Riverine Fish Flow Investigations

Federal Aid Project F-289-R6

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Study Objective: To determine relationships between flow and habitat availability for warm-water riverine fish communities of Colorado.

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INTRODUCTION

Conservation and management of native species is now a major consideration within the Colorado Division of Wildlife (CDOW). This is especially true for species that are listed as federally threaten or endangered. Four species of fish in the Colorado River basin are listed as endangered by the U.S. Fish and Wildlife Service. The Upper Colorado River Recovery Program was established to identify and resolve problems, so these fish can eventually be down-listed (Wydoski and Hamill 1991). The state of Colorado and the Recovery Program share the same goal of recovering the fish, but their agencies may not share common strategies. A unifying approach for native fish management objectives is to agree on the scientific validity of data involved in identification of limiting factors.

In Colorado State government instream flow protection for fish via water rights has been a common practice in high elevation headwaters (Espregren 1998). Water rights adjudication, however, has become a rigorous legal process for high profile warm water rivers like the Colorado and Yampa Rivers where water is already highly over-appropriated. In response, U. S. Fish and Wildlife Service (USFWS) conducted studies for instream flow recommendations in regard to recovery of endangered fish species in the 15-Mile Reach of the Colorado River (Osmundson et al. 1995) and the Yampa River (Modde and Smith 1995). Modde et al. (1999) was a field-based study on the Yampa River, also sponsored by the Recovery Program. Even though the intent of these flow studies was the same, to determine stream flow requirements for endangered fish, recommendations were based on vastly different methodologies.

The goal of this project was to develop biologically based instream flow recommendations for the Colorado in the 15-Mile Reach and Yampa rivers based on habitat and flow requirements for non-endangered native fish. The identification and validation of flow needs for non-endangered native fish may assist in preventing listing these species in the future. This data may also be of value to the Endangered Fish Recovery Program by providing ancillary information concerning the overall fish community and descriptions of physical habitat availability.

Typically CDOW uses the R2Cross method (Nehring 1979) or PHABSIM (Bovee 1982) for making instream flow recommendations for protecting cold water habitats. However these two methods were not considered appropriate for the warm water sections of the Colorado and Yampa Rivers given the elevated levels of biological, geomorphic and social complexities for these rivers.

This study employed a Meso-Habitat approach that is similar in concept to PHABSIM. PHABSIM is widely used in North America to quantify impacts of altered flow regimes to habitat. PHABSIM consists of two modeling components. The hydraulic component is a series of one-dimensional cross-sections that are linked to produce a series of rectangular cells that form a grid. Mean depth and velocity conditions are calculated for each cell for a given flow. The biological component is a set of suitability index curves for depth and velocity criteria that are used to rate micro-habitat suitability for each cell in the cross-sectional grid. Habitat availability is measured by an index called weighted useable area (WUA), the summation of cell areas weighted by its suitability index. When plotted versus discharge WUA typically peaks at a single flow that is considered the flow that maximizes habitat. PHABSIM has been criticized because of assumptions implicit with micro-habitat suitability curves, assumptions of positive relationships between habitat availability and fish abundance, and the tendency of users to recommend flows at the peak of the WUA-discharge relation regardless of natural flow occurrence. These assumptions have been obstacles for using PHABISM to model impacts of reduced flows on large warm water rivers of the west slope (Rose and Hahn 1989).

The Meso-Habitat method of this study is also an integration of hydraulic and biologic analyses. We used a 2-D flow model to simulate depths and velocity. Fish habitat suitability was derived from density estimates made at each site. Two-dimensional (2-D) flow models have been found to have high potential for application in instream flow studies (Leclerc *et al*., 1995; Bovee, 1996; Kondolf et al. 2000). Two-dimensional models offer a significant improvement over one-dimensional (1-D) modeling by increasing spatial resolution. This allows for a highly accurate quantification of the physical habitat for each flow of interest. 2-D models are not dependent on micro-habitat suitability curves for predicting habitat availability. Meso-habitat scale precision is more efficient for sampling biological data. Criteria can be established for individual species and also by guilds (sympatric species) (Parasiewicz 2001). A relationship between habitat availability to fish abundance assumes that fish distribute themselves in the river primarily as a function of habitat. A large part of this study was to develop meso-habitat criteria for two native suckers. This was accomplished by examining the relationship between their abundance and meso-habitat availability. The output of the meso-habitat methodology was the relationship among meso-habitat availability and the range of modeled flows.

Species Used for the Biological Analysis

The primary species used in the instream flow analysis were the bluehead sucker (*Catostomus discobolus*), flannelmouth sucker (*Catostomus latipinnis*) and roundtail chub (*Gila robusta*). These species, quite common in the Colorado River, comprised about 80 percent of fish sampled between Rifle and Palisade. Anderson (1977) speculated that fishery abundance was likely at carrying capacity set by the physical habitat. Samples made by the Recovery Program (ISMP) in the Colorado River downstream of Grand Junction to Loma found native fish were about 90% of the catch (Elmbald 2003). Osmundson (1999) reported high catch rates of native suckers in the Colorado River, with the highest catch rate in the 15-Mile Reach. The thriving populations of these three native species suggest that habitat, base flow alternations or non-native introductions have not negatively impacted their life history requirements in the river. In fact, studies suggest the Colorado River is an excellent location to study dynamics between these three native fish and physical habitat.

