
13	2	2621	126	0.92	1.00	1.56	131	121	58%	49	8	10251	126	0.47	1.04	0.87	173	69	54%
14	2	2626	111	0.68	1.42	1.02	238	67	47%	50	8	10451	222	0.43	0.86	0.93	399	124	66%
15	2	3411	95	0.56	1.05	1.08	160	92	36%	51	8	10551	212	0.38	1.69	0.97	319	101	53%
16	2	3415	87	0.86	1.33	1.50	101	74	38%	52	8	10801	161	0.54	1.20	0.80	644	83	46%
17	2	3601	127	0.77	1.27	1.13	271	61	44%	53	8	10981	193	0.36	1.25	0.62	511	108	48%
18	2	3605	82	1.04	1.63	1.33	104	85	48%	54	8	11131	190	0.55	1.04	0.48	525	85	50%
19	2	3751	202	0.76	0.92	1.95	259	158	41%	55	8	11551	210	0.27	1.68	0.41	1079	56	52%
20	2	3756	67	0.77	1.44	1.53	70	62	28%	56	8	11553	218	0.78	1.30	1.71	351	135	60%
21	2	4181	109	0.79	1.25	0.85	205	80	44%	57	8	11751	145	0.43	1.90	0.58	483	61	32%
22	2	4186	52	1.30	2.77	2.40	47	59	29%	58	8	11756	174	0.45	0.93	1.22	370	97	46%
23	2	4221	80	0.89	1.67	1.54	101	80	38%	59	8	11901	132	0.49	1.23	0.87	493	70	27%
24	2	4225	190	0.71	0.93	1.68	268	135	70%	60	8	12041	142	0.44	1.79	0.92	358	67	45%
25	2	4411	84	0.84	1.54	1.44	132	74	42%	61	8	12082	133	0.32	2.07	0.63	189	52	33%
26	2	4416	111	0.67	1.44	1.18	161	81	58%	62	8	12151	307	0.19	0.99	0.55	1537	100	54%
27	3	4551	110	0.51	1.69	0.64	283	59	19%				Width	Depth	Velo city	Stage	Ratio	Area	% WP
28	3	4556	92	0.90	1.64	1.63	107	79	37%	MEAN FOR STRATA 1			113	0.57	1.72	1.09	264	68	33%
29	4	5351	253	0.70	0.64	1.06	569	187	55%	MEAN FOR STRATA 2			101	0.95	1.42	1.65	150	86	41%
30	4	5355	166	0.58	1.14	0.92	426	76	60%	MEAN FOR STRATA 3			101	0.71	1.66	1.14	195	69	28%
31	4	5401	140	0.56	0.96	0.86	325	127	50%	MEAN FOR			177	0.60	0.93	0.96	387	122	54%

										STRATA 4							
32	4	**5406**	148	0.57	0.97	1.00	228	97	53%	MEAN FOR STRATA 6	157	0.54	1.69	0.86	415	71	48%
33	6	**6282**	264	0.46	1.00	0.84	625	109	60%	MEAN FOR STRATA 8	168	0.48	1.35	0.83	475	84	46%
34	6	**6287**	167	0.50	2.91	1.14	380	74	49%	MEAN FOR STRATA 1,2,3	105	0.80	1.55	1.41	194	79	37%
35	6	**6983**	167	0.41	1.56	0.64	527	55	51%	MEAN FOR STRATA 4,6,8	166	0.52	1.41	0.85	445	84	48%
36	6	**7081**	126	0.64	1.25	0.81	361	80	44%	MEAN FOR ALL	138	0.64	1.47	1.10	332	82	43%

Appendix Table 1.3. Flows (in cfs) at the curve breaks for the six variables for all runs surveyed in the study area.

Run	Strata	XSEC	Wetted	Mean	Mean	Rise in	W-D	S-C	Run	Strata	XSEC	Wetted	Mean	Mean	Rise in	W-D	S-C
#		ID	Width	Depth	Velocity	Stage	Ratio	Area	#		ID	Width	Depth	Velocity	Stage	Ratio	Area
1	1	403	80	20	100	60	60	100	41	6	6288	60	100	100	100	40	100
2	1	406	80	40	40	80	80	100	42	6	6984	60	125	125	100	125	80
3	1	1132	80	60	125	60	100	60	43	6	6985	60	150	80	80	20	100
4	1	1133	80	10	125	60	20	60	44	6	6986	100	80	100	100	60	100
5	1	1663	80	40	150	80	20	80	45	6	7335	100	60	60	100	60	100
6	1	1665	20	125	100	100	150	80	46	6	7633	40	80	125	60	60	60
7	1	1785	150	60	60	80	250	150	47	6	7783	150	80	150	150	125	80
8	1	1992	250	100	100	125	40	125	48	8	9202	125	40	125	60	40	150
9	1	1994	60	125	100	60	40	80	49	8	9403	80	100	100	80	80	100
10	2	2394	40	100	100	100	200	60	50	8	9405	125	60	80	100	125	125
11	2	2622	100	80	80	100	40	100	51	8	9406	125	80	125	100	60	100
12	2	3412	150	60	60	80	150	150	52	8	10453	40	125	80	80	40	80
13	2	3414	60	125	100	80	20	100	53	8	10455	60	80	125	100	80	80
14	2	3604	125	100	80	100	250	100	54	8	11552	200	250	100	100	250	100
15	2	4223	80	40	40	80	80	80	55	8	11554	150	60	40	150	150	150
16	2	4226	40	125	100	80	20	80	56	8	11555	20	20	20	20	20	20
17	2	4413	40	125	100	125	20	125	57	8	11752	40	125	100	80	20	100
18	2	4414	60	100	100	80	20	100	58	8	11753	60	40	100	80	40	100
19	3	4552	60	150	125	60	40	60	59	8	11754	40	20	100	80	20	100
20	3	4553	80	60	60	80	80	80	60	8	11903	40	80	80	100	20	100
21	3	4554	80	100	100	80	20	100	61	8	11904	150	80	100	100	80	80
22	3	5151	60	150	150	60	60	80	62	8	11905	150	150	100	100	150	80
23	3	5152	125	80	80	125	20	125	63	8	12153	80	60	125	60	60	80
24	3	5153	80	20	20	60	60	80	64	8	12154	200	60	125	60	60	60
25	3	5154	200	150	150	60	200	200	65	8	12156	40	100	100	80	20	80
26	4	5352	60	125	100	80	40	100	66	8	12401	125	40	40	80	40	125
27	4	5353	80	125	20	80	60	100	67	8	12402	40	40	100	80	40	80
28	4	5402	40	100	100	100	20	100	68	8	12404	100	40	40	80	100	125
29	4	5403	40	80	80	100	20	125	69	8	12405	125	20	20	60	20	125
30	6	5981	60	125	100	100	20	100									
31	6	5982	40	125	125	100	125	80				Width	Depth	Velocity	Stage	Ratio	Area
	6	5983	20	100	125	100	100	80	MEAN FOR STRATUM 1			98	64	100	78	84	93
33	6	5984	125	60	40	80	60	40	MEAN FOR STRATUM 2			77	95	84	92	89	99
34	6	5985	40	125	20	80	40	100	MEAN FOR			98	101	98	75	69	104

									STRATUM 3						
35	6	**5986**	150	150	100	80	150	80	MEAN FOR STRATUM 4	55	108	75	90	35	106
36	6	**6281**	60	20	20	60	60	60	MEAN FOR STRATUM 6	75	99	97	85	85	81
37	6	**6283**	40	100	100	40	125	80	MEAN FOR STRATUM 8	96	76	88	83	69	97
38	6	**6284**	200	100	125	80	200	60	MEAN FOR STRATA 1,2,3	90	86	94	82	82	98
39	6	**6285**	20	100	125	60	100	80	MEAN FOR STRATA 4,6,8	84	88	90	85	72	91
40	6	**6286**	20	100	125	60	60	80	MEAN FOR ALL	86	87	92	84	76	94

Appendix Table 1.4. Values at the curve breaks for the six variables for all runs surveyed in the study area.