Conversely, these three native species have not maintained a historically abundant population or relative composition in the Yampa River. Miller (1982), Carlson (1979), Wick (1981 and 1986) and Prewitt (1977) reported that native suckers had become fairly rare in the Yampa River upstream of Maybell at River Mile (RM) 74. The most common species is the introduced white sucker (*Catostomus commersoni*). Elmblad (2003) reported native fish were only 24% and 35% of the catch during Interagency Standardized Monitoring Program (ISMP) surveys upstream of Maybell (River Mile 75). The Yampa River has experienced reduced base flows and has an established population of introduced nonnative predators, which obscure determination of the relationship between habitat and native fish density.

The bluehead sucker is a large fish (up to 45 cm in length) that remains abundant in most west slope rivers. Not a lot of data is available from life-history studies of the bluehead sucker. However, biologists who sample in the Colorado drainage strongly associate this species with a single meso-habitat. This makes the bluehead sucker an excellent species for flow and habitat evaluation studies. Adult fish are typically found in moderate to deep riffle habitat, which is a combination of fast flowing water over cobble-rubble substrate (Woodling 1985; Sublette 1990). The bluehead feeds on invertebrates, which have their highest densities in riffles. Because the bluehead is an obligate riffle species, it's meso-habitat suitability can be defined by the depths and velocities of the riffle habitats the sucker occupies.

The flannelmouth sucker is another large bodied fish that grows up to 60 cm long. The flannelmouth is abundant in most west slope rivers where hybridization with white sucker has not occurred. The flannelmouth is another species whose habitat requirements can be defined by depth and velocity combinations. Adults of generally occupy deeper run habitats (Woodling 1985). Runs are typically defined as areas with low to moderately fast currents. In the Colorado and Yampa Rivers, run habitat is generally more ubiquitous. Likewise, the flannelmouth tends to be more common in run dominated rivers. The flannelmouth's habitat overlaps with the bluehead's in the glide section of the river. Glides have similar depths and velocities as runs, but glides are located between the tail of the pool and the head of a riffle where bed elevation is rising.

The roundtail chub is a cyprinid that achieves a large body size (up to 45 cm in length) and is still fairly common in parts of its range in Colorado. The roundtail chub is a predator and has a much different life history and behavior than the two native suckers. These fish generally seek cover during the day and patrol or forage during the evening. These fish do not rely on one particular meso-habitat type; therefore, their habitat use can not be modeled by a simple range of depth and velocity criteria. This is a true multi-meso-habitat species. Factors that control their density may be more a function of forage availability than of meso-habitat availability.

The speckled dace (*Rhinichthys osculus*) is a small-bodied cyprinid that may attain a length of 12-cm (Woodling 1985). Speckled dace are generally very abundant and like the bluehead sucker are a riffle-obligate species. Since dace are small-bodied fish they can occupy shallow riffles, which means during periods of reduced flows bluehead sucker habitat would become unsuitable long before dace habitat loss would become problematic. Therefore, meso-habitat availability for speckled dace and another small-bodied native fish, the mottled sculpin (*Cottus bairdi*) were not modeled in this study. It was necessary, however, to include these species in an ancillary analysis because the dace and sculpin populations have been noticeably impacted on the Yampa River during low-flow scenarios.

Study Objectives:

1). Quantify fish habitat on warm water sections of the Yampa, Colorado and Dolores rivers using 2-D flow models

2). Determine community structure, density and biomass for fish assemblages for the three study rivers

3). Determine relationships between habitat availability and fish abundance for the native species bluehead sucker, flannelmouth sucker and roundtail chub

4). Develop biologically based instream flow recommendations for the Yampa River and Colorado Rivers in the 15-mile reach

5) Provide validation for meso-habitat suitability values used in the 2-D model and for predicting habitat as a function of flow

STUDY AREA

Yampa River

There are three study areas on the Yampa River. The two sites established in 1998 are called the Sevens and Duffy stations. A third site at Lily Park was added in 2000. The Sevens station is located at River Mile (RM) 63 and is 1.8 mile in length. Duffy is at River Miler (RM) 109 and is 1.3 miles in length (Figure 1). Sevens and Duffy were electro-fished in 1998, 1999, 2000 and 2001. The habitat was mapped in 1999. The Lily Park site is located just below Cross Mountain Canyon and just above the mouth of the Little Snake River (Figure 1). The Lily Park site extends 19 miles from RM 52.7 to RM 54.5. The bridge on County Road (CR) 25 is located at RM 52.5.