Run #	Str.	XSEC ID	Wetted Width (ft)	Mean Depth (ft)	Mean Velocity (f/s)	Rise in Stage (ft)	W-D Ratio	S-C Area (sq ft)	% Wet. Perm.	Run #	Str	XSEC ID	Wetted Width	Mean Depth (ft)	Mean Velocity (f/s)	Rise in Stage (ft)	W-D Ratio	S-C Area (sq ft)	% Wet. Perm.
1	1	403	182	1.27	0.45	1.17	166	220	69%	41	6	6288	128	1.62	0.46	1.17	93	219	49%
2	1	406	92	0.66	0.93	1.43	114	87	36%	42	6	6984	70	0.88	1.71	1.23	95	56	19%
3	1	1132	66	4.48	0.46	1.27	80	245	13%	43	6	6985	106	0.90	1.05	1.14	104	90	30%
4	1	1133	90	1.29	1.06	1.27	91	96	19%	44	6	6986	169	1.63	0.35	1.35	101	286	70%
5	1	1663	258	3.03	0.91	4.04	222	773	61%	45	6	7335	120	0.86	0.80	1.52	101	116	43%
6	1	1665	89	1.06	1.02	1.17	141	85	20%	46	6	7633	175	1.41	0.45	0.77	131	246	63%
7	1	1785	95	0.83	2.70	1.61	159	63	26%	47	6	7783	178	1.76	0.46	0.84	410	287	71%
8	1	1992	124	0.77	1.86	0.96	105	63	46%	48	8	9202	157	1.09	0.59	0.91	122	233	53%
9	1	1994	75	1.13	1.21	1.53	105	71	21%	49	8	9403	232	1.57	0.27	1.13	158	367	81%
10	2	2394	26	1.58	1.90	2.60	62	35	10%	50	8	9405	199	0.91	0.49	0.90	195	203	85%
11	2	2622	112	0.66	1.18	1.10	172	79	52%	51	8	9406	140	2.18	0.38	0.91	63	309	63%
12	2	3412	115	0.70	1.15	1.04	123	108	45%	52	8	10453	221	1.02	0.42	0.75	315	194	65%
13	2	3414	146	0.75	1.00	0.87	418	99	56%	53	8	10455	212	1.60	0.33	0.83	133	342	83%
14	2	3604	52	1.06	1.84	1.35	45	51	35%	54	8	11552	104	1.04	1.00	0.87	142	101	31%
15	2	4223	160	0.67	0.69	1.51	226	114	51%	55	8	11554	359	0.67	0.69	1.79	589	219	74%
16	2	4226	148	1.64	0.45	1.82	198	192	60%	56	8	11555	218	1.11	0.08	0.90	196	242	60%
17	2	4413	102	1.57	0.65	1.44	115	171	59%	57	8	11752	225	0.91	0.52	0.98	648	193	49%
18	2	4414	104	0.80	1.16	0.80	266	86	66%	58	8	11753	210	1.42	0.28	1.00	139	354	62%
19	3	4552	61	0.63	2.85	0.64	135	29	19%	59	8	11754	171	0.85	0.41	1.02	196	243	49%
20	3	4553	178	0.53	0.79	1.20	317	100	50%	60	8	11903	180	0.62	0.68	1.09	450	139	52%
21	3	4554	38	1.46	1.69	1.75	45	58	11%	61	8	11904	192	1.02	0.63	1.07	138	143	42%
22	3	5151	167	0.81	1.03	1.38	341	99	49%	62	8	11905	239	1.04	0.50	1.09	230	183	71%
23	3	5152	232	0.59	0.75	1.25	408	153	56%	63	8	12153	184	1.39	0.45	0.59	126	254	40%
24	3	5153	291	0.49	0.85	1.20	765	111	43%	64	8	12154	161	2.17	0.36	0.61	68	319	48%
25	3	5154	298	1.05	0.84	1.53	335	265	38%	65	8	12156	176	0.72	0.76	0.84	535	115	58%
26	4	5352	249	1.24	0.36	1.30	356	275	88%	66	8	12401	184	0.85	0.55	1.60	101	195	49%
27	4	5353	186	1.48	0.29	2.74	165	263	71%	67	8	12402	200	1.92	0.18	1.65	104	506	44%
28	4	5402	228	0.66	0.65	0.87	829	154	80%	68	8	12404	123	0.79	1.03	1.65	155	119	35%
29	4	5403	174	0.70	0.62	0.93	524	175	65%	69	8	12405	220	0.50	0.75	1.13	107	142	65%
30	6	5981	171	1.00	0.60	1.28	360	167	42%										
31	6	5982	150	1.40	0.52	1.30	123	197	48%				Width	Depth	Velocity	Stage	Ratio	Area	% W P
32	6	5983	74	1.87	0.70	1.31	47	154	29%	MEAN FOR STRATUM 1			119	1.61	1.18	1.61	132	189	34%
33	6	5984	153	0.43	1.31	1.32	248	31	35%	MEAN FOR STRATUM 2			107	1.05	1.11	1.39	180	104	48%

34	6	**5985**	123	0.87	0.83	1.18	300	109	22%	MEAN FOR STRATUM 3	181	0.79	1.26	1.28	335	116	38%
35	6	**5986**	137	0.99	0.96	1.69	138	92	54%	MEAN FOR STRATUM 4	209	1.02	0.48	1.46	469	217	76%
36	6	**6281**	140	1.09	0.38	2.63	125	156	42%	MEAN FOR STRATUM 6	140	1.25	0.73	1.25	160	164	45%
37	6	**6283**	181	1.07	0.48	0.80	179	188	61%	MEAN FOR STRATUM 8	196	1.15	0.52	1.06	223	232	57%
38	6	**6284**	239	1.24	0.55	1.01	206	186	78%	MEAN FOR STRATA 1,2,3	132	1.18	1.18	1.44	206	138	40%
39	6	**6285**	135	2.07	0.41	0.94	68	277	34%	MEAN FOR STRATA 4,6,8	174	1.18	0.60	1.17	220	203	54%
40	6	**6286**	65	1.39	1.16	0.95	54	94	16%	MEAN FOR ALL	159	1.18	0.81	1.27	215	180	49%

Appendix Table 1.5. Flows (in cfs) at the curve breaks for the six variables for all pools surveyed in the study area.

Run #	Str.	XSEC ID	Wetted Width	Mean Depth	Mean Velocity	Rise in Stage	W-D Ratio	S-C Area
1	1	402	60	80	125.0	60	20.00	80
2	1	1662	80	80	125.0	80	20.00	80
3	1	1782	80	80	150.0	80	20.00	80
4	1	1783	40	100	125.0	100	20.00	100
5	1	1993	100	125	100.0	125	100.00	125
6	2	2392	100	60	60.0	100	100.00	150
7	2	2393	80	60	20.0	100	80.00	150
8	2	2623	300	125	100.0	125	20.00	125
9	2	3413	125	80	80.0	100	20.00	125
10	2	3602	40	80	125.0	60	20.00	60
11	2	3603	40	60	125.0	60	20.00	60
12	2	3752	100	125	80.0	100	250.00	100
13	2	3753	40	100	100.0	80	20.00	100
14	2	4182	40	100	125.0	60	20.00	60
15	2	4183	40	100	125.0	60	40.00	100
16	2	4222	80	40	40.0	80	80.00	80
17	2	4412	100	125	100.0	125	20.00	125
18	6	6289	60	125	100	100	20	100
19	6	7333	100	80	125	80	100	100
20	6	7334	150	100	125	80	80	100
21	6	7454	150	150	125	100	150	100
22	6	7455	60	100	125	100	100	100
23	6	7634	60	80	125	60	20	60
24	6	7782	60	20	125	125	20	100
25	6	7784	60	125	200	100	150	80
26	8	9407	100	80	125	100	80	100
27	8	10454	60	80	125	100	80	80
28	8	11556	20	20	100	20	20	20
29	8	12155	100	60	125	60	60	60
30	8	12403	60	80	125	80	80	80
			Width	**Depth**	**Velocity**	**Stage**	**Ratio**	**Area**
MEAN FOR STRATUM 1			72	93	125	89	36	93
MEAN FOR STRATUM 2			90	88	90	88	58	103
MEAN FOR STRATUM 6			88	98	131	93	80	93
MEAN FOR STRATUM 8			68	64	120	72	64	68
MEAN FOR STRATA 1,2,3			85	89	100	88	51	100
MEAN FOR STRATA 4,6,8			80	85	127	85	74	83
MEAN FOR ALL			83	87	112	87	61	93

Appendix Table 1.6. Values at the curve breaks for the six variables for all pools surveyed in the study area.