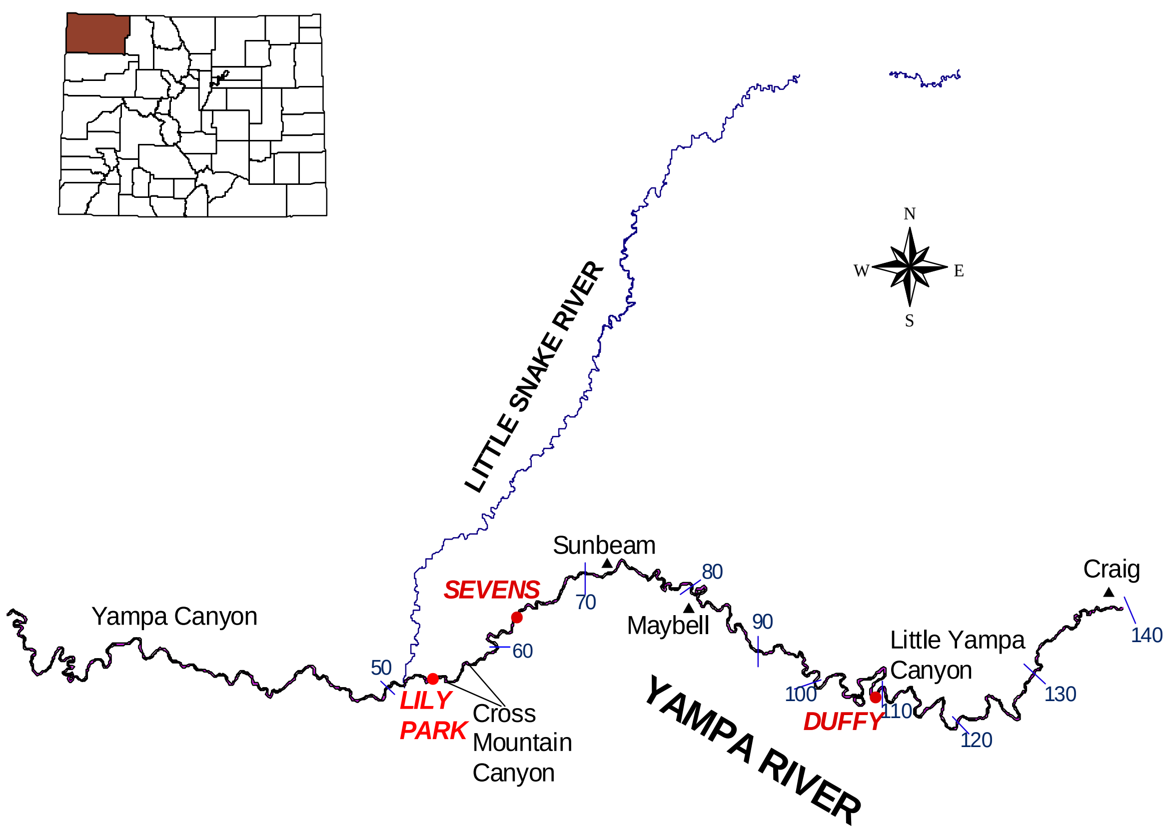

Figure 1. Location of the three study sites for the Yampa River, Lily Park, Sevens and Duffy.

The Cross Mountain Ranch is the landowner for most of the river at Sevens and Lily Park. The BLM is the primary landowner at Duffy. In general, each site on the Yampa River has distinctly different fish and habitat characteristics. Duffy is located in Little Yampa Canyon and has some deep pools with large boulders that provide cover. Duffy is low gradient. The primary habitat during the base-flow period consists of shallow pools. Sevens is also low gradient with gravel-sand substrate. At typical base flows, shallow, low-velocity pools and runs are the most common habitats. The Lily Park site is higher gradient with a cobble-boulder substrate. Faster flowing habitats (runs and riffles) dominate in Lily Park. The Lily Park site was added because of its better native fish composition than at Duffy.

Peak flows recorded at the Maybell gage were fairly similar for the years 1998, 1999 and 2000, at 10,040 cfs, 9,980 cfs and 9,830 cfs respectively. Peak flows in these three years are near the magnitude of the median peak flow of 9,980 cfs for the 86 year period of record (Figure 2). Peak flow in 2001 was 7,650 cfs, which has been exceeded in 77% of the years during the period of record. The peak flow in 1997 was 16,400, and has been exceeded in only 5% of the period of record (Figure 2). Andrews (1982) calculated bankfull flow for the Yampa from the Maybell gage to be 9,.000 cfs.

Determining impacts of low flows are one of the primary objectives of this study. Modde et al. (1999) used a cross section methodology (modified R2Cross) to identify habitat availability at low flows for endangered fish on the Yampa River. The result was a recommendation that 93 cfs be used as a reference flow that signals the beginning of severely degraded conditions. The 93-cfs reference flow was specifically not meant to be an instream flow recommendation since it was believed the endangered pikeminnow could likely survive severely degraded conditions for a short term.

Annual minimum flows recorded at the Maybell gage for 1997, 1998, 1999, 2000 and 2001 were 320 cfs, 115 cfs, 166 cfs, 30 cfs and 50 cfs respectively. The 86-year median minimum flow is 126 cfs (Figure 3). The 2000 minimum flow of 30 cfs was exceeded in 93% of the years, and the 2001 minimum flow of 50 cfs was exceeded in 83% of the years for the period of record (Figure 3). Flow did not drop below the 93-cfs reference flow in 1998 and 1999, but flow was less than 93 cfs for 34 days in 2000 and 17 days in 2001.