Run #	Str.	XSEC ID	Wetted Width (ft)	Mean Depth (ft)	Mean Velocity (ft/s)	Rise in Stage (ft)	W-D Ratio	S-C Area (sq. ft)	% Wet. Perm.
1	1	402	194	2.29	0.25	1.17	99	446	75%
2	1	1662	102	4.41	0.27	0.81	24	450	37%
3	1	1782	149	3.14	0.36	0.60	55	469	65%
4	1	1783	185	3.83	0.17	0.75	54	714	84%
5	1	1993	108	1.57	0.63	0.96	73	172	42%
6	2	2392	65	2.00	0.72	3.82	34	180	35%
7	2	2393	102	0.93	1.11	2.51	117	183	50%
8	2	2623	94	2.12	0.75	1.24	39	144	56%
9	2	3413	121	1.02	0.79	1.55	153	143	44%
10	2	3602	70	1.19	1.24	1.13	86	80	34%
11	2	3603	73	1.58	0.90	1.13	58	117	44%
12	2	3752	82	1.58	0.82	1.99	54	115	52%
13	2	3753	77	1.85	0.62	2.26	73	159	32%
14	2	4182	137	0.94	0.80	0.84	242	111	50%
15	2	4183	117	0.93	0.94	1.04	213	116	51%
16	2	4222	82	1.33	0.63	2.46	57	119	42%
17	2	4412	114	2.23	0.41	1.44	59	259	65%
18	6	6289	165	2.46	0.25	1.20	84	397	80%
19	6	7333	108	3.24	0.34	1.10	34	349	41%
20	6	7334	142	4.26	0.21	1.10	32	583	86%
21	6	7454	224	2.31	0.25	1.03	97	469	93%
22	6	7455	137	4.25	0.20	1.04	33	594	76%
23	6	7634	148	2.77	0.29	0.77	56	405	71%
24	6	7782	181	3.53	0.18	0.74	48	662	90%
25	6	7784	179	2.27	0.43	0.67	82	391	62%
26	8	9407	175	2.22	0.29	0.92	78	404	80%
27	8	10454	168	4.01	0.18	0.83	42	673	83%
28	8	11556	191	3.74	0.14	0.90	51	714	78%
29	8	12155	161	3.76	0.20	0.61	42	597	46%
30	8	12403	174	3.09	0.21	1.66	57	544	52%
			Width	**Depth**	**Velocity**	**Stage**	**Ratio**	**Area**	**% W. P.**
MEAN FOR STRATUM 1			148	3.05	0.34	0.86	61	450	
MEAN FOR STRATUM 2			95	1.48	0.81	1.78	99	144	
MEAN FOR STRATUM 6			161	3.14	0.27	0.96	58	481	
MEAN FOR STRATUM 8			174	3.36	0.20	0.98	54	586	
MEAN FOR STRATA 1,2,3			110	1.94	0.67	1.51	88	234	
MEAN FOR STRATA 4,6,8			166	3.22	0.24	0.97	57	522	
MEAN FOR ALL			134	2.50	0.49	1.28	74	359	

Appendix Table 1.7. Habitat data for all riffle cross sections at simulated flows of 80, 150 and 300 cfs.

	Wetted Width			*Width-Dept. Ratio*			*Average Depth*			*Rise in stage*			*Average Velocity*			*% Wetted Perimeter*			*Cross Section Area*		
	80	**150**	**300**	**80**	**150**	**300**	**80**	**150**	**300**	**80**	**150**	**300**	**80**	**150**	**300**	**80**	**150**	**300**	**80**	**150**	**300**
XS ID	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)	(cfs)
401	101	117	144	158	138	126	0.64	0.85	1.14	1.28	1.61	2.10	1.23	1.50	1.83	26%	30%	37%	25.8	64.8	99.6
404	136	185	195	191	215	155	0.71	0.86	1.26	1.03	1.43	1.88	0.83	0.94	1.22	58%	79%	84%	37.6	96.5	158.7
1131	84	87	91	179	129	93	0.47	0.67	0.98	1.35	1.57	1.93	2.01	2.56	3.32	17%	18%	19%	13.0	39.4	58.1
1136	146	158	176	396	303	242	0.37	0.52	0.73	0.80	0.97	1.26	1.47	1.82	2.32	53%	57%	64%	20.2	54.2	82.0
1661	147	165	185	358	295	234	0.41	0.56	0.79	0.79	0.99	1.30	1.33	1.62	2.05	25%	28%	32%	18.5	60.2	92.4
1666	106	126	146	193	172	144	0.55	0.73	1.01	0.74	1.04	1.44	1.37	1.63	2.04	32%	37%	43%	23.7	58.2	91.9
1781	106	115	127	207	163	126	0.51	0.71	1.01	0.67	0.92	1.31	1.48	1.83	2.33	32%	35%	38%	19.8	53.9	82.0
1786	57	105	129	102	172	157	0.56	0.61	0.82	1.64	2.02	2.37	2.48	2.33	2.82	16%	30%	37%	8.4	31.9	64.0
1991	58	80	102	111	130	124	0.52	0.62	0.82	0.75	1.04	1.40	2.65	3.00	3.60	17%	24%	30%	11.0	30.1	49.9
1996	80	115	149	142	177	175	0.56	0.65	0.85	0.96	1.28	1.66	1.79	2.00	2.37	15%	22%	28%	16.5	44.7	74.7
2391	23	30	52	11	11	19	2.18	2.70	2.72	3.44	4.58	6.12	1.47	1.74	2.01	16%	21%	36%	18.7	50.8	80.8
2396	53	92	155	56	90	134	0.95	1.02	1.15	2.15	2.73	3.41	1.57	1.59	1.68	15%	26%	44%	17.6	50.7	94.1
2621	104	134	149	127	130	101	0.82	1.03	1.47	1.56	2.01	2.57	0.93	1.08	1.36	48%	61%	68%	25.6	85.4	137.6
2626	104	116	140	193	154	139	0.54	0.75	1.01	1.02	1.29	1.73	1.42	1.73	2.11	44%	49%	59%	21.4	56.3	86.6
3411	98	115	123	145	128	94	0.68	0.90	1.31	1.08	1.42	1.91	1.19	1.45	1.86	37%	44%	47%	22.9	66.9	103.5
3415	70	96	142	81	93	114	0.86	1.03	1.24	1.31	1.77	2.45	1.33	1.51	1.70	30%	42%	62%	22.0	59.8	99.2
3601	131	147	240	233	191	279	0.56	0.77	0.86	1.23	1.51	2.00	1.09	1.32	1.45	46%	51%	84%	21.4	73.2	113.1
3605	62	82	94	73	79	65	0.85	1.04	1.45	1.33	1.81	2.39	1.52	1.75	2.19	36%	48%	55%	20.2	52.7	85.5
3751	99	202	222	119	259	199	0.83	0.78	1.12	1.74	2.26	2.69	0.97	0.95	1.20	20%	41%	45%	26.0	82.2	157.8
3756	75	83	96	82	67	55	0.91	1.25	1.74	2.03	2.48	3.19	1.16	1.42	1.77	31%	35%	40%	17.4	51.5	82.9
4181	111	119	133	180	137	107	0.62	0.87	1.24	0.95	1.25	1.73	1.16	1.44	1.82	45%	49%	54%	25.8	69.1	104.0
4186	26	52	64	22	47	43	1.18	1.12	1.50	1.57	2.40	3.04	2.62	2.53	3.08	14%	29%	35%	11.3	30.1	58.7
4221	63	80	91	79	80	65	0.80	1.00	1.41	1.24	1.67	2.23	1.56	1.84	2.31	30%	38%	43%	18.8	50.4	80.3
4225	125	191	195	179	242	165	0.70	0.79	1.18	1.68	2.07	2.48	0.91	0.99	1.30	46%	70%	72%	25.8	87.8	151.0
4411	68	88	102	90	92	77	0.76	0.96	1.33	1.15	1.56	2.10	1.54	1.77	2.20	34%	44%	51%	20.0	52.0	84.6
4416	83	120	157	124	154	155	0.67	0.78	1.01	1.03	1.41	1.87	1.44	1.59	1.89	43%	63%	82%	20.9	55.5	93.9
4551	113	124	139	252	200	158	0.51	0.72	1.00	0.71	0.93	1.27	1.57	1.95	2.45	20%	21%	24%	17.6	51.0	76.9
4556	54	94	108	60	100	82	0.55	0.64	0.81	1.36	1.88	2.41	1.64	1.69	2.10	22%	38%	44%	18.7	48.6	88.3
5351	214	261	289	340	322	249	0.63	0.81	1.16	0.82	1.15	1.60	0.59	0.71	0.89	46%	56%	63%	54.7	134.8	211.4
5355	166	178	201	361	278	224	0.46	0.64	0.90	0.84	1.06	1.42	1.05	1.31	1.65	60%	64%	72%	26.3	76.3	114.0
5401	140	167	189	241	219	176	0.58	0.76	1.07	0.86	1.16	1.59	0.98	1.18	1.48	50%	59%	67%	31.2	81.2	126.8
5406	128	154	182	206	191	164	0.62	0.81	1.11	0.88	1.19	1.65	1.01	1.20	1.48	45%	55%	65%	27.7	79.1	125.0
6282	268	287	316	765	575	446	0.35	0.50	0.71	0.90	1.07	1.34	0.85	1.04	1.34	61%	65%	72%	95.0	142.5	224.1
6287	64	113	195	142	240	383	0.45	0.47	0.51	0.77	1.07	1.36	2.79	2.83	3.01	19%	33%	57%	29.0	53.1	100.3
6983	167	193	231	505	440	385	0.33	0.44	0.60	0.64	0.80	1.05	1.45	1.76	2.17	51%	60%	71%	54.8	84.7	137.6
7081	140	146	159	279	205	155	0.50	0.71	1.02	0.81	1.04	1.43	1.15	1.45	1.85	58%	60%	66%	69.4	102.8	161.4
7331	105	112	205	263	200	348	0.40	0.56	0.59	0.61	0.80	1.18	1.90	2.39	2.48	40%	43%	78%	41.6	62.4	120.1
7336	161	185	197	251	218	157	0.64	0.85	1.25	1.54	1.86	2.31	0.78	0.95	1.22	42%	49%	52%	65.1	97.1	172.1
7452	167	223	311	440	475	537	0.38	0.47	0.58	0.72	0.94	1.22	1.26	1.43	1.66	49%	66%	92%	64.2	105.1	181.7
7456	65	129	233	124	259	440	0.52	0.50	0.53	0.84	1.20	1.54	2.38	2.32	2.43	17%	33%	60%	33.3	64.3	123.4
7531	67	88	130	82	86	107	0.82	1.02	1.22	1.10	1.54	2.20	1.46	1.68	1.89	22%	29%	43%	55.0	89.3	158.5
7781	181	196	264	377	292	310	0.48	0.67	0.85	0.57	0.81	1.23	0.92	1.14	1.34	59%	64%	86%	87.2	131.1	223.8
7785	197	212	225	705	558	401	0.28	0.38	0.56	0.58	0.71	0.92	1.45	1.86	2.39	76%	81%	86%	54.3	81.5	126.2
9201	152	176	302	298	255	402	0.51	0.69	0.75	0.95	1.21	1.63	1.03	1.24	1.33	33%	38%	66%	77.8	120.6	226.4
9401	118	158	169	211	232	171	0.56	0.68	0.99	0.98	1.29	1.66	1.21	1.40	1.79	43%	58%	62%	65.7	107.6	167.7
9404	161	166	178	373	268	198	0.43	0.62	0.90	0.55	0.75	1.09	1.16	1.46	1.87	59%	61%	66%	69.5	102.6	160.2
9408	122	174	240	235	285	311	0.52	0.61	0.77	0.68	0.98	1.36	1.26	1.41	1.63	36%	52%	71%	63.8	106.8	185.0
9902	85	90	117	144	107	109	0.59	0.84	1.08	0.78	1.06	1.59	1.60	1.99	2.37	39%	41%	53%	50.3	75.0	126.6
10251	126	134	149	229	175	135	0.55	0.77	1.10	0.87	1.13	1.55	1.16	1.45	1.84	54%	57%	63%	68.9	103.4	163.1
10451	187	229	248	399	375	282	0.47	0.61	0.88	0.84	1.09	1.42	0.91	1.08	1.37	55%	68%	73%	88.8	140.2	219.3
10551	121	145	225	319	290	381	0.38	0.50	0.59	0.97	1.17	1.49	1.74	2.07	2.26	30%	36%	56%	46.6	72.9	131.7
10801	168	183	197	392	310	228	0.43	0.59	0.86	0.80	1.00	1.33	1.10	1.39	1.78	48%	52%	56%	72.3	108.6	169.8
10981	193	237	273	536	515	426	0.36	0.46	0.64	0.56	0.75	1.00	1.15	1.38	1.72	48%	59%	68%	68.5	108.4	173.6
11131	198	213	233	460	356	270	0.43	0.60	0.86	0.48	0.68	1.01	0.94	1.17	1.50	52%	56%	61%	85.0	127.5	200.3
11551	199	223	238	828	676	497	0.24	0.33	0.48	0.37	0.48	0.66	1.68	2.04	2.62	49%	55%	59%	48.1	73.3	114.2
11553	89	218	231	121	351	254	0.73	0.62	0.91	1.18	1.71	2.05	1.24	1.11	1.43	25%	60%	64%	65.0	135.4	210.5
11751	150	168	212	428	357	342	0.35	0.47	0.62	0.64	0.81	1.09	1.53	1.90	2.28	33%	37%	46%	51.9	79.4	131.6
11756	174	209	262	370	336	320	0.47	0.62	0.82	1.22	1.46	1.81	0.98	1.16	1.40	46%	55%	69%	82.4	128.9	214.3
11901	161	206	312	365	374	480	0.44	0.55	0.65	0.70	0.94	1.28	1.13	1.33	1.48	33%	42%	63%	70.3	113.2	203.0
12041	121	143	151	302	270	196	0.40	0.53	0.77	0.92	1.12	1.40	1.65	1.98	2.59	39%	46%	48%	48.3	75.2	116.5
12082	103	138	181	293	320	330	0.35	0.43	0.55	0.63	0.82	1.07	2.23	2.53	3.01	25%	34%	45%	36.1	59.2	100.2
12151	319	355	369	1387	1111	784	0.23	0.32	0.47	0.59	0.71	0.87	1.09	1.32	1.73	56%	62%	64%	73.7	112.2	172.2

Appendix Table 1.8. Wetted Useable Area and curve breaks (cfs) by day and night use of Colorado pikeminnow and shoreline use by Humpback chub for each habitat cluster, Yampa River, Colorado, August through October 1996 and 1997.

Cluster	Colorado Pikeminnow						Humpback Chub		
		Day Time		Night Time			Shoreline		
(rm)	Cfs	%	Sq. ft	cfs	%	sq. ft	cfs	%	sq. ft
4.0	250	7.8	15000.6	250	54.8	104952	100	13.5	22251
11.3	100	8.8	6663.35	200	29.6	28727	200	26.4	25652
16.6	40	16.7	16859.4	150	29	36711	60	13.1	14635
17.8	60	23.6	29772.3	60	57.5	72508	20	17.8	21159
19.9	200	1	1219.36	200	33.5	40067	200	15.9	18979
23.9	20	0.8	233.14	20	21.3	6208	250	31.5	33929
26.2	250	0.6	660.2	250	39.6	45167	60	20.4	16831
34.1	125	0.2	289.51	80	12	12263	20	7.9	5691
36.0	125	2	1919.42	100	37.3	33221	250	19.7	26441
37.5	20	2.5	1321.88	150	50.1	54178	200	22.7	26619
41.8	80	0.2	182.16	40	5.2	4757	40	5.3	4877
42.2	250	4.2	6564.78	250	42	65223	80	5.9	6549
44.1	20	0.2	165.42	250	59.1	64447	250	26.6	29013
45.5	125	1.3	1484.57	250	22.3	38077	200	20.4	33058
51.5	60	0	85.55	40	3.2	4694	60	9.4	17962
53.5	20	0.3	326.96	20	5.7	6142	40	10.0	16698
54.0	250	1.3	2662.13	200	35.8	70875	20	11.1	16544
59.8	125	2	3062	100	30	40123			
62.8	80	4	5488	100	38	60177			
69.8	200	4	6981	150	39	59733			
73.3	60	26	28264	150	28	36314			
74.5	60	15	21583	40	25	31757			
76.3	60	7	14917	60	33	67644			
77.8	100	29	51164	40	46	75694			
94.0	100	6	9647	100	47	80882			
104.5	100	18	35564	80	30	59245			
115.5	100	8	11220	150	28	60228			
117.5	40	1	2091	40	25	45353			
119.0	200	1	3038	40	13	18831			
121.5	80	18	33378	60	33	60905			
124.0	150	27	49764	80	50	78825			
	Day Time			Night Time			Shoreline		
	cfs	%	sq. ft	cfs	%	sq. ft	cfs	%	sq. ft
Stratum 1	130	11.4%	13903	172	46%	56593	116	16.8%	20535
Stratum 2	111	1.4%	1417	143	35%	35683	144	18.2%	18744
Stratum 3	93	0.4%	785	145	12%	21386	130	14.5%	25510
Stratum 4	135	0.9%	1495	110	24%	38509			
Stratum 6	98	11.6%	18780	91	33%	53063			
Stratum 8	110	10.8%	20672	79	30%	57753			
123	115	4.6%	5495	153	34%	40747	121	16.6%	19817
468	108	10.0%	17447	88	31%	53296			
All	111	7.9%	11664	119	32%	47223			