Two consecutive years of low flow may have more significant and lasting impacts on the aquatic community (carrying capacity) than a single low flow year. Stream flow was less than the 93-cfs reference flow for 0 days in 1997, 2 days in 1996, 0 days in 1995. In 1994, the minimum flow was 8 cfs and flow was less than 93-cfs for 73 days that year. Presumably habitat was severely restricted in 1994 and there were impacts to the fish community. The four-year interval between 1994 and the start of sampling in 1998 may have been enough time to allow the fish community to adjust back to normal flows. There were two days of flow below the 93 cfs in 1996. As of 2000, flow had not been below the 93 cfs for the previous three years. However, 2001 was a second consecutive low-flow year (Figure 3).

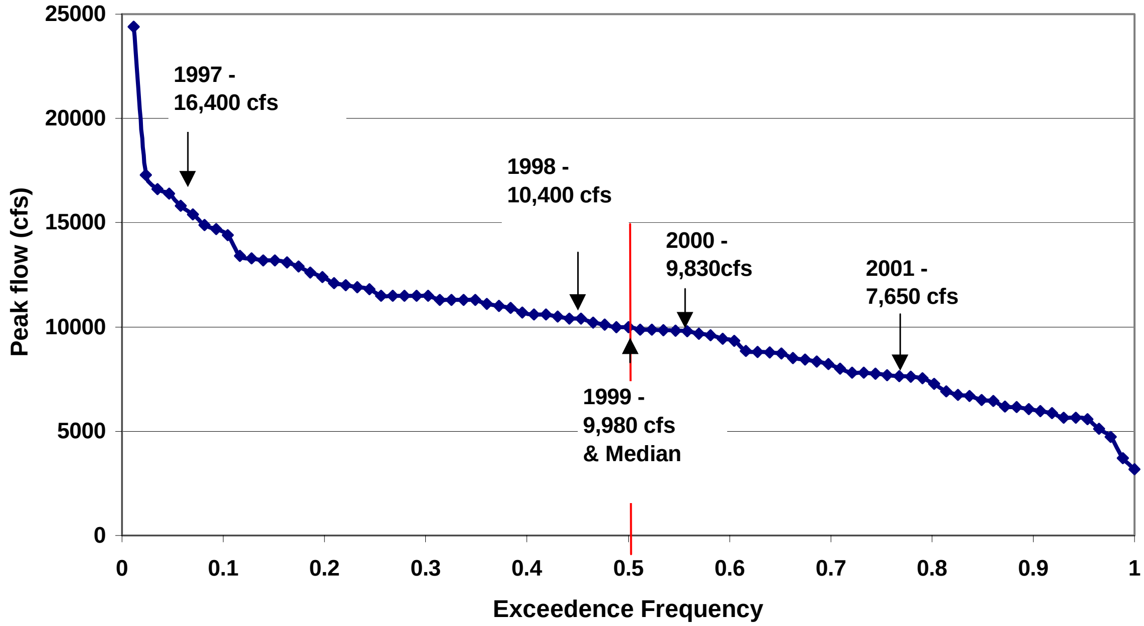

Figure 2. Peak flow during the study period at the Maybell gage with exceedence frequency for the period of record.

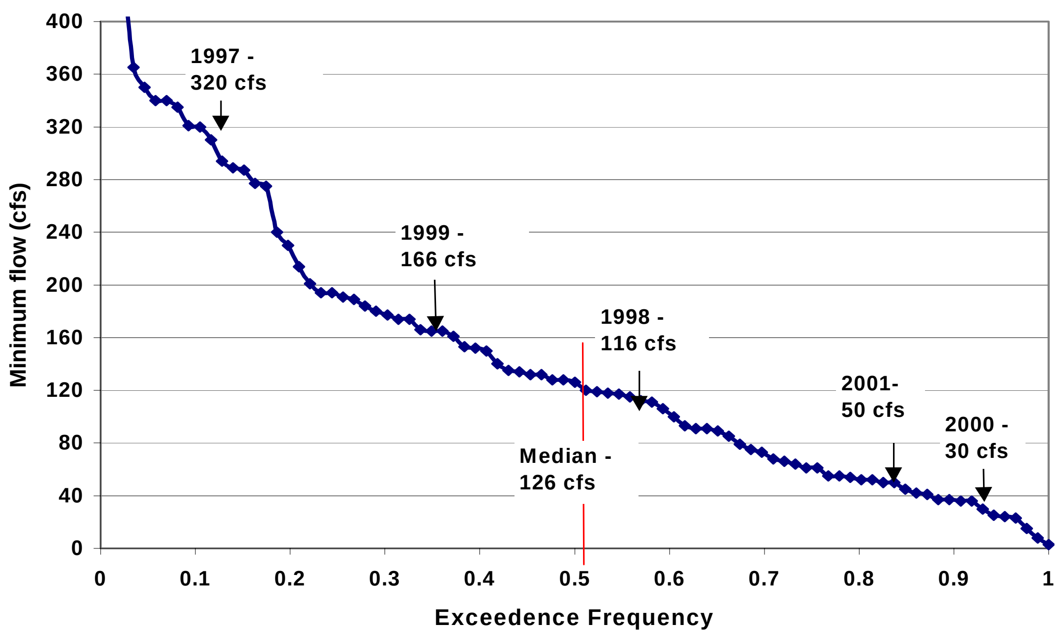

Figure 3. Minimum flows during the study period recorded at the Maybell gage with exceedence frequency for the period of record.