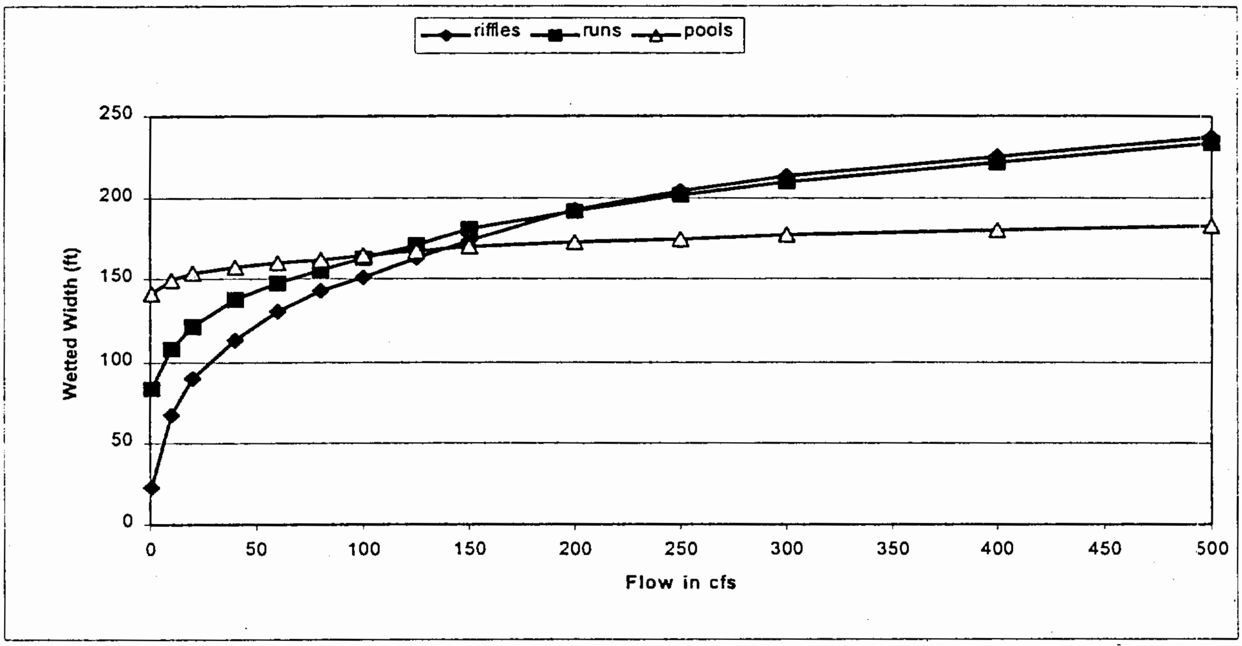


Figure 1-1. Average stream widths of riffles, runs, and pools at flow between 1 and 500 cfs.

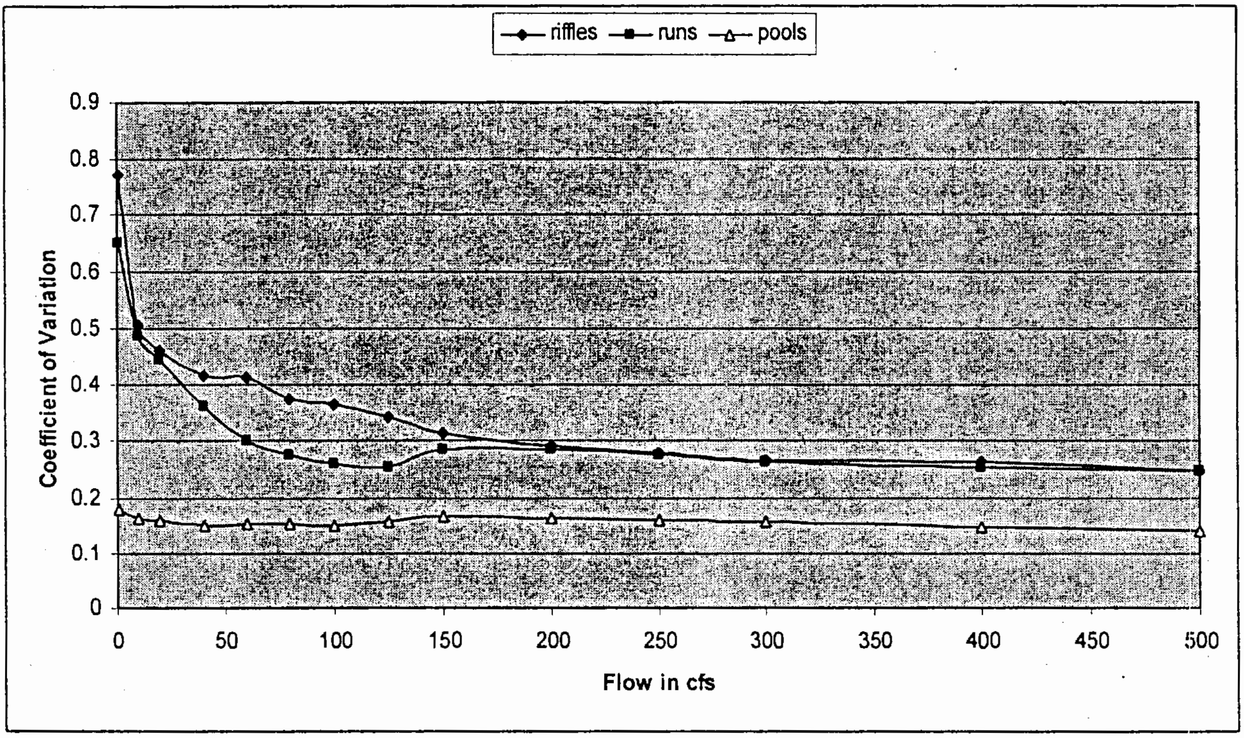


Figure 1-2. Coefficient of variation for stream width at flows between 1 and 500 cfs.

APPENDIX 2 – HABITAT SUITABILITY CRITERIA

Habitat Use Criteria Curves for Use in Modeling Habitat Availability

Habitat use criteria were derived from diurnal and nocturnal depth and velocity observation data. Data collected in 1996 and 1997 were combined to construct the habitat use criteria. The criteria were developed using non-parametric tolerance limits as described in Bovee (1986) and Slauson (1988).

Observation data show that total depths of less than 3 feet were used infrequently in daylight hours. Nocturnal observations showed that the most used depths were in the range of 1.6 feet to 4.2 feet. Depths as shallow as 1.2 feet were used at night by Colorado pikeminnow.

Appendix Table 2.1. Habitat use criteria for depth.

Use criteria for all habitats 1996 and 1997 data.
Total depth

Day	Depth (ft.)	S.I.	Night	Depth (ft.)	S.I.
n=82	1.4	0.0	n=21	1.0	0.0
	2.6	0.125		1.2	0.25
	3.0	0.25		1.4	0.50
	3.8	0.5		1.6	1.00
	4.2	1.0		4.2	1.00
	>6.0	1.0		4.21	0.50
				4.6	0.25
				5.0	0.00

Appendix Table 2.2. Habitat use criteria for bottom velocity.

Use criteria for all habitats 1996 and 1997 data.
Bottom velocity

Day	Velocity (ft./s)	S.I.	Night	Velocity (ft./s)	S.I.
n=47	0.0	0.25	n=20	0.0	0.25
	0.09	0.5		0.01	0.50
	0.1	1.0		0.1	1.00
	0.8	1.0		1.3	1.00
	1.2	0.5		1.6	0.50
	1.3	0.25		1.9	0.25

Appendix Table 2.3. Habitat use criteria for mean column velocity.

Use criteria for all habitats 1996 and 1997 data.
Mean column velocity

Day	Velocity (ft./s)	S.I.	Night	Velocity (ft./s)	S.I.
n=54	0.0	0.125	n=20	0.0	0.25
	0.1	0.25		0.01	0.50
	0.2	0.50		0.1	1.00
	0.7	1.00		2.2	1.00
	1.6	1.00		3.0	0.50
	1.9	0.50		3.6	0.25
	2.0	0.25		4.2	0.00
	2.1	0.125			
	2.2	0.0			

Appendix Table 2.4. Telemetry data for fish caught in the Yampa River in 1996 and 1997

Date	River Mile	Freq	Species				Distance from last location	Init-last	TL	WT	PITTAG	Status
7/1/96	37.5	40.2712	HMPBK						282	170	1F657D3946	NEW FISH
8/5/96	19.9	40.2712	HMPBK	17.6		17.6	17.6					
8/15/96	30.1			10.2		10.2	-10.2					
8/22/96	41.4			11.3		11.3	-11.3					
8/26/96	41.8			0.4		0.4	-0.4					
9/3/96	41.1			0.7		0.7	0.7					
9/9/96	42.4			1.3		1.3	-1.3					
9/19/96	28.2			14.2		14.2	14.2					
10/29/96	25.6			2.6		2.6	2.6					
			average=	7.2875	total=	58.3	Total=	11.9				
7/3/96	23.8	40.2618	HMPBK						302	216	1F64003647	NEW FISH
8/5/96	30.5	40.2618	HMPBK	6.7		6.7	-6.7					
8/14/96	39.6			9.1		9.1	-9.1					
8/21/96	21			18.6		18.6	18.6					
8/26/96	21.7			0.7		0.7	-0.7					
9/3/96	18.3			3.4		3.4	3.4					
9/9/96	18.7			0.4		0.4	-0.4					
9/19/96	21.4			2.7		2.7	-2.7					
10/29/96	24.2			2.8		2.8	-2.8					
				5.55		44.4		-0.4				
7/3/96	18.2	40.2811	HMPBK						283	192	1F62651C7E	NEW FISH
8/5/96	25.5	40.2811	HMPBK	7.3		7.3	-7.3					
8/14/96	10.7			14.8		14.8	14.8					
8/21/96	5.2			5.5		5.5	5.5					
8/27/96	9			3.8		3.8	-3.8					
9/4/96	16.9			7.9		7.9	-7.9					
9/9/96	NF											
9/20/96	9.7			7.2		7.2	7.2					
10/29/96	NF											
				7.75		46.5		8.5				
7/4/96	16.8	40.2409	HMPBK						287	180	1F623E7948	NEW FISH
8/6/96	16	40.2409	HMPBK	0.8		0.8	0.8					
8/14/96	15.9			0.1		0.1	0.1					
8/21/96	12.5			3.4		3.4	3.4					
8/27/96	NF											