Colorado River – 15-Mile Reach

The 15-Mile Reach of the Colorado River extends from Palisade, Colorado (RM 185), downstream to the confluence of the Gunnison River at about RM 170 (Figure 4). The Colorado River Recovery Program (Osmundson et al. 1995) considers the 15-Mile Reach important for endangered fish recovery. Flows are an issue because of two major upstream diversions that divert flow from the river during the irrigation season (April 1 to November 1). The Government Highline diversion is located in lower Debeque Canyon (RM 193.7) and the Highline canal has a capacity of 1620 cfs. The Grand Valley diversion dam is at RM 185.4. The Grand Valley canal has a capacity of 640 cfs.

A USGS gage, which is located about 0.4 km downstream from the intake for the Grand Valley canal (Figure 4), began operation in 1990. Flows at the Palisade gage are typically 1200 to 1600 cfs less than above the diversion structures in spring and summer. Winter (November to March) flows in the 15-Mile Reach do not appear to create fishery concerns. Flows recorded at the Cameo gage (RM 199.9) appear to be at least at pre-development levels or higher due to senior water right calls at the Shoshone power plant in Glenwood Canyon. Also there can be additional releases for power generation from Green Mountain Reservoir (Per comm. Karen Flogequest (USBR). Flows recorded at the Palisade gage are usually higher than at Cameo between November and April because Plateau Creek joins the river at RM 193.3. Pitlick (1999) determined bankfull flow to be near 22000 cfs for the 15-Mile Reach.

There are two study sites in the 15-Mile Reach. In 1999, bed topography was mapped from the boat launch at Corn Lake (RM 177.5) downstream to RM 175.3 (Figure 4). This station is named the Corn Lake Site. The Corn Lake site length, which is 3.9 km long and has an average width of 55.2 m at a flow of 1400 cfs, was electro-fished in 1999, 2000 and 2001. The river in this section includes five small backwaters. Flow is generally confined within the main channel as opposed to a braided channel (Figure AF7).

The Clifton Site was added in 2000. This site is about 300 m upstream from the Corn Lake site. The Clifton site is from RM 177.7 to 180.4 and has a total length of 4.2 km. In this section, the river has split flow in two large sections of the channel. There is an old diversion structure located at RM 179.7. The dam backs up water along the north shoreline. There is a large backwater at lower flows. Smaller backwaters like those found in the Corn Lake are uncommon in this site (Figure AF8).

The peak flow for the Palisade gage in 1999 was 12700 cfs on June 10. The peak flow in 2000 was 13,500 cfs on May 31. In 2001 the peak flow was 8,410 cfs on May 21. The median peak flow for the 11-year Palisade gage history is 13,500 cfs indicating that peaks for 1999 and 2000 were near normal. Typically, flows in March are near 2000 cfs, but in some years flows can drop after April 1 due to diversions into the Government Highline and Grand Valley canals. In 1999, flows during the ascending limb (April and May) of the hydrograph flow dropped to 435 cfs on April 15, 1999. That was the minimum flow for the year. The minimum spring flow was 1110 cfs on April 5th, 2000 and 500 cfs on April 17th, 2001.