9/4/96	17.8			5.3		5.3	-5.3					
9/10/96	NF											
9/20/96	5.2			12.6		12.6	12.6					
10/29/96	NF											
				4.44		22.2		11.6				
7/15/96	36.2	40.211	HMPBK						276	162	1F607D0D77	NEW FISH
8/5/96	30	40.211	HMPBK	6.2		6.2	6.2					
8/15/96	36.1			6.1		6.1	-6.1					
8/22/96	29.9			6.2		6.2	6.2					
8/26/96	18.2			11.7		11.7	11.7					
9/3/96	26.1			7.9		7.9	-7.9					
9/9/96	26.2			0.1		0.1	-0.1					
9/19/96	33.5			7.3		7.3	-7.3					
10/29/96	30.3			3.2		3.2	3.2					
				6.0875		48.7		5.9				
7/8/97	26.4	40.461	HMPBK						259	186	223F5F2C5A	NEW FISH
7/24/97	19.4	40.461	HMPBK	7		7	7					
8/6/97	16.9			2.5		2.5	2.5					
8/13/97	22.1			5.2		5.2	-5.2					
8/18/97	17.2			4.9		4.9	4.9					
8/22/97	NF											
9/24/97	36.7			19.5		19.5	-19.5					
10/21/97	36.1			0.6		0.6	0.6					
				6.616666		39.7		-9.7				
7/10/97	20.5	40.451	HMPBK						336	445		
7/24/97	18.9			1.6		1.6	1.6					
8/6/97	18.9			0		0	0					
8/13/97	18.3			0.6		0.6	0.6					
8/18/97	18.6			0.3		0.3	-0.3					
8/22/97	NF											
9/24/97	21.5			2.9		2.9	-2.9					
10/21/97	19.1			2.4		2.4	2.4					
				1.3		7.8		1.4				
7/10/97	18.2	40.442	HMPBK						325	257		
7/24/97	18.3			0.1		0.1	-0.1					
8/6/97	18.7			0.4		0.4	-0.4					
8/13/97	17.7			1		1	1					
8/18/97	17.8			0.1		0.1	-0.1					
8/22/97	NF											

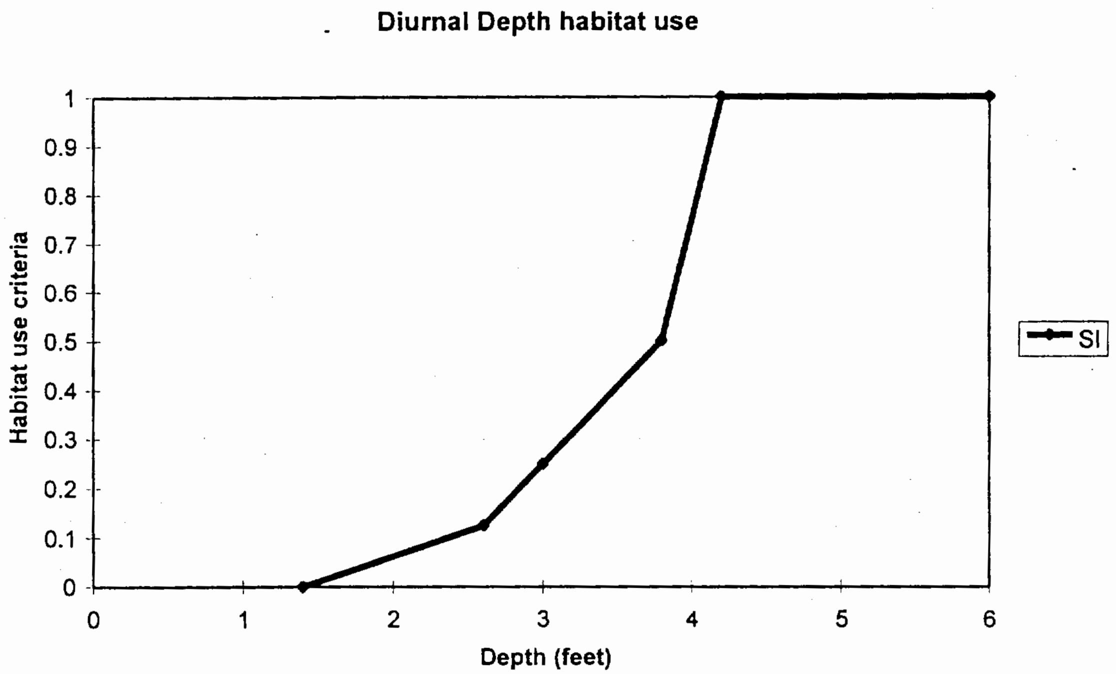
9/24/97	20.1			2.3		2.3	-2.3					
10/21/97	20.8			0.7		0.7	-0.7					
				0.766666		4.6		-2.6				
7/15/97	37.5	40.481	HMPBK						286	193		
7/24/97	8.3			29.2		29.2	29.2					
8/6/97	NF											
8/13/97	21.6			13.3		13.3	-13.3					
8/18/97	20.8			0.8		0.8	0.8					
8/22/97	NF											
9/24/97	25.1			4.3		4.3	-4.3					
10/21/97	24.6			0.5		0.5	0.5					
				9.62		48.1		12.9				
7/15/97	37.5	40.471	HMPBK						298	196		
7/24/97	37.7			0.2		0.2	-0.2					
8/6/97	35.2			2.5		2.5	2.5					
8/13/97	35.2			0		0	0					
8/18/97	NF											
8/22/97	NF											
9/24/97	35.3			0.1		0.1	0.1					
10/21/97	35.3			0		0	0					
				0.56		2.8		2.2				
7/2/96	36	40.6436	CC						435	740		
8/6/96	35.8	40.6436	CC	0.2		0.2	0.2					
8/14/96	35			0.8		0.8	0.8					
8/21/96	35.9			0.9		0.9	-0.9					
8/27/96	38.6			2.7		2.7	-2.7					
9/4/96	35.4			3.2		3.2	3.2					
9/10/96	35.6			0.2		0.2	-0.2					
9/20/96	35.7			0.1		0.1	-0.1					
10/29/96	43.9			8.2		8.2	-8.2					
				2.0375		16.3		-7.9				
4/22/97	20.5											
7/24/97	30.4			9.9		9.9	-9.9					
8/7/97	32.1			1.7		1.7	-1.7					
8/13/97	30.1			2		2	2					
8/18/97	31.3			1.2		1.2	-1.2					

8/22/97	31.2			0.1		0.1	0.1					
9/24/97	30.9			0.3		0.3	0.3					
10/21/97	31.2			0.3		0.3	-0.3					
				2.214285		15.5		-10.7				
7/4/96	18.2	40.5739	CC						460	825		
8/6/96	17.7	40.5739	CC	0.5		0.5	0.5					
8/14/96	17.9			0.2		0.2	-0.2					
8/22/96	18.3			0.4		0.4	-0.4					
8/27/96	18			0.3		0.3	0.3					
9/4/96	18.1			0.1		0.1	-0.1					
9/10/96	19.9			1.8		1.8	-1.8					
9/20/96	18.2			1.7		1.7	1.7					
10/29/96	17.7			0.5		0.5	0.5					
				0.6875		5.5		0.5				
4/22/97	17.9											
7/24/97	NF											
8/7/97	24.1			6.2		6.2	-6.2					
8/13/97	NF											
8/18/97	NF											
8/22/97	NF											
9/24/97	20.8			3.3		3.3	3.3					
10/21/97	47.9			27.1		27.1	-27.1					
				12.2		36.6		-30				
7/4/96	16.8	40.6938	CC						476	844		
8/6/96	16.6	40.6938	CC	0.2		0.2	0.2					
8/14/96	16.8			0.2		0.2	-0.2					
8/21/96	17.2			0.4		0.4	-0.4					
8/27/96	15.9			1.3		1.3	1.3					
9/4/96	17.8			1.9		1.9	-1.9					
9/10/96	18.6			0.8		0.8	-0.8					
9/20/96	15.5			3.1		3.1	3.1					
10/29/96	16.8			1.3		1.3	-1.3					
				1.15		9.2		0				
4/22/97	17.9											
7/24/97	19.2			1.3		1.3	-1.3					
8/7/97	17.2			2		2	2					
8/13/97	44.3			27.1		27.1	-27.1					
8/18/97	NF											
8/22/97	31			13.3		13.3	13.3					
9/24/97	19.1			11.9		11.9	11.9					