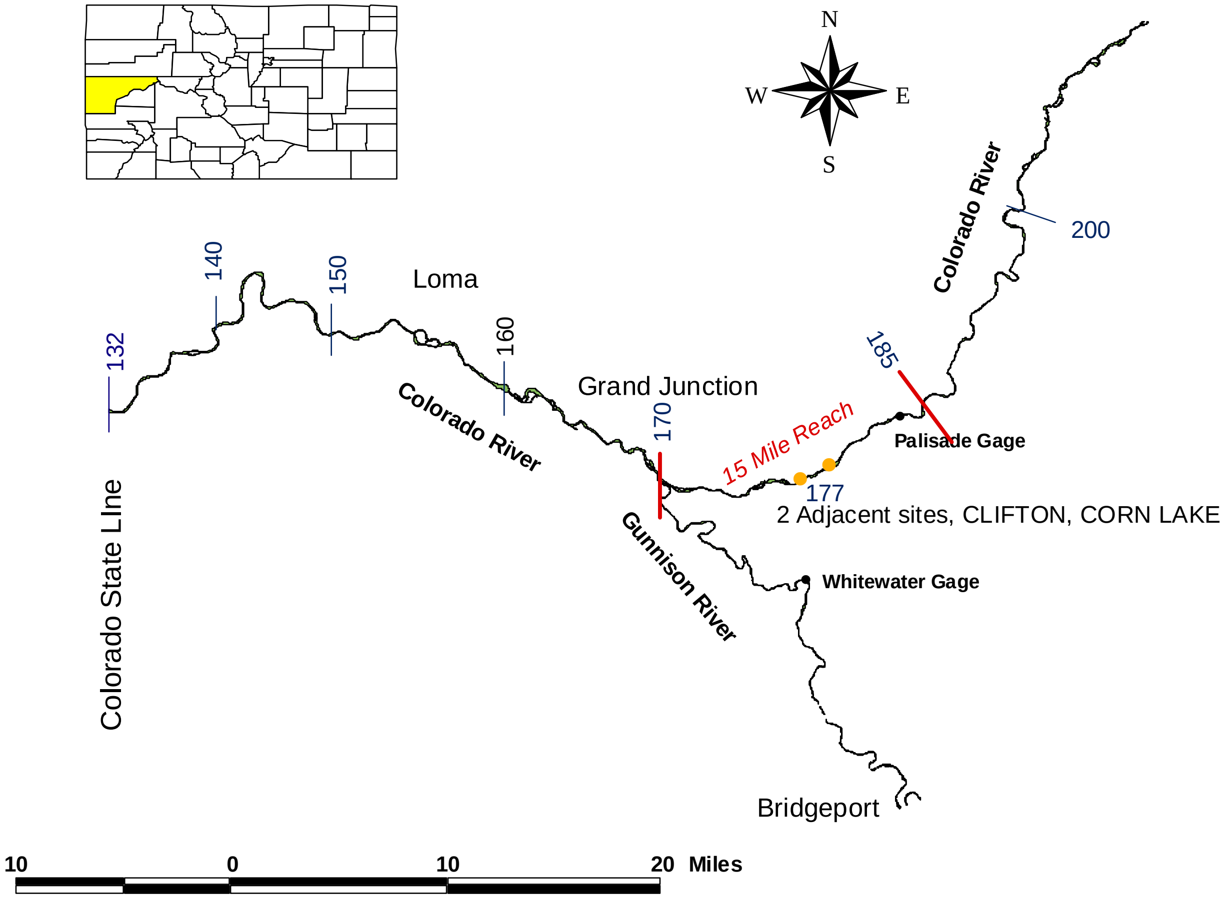

Figure 4. Location of the two study sites in the 15-Mile Reach, Colorado River, Corn Lake and Clifton.

Summer flows were much less in 2000 and 2001 than in 1999. They provided an opportunity to sample the fish population at different flows. Osmundson et al. (1995) made instream flow recommendations for the 15-Mile Reach based on a study of habitat availability for endangered fish. The recommendations from Osmundson et al (1995) were somewhat complex because they wanted to avoid using a single minimum flow. These instream flow recommendations were provided as mean monthly (not mean daily) minimums flows. They varied by season and depending on wet, average and dry flow-year categories determined from historic flow data. The lowest mean monthly flow recommendation was 810 cfs (Table 1), which should only occur at the same frequency as dry years, which was defined as two in ten years. In half the years, the mean monthly minimum flow for August to September should exceed 1630 cfs (Table 1).

Table 1. Recommended mean monthly flows [Osmundson et al (1995)] for the 15-Mile Reach in cubic ft/sec. The exceedence percent indicates frequency that the given flow should be met. For example, during a ten-year period, half the years should exceed a mean flow of 1630 cfs in August, September and October; three of the years should exceed 1240 cfs; and two years should exceed 810 cfs for a mean monthly flow.

Exceedence	**July Mean Monthly (cfs)**	**August Mean Monthly (cfs**	**September Mean Monthly (cfs)**	**October Mean Monthly (cfs)**
50% (Wet)	5,370	1,630	1,630	1,630
80% (Normal)	3,150	1,240	1,240	1,240
100% (Dry)	1,480	810	810	810

Since the recommendations from Osmundson et al. (1995) are presented as averages, minimum flows are not the primary consideration. For example, the minimum flow for 2000 was 542 cfs and it was 477 cfs in 2001. The median minimum summer flow for the period of record (11 years) was 588 cfs. Even though flows were less than 810 cfs for 32 days in both 2000 and 2001, these years do not violate Osmundson et al (1995) recommendations. Summer flows in 1999 exceeded the 50% exceedence (wet year) recommendations for all months except July (Table 2) indicating Osmundson considered flows in 1999 optimal. Summer flows in both 2000 and 2001 exceeded the 100% (dry year criteria) in all months except July (Table 2). The federal recommendations, however, will not be “met” if another “dry year” occurs before 2009.

Table 2. Mean monthly and monthly minimum flows recorded at the Palisade gage, 15-Mile Reach, Colorado River for summer months during the three years of the study.

Year		July (cfs)	August (cfs)	September (cfs)	October (cfs)
1999	Mean	4,721	2,221	1,752	1,837
	Minimum	2,500	1,380	1,180	1,430
2000	Mean	1,271	913	986	916
	Minimum	648	581	665	543
2001	Mean	995	1,133	1,014	809
	Minimum	477	686	754	535

Dolores River

The headwaters of the Dolores River lie in the San Juan Mountains. The river flows mostly northward about 200 miles to its confluence with the Colorado River in Utah. The McPhee Dam, which stores water primarily for irrigation, regulates flow for most of the river's course. The McPhee Dam has a capacity of 38 1000 acres/feet and began storing water in 1984. The magnitude of runoff and peak flows are much reduced compared to before 1984. The San Miguel River is of comparable size and joins the Dolores about 117 miles below the McPhee Reservoir. The San Miguel has a relatively unregulated flow.