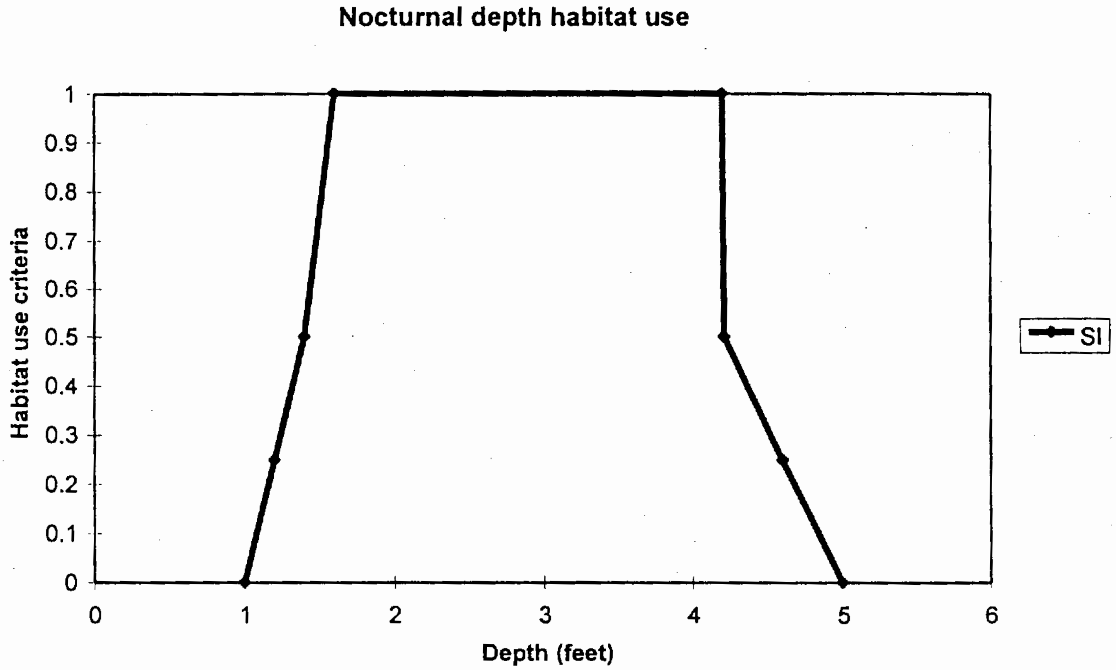
10/21/97	16.5			2.6		2.6	2.6					
				9.7		58.2		1.4				
7/15/96	39.5	40.253	CC						468	973		
8/6/96	39.8	40.253	CC	0.3		0.3	-0.3					
8/15/96	40.2			0.4		0.4	-0.4					
8/22/96	39.6			0.6		0.6	0.6					
8/27/97	39.7			0.1		0.1	-0.1					
9/4/96	39.8			0.1		0.1	-0.1					
9/10/96	39.1			0.7		0.7	0.7					
9/20/96	39.4			0.3		0.3	-0.3					
10/29/96	37.6			1.8		1.8	1.8					
				0.5375		4.3		1.9				
4/22/97	39.8											
7/24/97	40.1			0.3		0.3	-0.3					
8/7/97	39.8			0.3		0.3	0.3					
8/13/97	39.5			0.3		0.3	0.3					
8/18/97	39.7			0.2		0.2	-0.2					
8/22/97	42.2			2.5		2.5	-2.5					
9/24/97	40.1			2.1		2.1	2.1					
10/21/97	39.6			0.5		0.5	0.5					
				0.885714		6.2		0.2				
7/15/96	37.25	40.6037	CC						531	1606		
8/6/96	37.4	40.6037	CC	0.15		0.15	-0.15					
8/14/96	37.3			0.1		0.1	0.1					
8/22/96	37.7			0.4		0.4	-0.4					
8/27/96	37.6			0.1		0.1	0.1					
9/4/96	37.6			0		0	0					
9/10/96	37.3			0.3		0.3	0.3					
9/20/96	38.5			1.2		1.2	-1.2					
10/29/96	18.2			20.3		20.3	20.3					
				2.81875		22.55		19.05				
4/22/97	NF											
7/24/97	3.8											
8/7/96	NF											
8/13/97	NF											
8/18/97	16			12.2		12.2	-12.2					
8/22/97	NF											
9/24/97	19.8			3.8		3.8	-3.8					
10.21/97	27.8			8		8	-8					
				8		24		-24				

7/7/97	26.6	40.162	CC						645	2706		
7/24/97	14.3			12.3		12.3	12.3					
8/7/97	11.4			2.9		2.9	2.9					
8/13/97	NF											
8/18/97	5.7			5.7		5.7	5.7					
8/22/97	NF											
8/22/97	NF											
9/24/97	NF											
10/21/97	NF											
				6.966666		20.9		20.9				
7/8/97	34.5	40.152	CC						570	1452		
7/24/97	NF											
8/7/97	20.9			13.6		13.6	-13.6					
8/13/97	54.2			33.3		33.3	-33.3					
8/18/97	53.8			0.4		0.4	0.4					
8/22/97	NF											
9/24/97	NF											
10/21/97	55.4			1.6		1.6	-1.6					
				12.225		48.9		-20.9				
7/3/96	23.8	40.7236	CS						543		1F73015914	NEW FISH
8/6/96	32.2	40.7236	CS	8.4		8.4	-8.4					
8/15/96	25.1			7.1		7.1	7.1					
8/22/96	0			25.1		25.1	25.1					
7/3/96	23.8	40.6332	CS						561		7F7D1A4A19	RECAP
8/5/96	9.6	40.6332	CS	14.2		14.2	14.2					
8/15/96	9.8			0.2		0.2	-0.2					
8/22/96	9.9			0.1		0.1	-0.1					
8/26/96	10.2			0.3		0.3	-0.3					
9/3/96	10.7			0.5		0.5	-0.5					
9/9/96	16.4			5.7		5.7	-5.7					
				3.5		21		7.4				
9/19/97	9.8			6.6		6.6	6.6					
10/29/97	10.4			0.6		0.6	-0.6					
				3.6		7.2		-0.6				

7/3/96	23.8	40.6233	CS						530	1247	1F63177A60	NEW FISH
8/5/96	31.5	40.6233	CS	7.7		7.7	-7.7					
8/15/96	45.4			13.9		13.9	-13.9					
8/22/96	42.1			3.3		3.3	3.3					
8/26/96	43.3			1.2		1.2	-1.2					
9/3/96	39.1			4.2		4.2	4.2					
9/9/96	37.1			2		2	2					
9/19/96	36.8			0.3		0.3	0.3					
10/29/96	29.7			7.1		7.1	7.1					
				8.221825		39.7		-5.9				
4/22/97	33.7											
7/24/97	15.1			18.6		18.6	18.6					
8/6/97	32.7			17.6		17.6	-17.6					
8/13/97	37			4.3		4.3	-4.3					
				13.5		40.5		-3.3				
7/3/96	23.8	40.5626	CS						535		1F6511303B	NEW FISH
8/5/96	19.8	40.5626	CS	4		4	4					
8/15/96	24.1			4.3		4.3	-4.3					
8/22/96	0			24.1		24.1	24.1					
7/3/96	23.8	40.7334	CS						555		1F614C5F55	NEW FISH
8/5/96	32	40.7334	CS	8.2		8.2	-8.2					
8/15/96	15.8			16.2		16.2	16.2					
8/22/96	20.1			4.3		4.3	-4.3					
8/26/96	12.1			8		8	8					
9/4/96	15.3			3.2		3.2	-3.2					
9/9/96	15.5			0.2		0.2	-0.2					
9/19/96	12.9			2.6		2.6	2.6					
10/29/96	21.6			8.7		8.7	-8.7					
				6.425		51.4		2.2				
4/22/97	27.8											
7/24/97	24.2			3.6		3.6	3.6					
8/6/97	33.4			9.2		9.2	-9.2					
8/13/97	30.2			3.2		3.2	3.2					
				5.333333		16		-2.4				

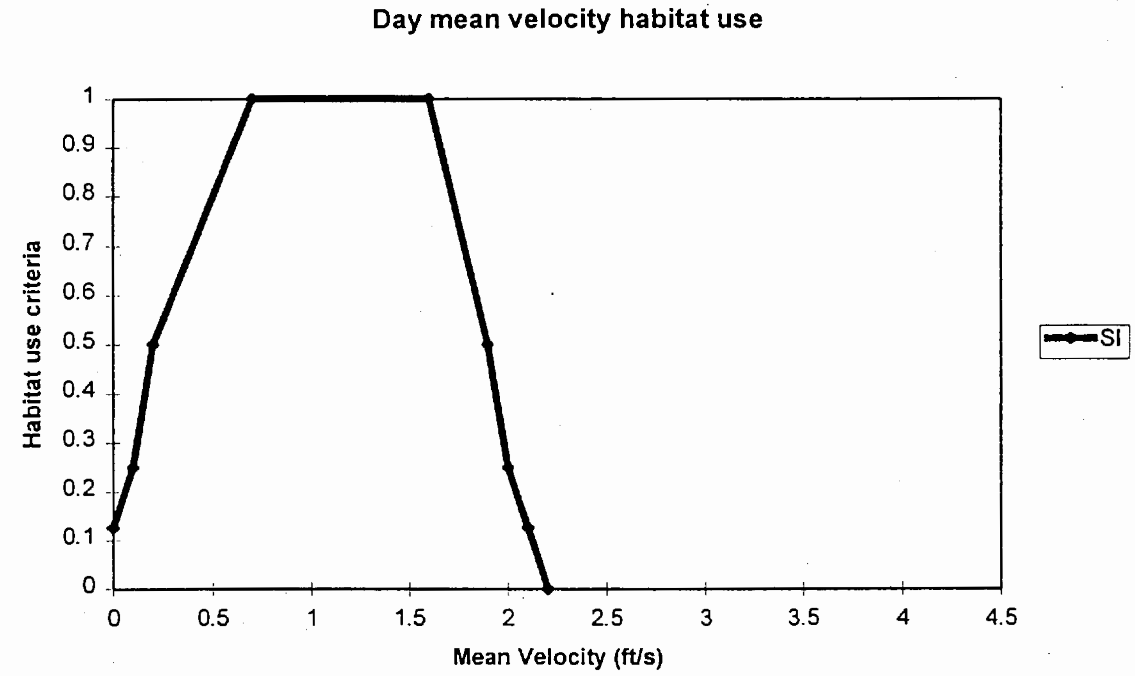


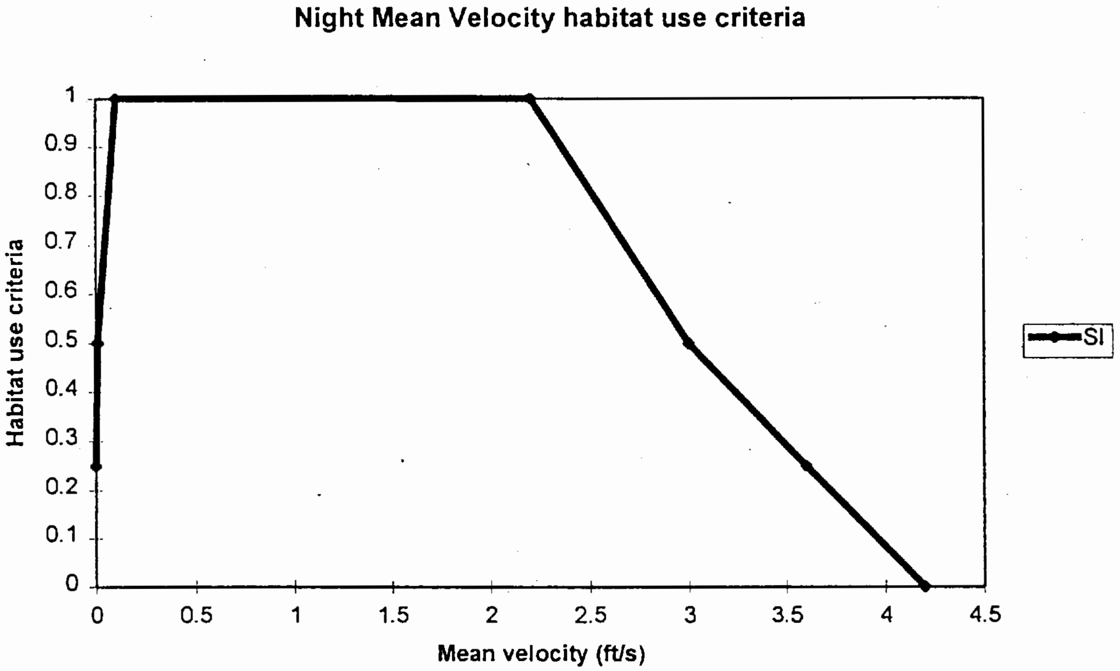
Diurnal Depth habitat use



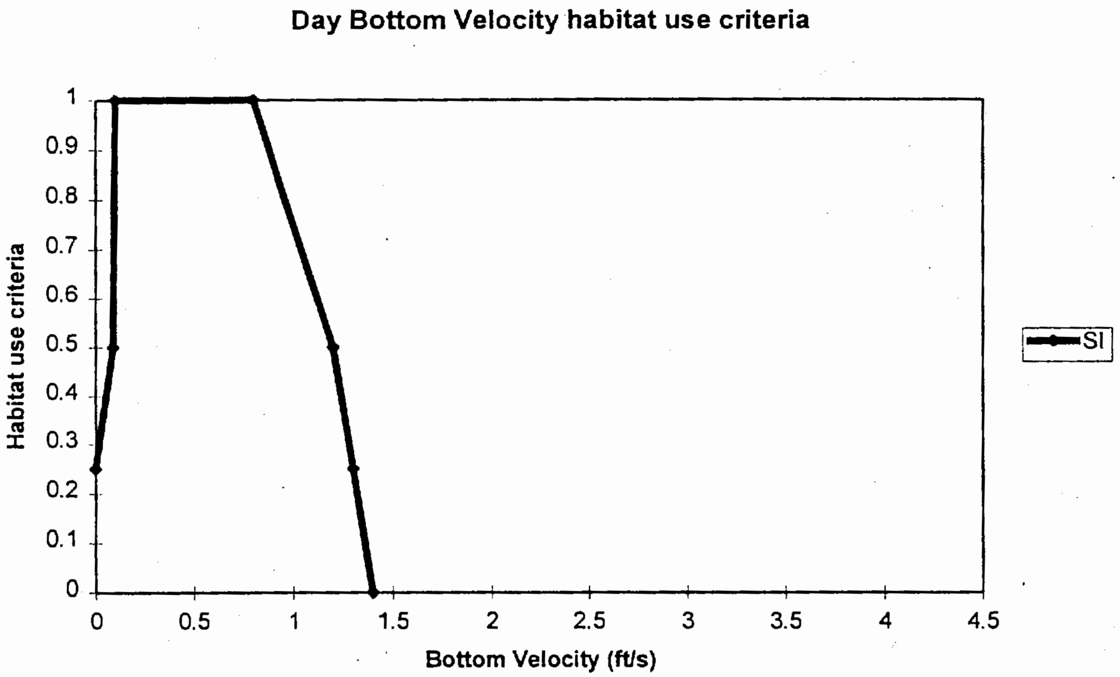
Nocturnal depth habitat use

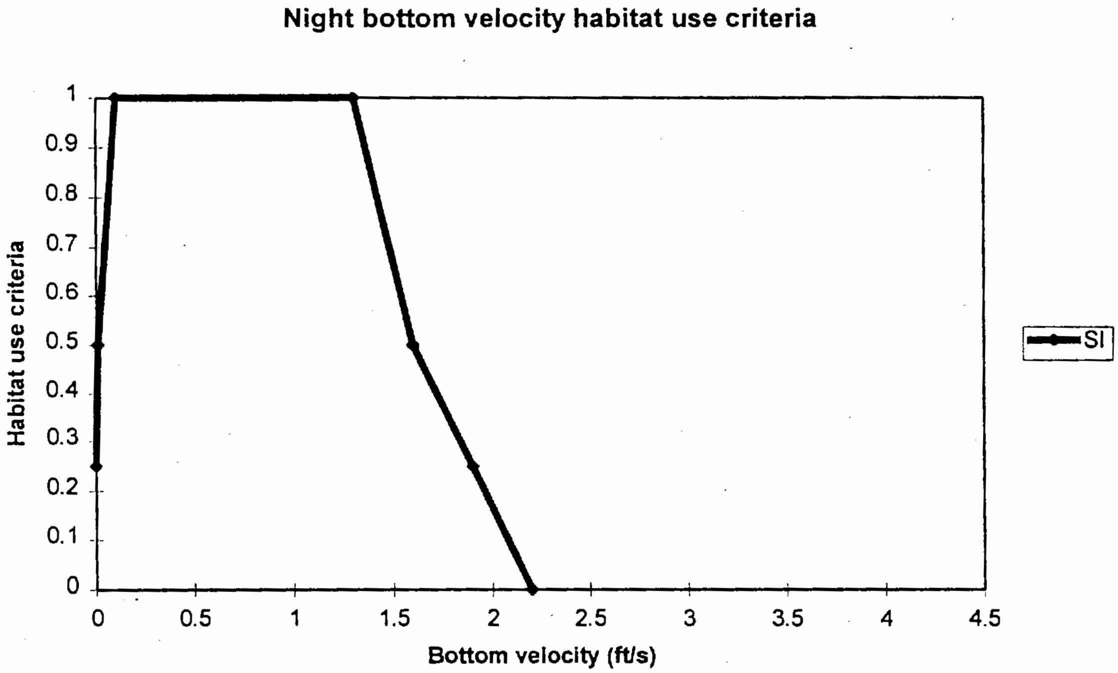
Appendix Figure 2.1. Colorado pikeminnow habitat use criteria for depth (diurnal and nocturnal).





Appendix Figure 2.2. Colorado pikeminnow habitat use criteria for mean column velocity (day and night).





Appendix Figure 2.3. Colorado pikeminnow habitat use criteria for bottom velocity (day and night).

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