Access points for boat launches and take-outs were found to be very limited over most of the Dolores River's length. A study site was located in the Big Gypsum Valley, which is 14 river miles downstream from the Slick Rock Bridge and 34 river miles upstream of the Bedrock boat launch (Figure 5). The Dolores River Guidebook (DeVries and Maurer 1977) starts with River Mile (RM) 0.0 at the Bradfield Bridge. The confluence of the Dolores with the Colorado River is RM 171. We used the river guide in reverse RM order to identify landmarks. Beginning at the confluence as River Mile 0.0, the Utah-Colorado State line is RM 22.4, and the **Big Gypsum Study Site is RM 107.1 to 109.9**. The study site starts at the BLM Gypsum Valley Recreation site and ends about 3.0 miles downstream at the 20R (county road) bridge crossing. The study station is about 70 river miles downstream from McPhee Reservoir.

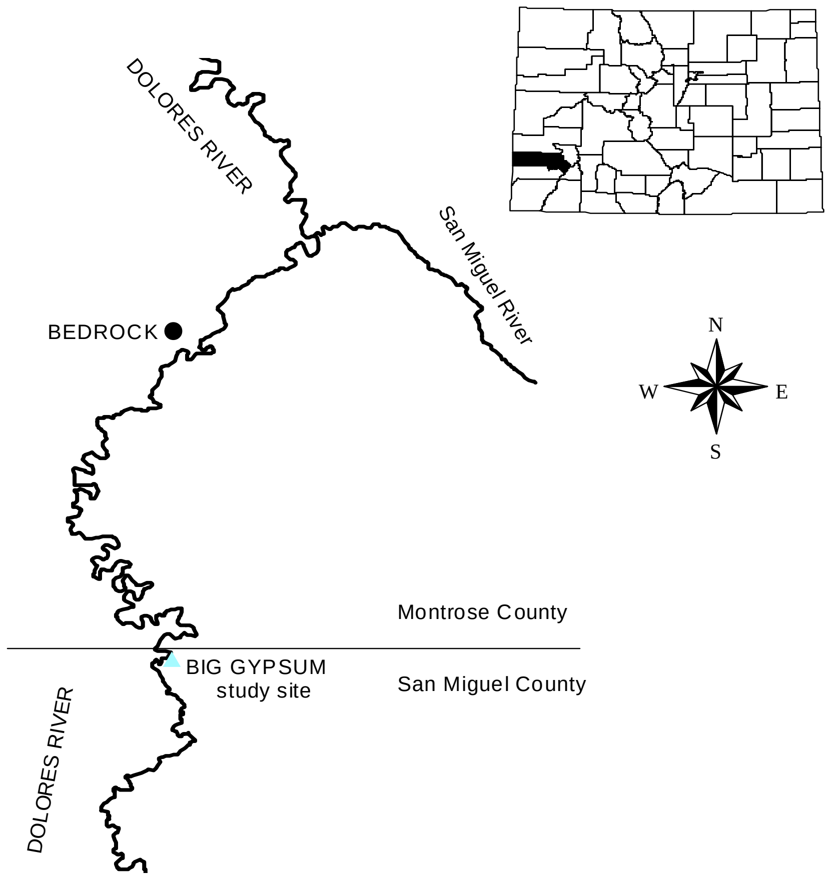

Figure 5. Location of the Big Gypsum (Big Gypsum Valley) study site on the Dolores River.

METHODS

FISH SAMPLING

Fish sampling was performed by electro-shock on the Yampa and Colorado Rivers between 1998 and 2001. Fish were electro-shocked and netted from a 15 ft Achilles raft between 1998 and 2000. A 16-ft Hyside self-bailer raft was equipped for electro-fishing in 2001 using the same Smith-Root electro-fisher, 5000-watt generator and anode array mounted on a forward boom as in the three earlier years. Flows below 120 cfs on the Yampa River were highly problematic for the Achilles boat because it had to be frequently dragged in shallow reaches. Dragging became the case for the Hyside at flows less than 100 cfs on the Yampa. The boat was maneuvered by either oars or by a battery powered 40-pound thrust trolling motor. Two netters caught as many fish as they could while the shocker was in operation. All fish were measured to the nearest millimeter. Only fish over 150 mm were marked and therefore used for mark and recapture population estimates. Density estimates were made for the each study site on the Yampa, Colorado and Dolores.

The Darroch multiple mark method (Everhart and Youngs 1981) was used to make the population estimate with ninety-five percent confidence intervals. A total fish estimate was made for all species and for each species. Recapture rates generally varied between species and size-groups. For our samplings larger suckers had the highest recapture probabilities. Species with appreciably lower recapture probabilities included catfish, bass, pike and carp (the lower group). The total fish estimate was a blend of recapture probabilities, but should produce reliable comparisons for total fish abundance between years, when species and size composition was consistent. For rare species (pikeminnow, etc) with zero or one recapture in the sample, abundance was estimated by dividing the number in the sample by the mean recapture probability of the lower group.

The z-test with an alpha of 0.05 ($z = 1.96$) was used to test for significant differences in density estimates between years at each station. At stations with three or more years of sampling, the Bonferroni inequality was also used to control the overall significance level (.05) for the simultaneous comparison of all pairs of years (Dr. David Bowden, CSU, pers. communication). At stations with 4 years of data, (Duffy and Sevens) the z value (2.631) corresponds to an alpha of 0.05 divided by six (0.0083).

On the Yampa River, a different mark was used for each run-riffle sequence, which allowed for determining if recaptured fish had moved up, down or had not moved between captures. The dates and the flow for each field trip during the four-year period 1998 to 2001 for Sevens and Duffy are given in Table 3. The Lily Park Site was electro-fished for two years in 2000 and 2001 (Table 3). Flow readings were taken from the Maybell gage. Flows recorded from the Lily Park gage tended to be somewhat higher than Maybell and are included in Table 3 parenthetically.

On the Colorado River, fish in both study sites within the 15-Mile reach were marked to designate the upper, middle and lower sections of the site to give a general idea of movement between passes within the station. A total of eight electro-fishing passes were made at the Corn Lake station in 1999. Four passes were made on the left half and four on right half of the river. The Clifton site was added in 2000 and fish from Clifton were given a unique mark so they could be distinguished from fish marked downstream at the Corn Lake station. The sampling strategy was modified in 2000. The total number of electro-fishing passes was six at both Corn Lake and Clifton. Instead of sampling left and right sides, the river was divided into three longitudinal zones, i.e., right shoreline, left shoreline and mid channel so that fish caught in shallow shoreline habitat were distinguished from the deeper channel habitat. The electro-fishing boat sampled each zone (right and left shoreline and mid channel) twice. In 2001, the same sampling scheme was used as in 2000 except a seventh pass was performed in the mid-river zone. The additional mid- river pass was found necessary to improve the recapture probabilities for large fish mid-channel. The dates and the mean daily flow (Palisade gage) for that day for the period of sampling is given in Table 3.

The Dolores River was electro-fished in July 2000 and 2001. In both years on the first pass block nets were placed at the downstream end of each run (upstream of riffles). Also, each run was repetitively electro-fished three to five times. Fish from each pass were held in nets, then marked and released into the same run of capture. This process was continued over the entire reach. Block nets were not used on recapture passes. Dates of electro-fishing and flows from the Slick Rock gage is given in Table 3.

CHANNEL TOPOGRAPHY

Global Positioning Systems and Sonar

In 1999 and 2000, bathymetric surveys of the channel were taken of the six study sites using Global Positioning Systems (GPS) and sonar technology. The channel surveying technique previously described in Anderson and Stewart (2000) was performed from a moving boat. A large amount of bathymetry data was gathered in a short amount of time. The GPS system was a Javad Oddessy L1/L2 RTK GPS with Glonass and Multi-path reduction options turned on. The system had a published vertical accuracy of 15mm +/- 1.5 mm. The sonar unit was an ODOM Hyrographic Systems, Hydrotrac - Single Frequency, Portable Survey Sounder. The sonar unit used a 200kHZ frequency with a published accuracy of 1cm +/- 1% of depth and an output resolution of 1cm. The sonar unit pinged and logged ten depth readings per second. The RTK GPS logged one position per second. The RTK GPS system output a NMEA GGA string at a rate of 1Hz while the sonar output text strings indicated depth at a rate of 10Hz. Data from these instruments were sent to a laptop computer and recorded using the COMLOG software from ODOM Hydrographic. Because the RTK GPS and Sonar data were received at different rates, all data entries collected by the COMLOG software were time-tagged to the millisecond using the computer’s clock. The depth readings immediately before and after the RTK GPS reading were interpolated by the computer clock time (nearest millisecond) to produce the XYZ coordinates used to map bed topography of the river channel.

Bathymetric data were collected from longitudinal runs and cross-sectional surveys. Special care was taken to ensure that the transducer and GPS antenna were mounted in such a way as to remain nearly vertical during each run.

Table 3. Dates for electro-fishing and flows on the day of the sample.

SEVENS	DATE OF ELECTROFISHING			FLOW IN CFS		
	August	September	October	August	September	October
1998		18, 23, 29	1		222, 189, 163	172
1999	30	1, 14, 16		315	280, 219, 201	
2000		28	4, 9		334	240, 206
2001	24, 30	4		114, 70	64	

DUFFY	DATE OF ELECTROFISHING			FLOW IN CFS		
FULL STAT	August	September	October	August	September	October
1998		16, 22, 24, 30			264, 174,194, 162	
1999	25	2, 15, 17		237	247, 212, 180	
2000		12, 26	10		69, 518	199
2001	21, 23, 28	6		105, 98, 77	57	

DUFFY	DATE OF ELECTROFISHING			FLOW IN CFS		
DEEP RUN	August	September	October	August	September	October
1998		3, 14, 15			209, 261, 287	
1999	23, 24, 31	7		284, 282, 329	357	
2000		11, 19, 25			79, 57, 632	
2001	20, 27			123, 94		
LILY PARK	DATE OF ELECTROFISHING			FLOW IN CFS		
	August	September	October	August	September	October
2000		13,27	3, 5		70, 420	260, 215
2001	22, 29	5		91, 85 (151, 110)	61 (96)	

CORN LAKE	DATE OF ELECTROFISHING			FLOW IN CFS		
	Aug.	September	October	Aug.	September	October
1999		28(2x), 29, 30	5, 6, 8, 12		2060,2000,1990	1660,1420, 1740,1860
2000	15, 17 22, 24	5, 8		903, 821 1110, 907	1100, 1090	
2001		16,19,24 26,28	2,4		701, 915, 857, 859, 790	715, 689

CLIFTON	DATE OF ELECTROFISHING			FLOW IN CFS		
	August	September	October	August	September	October
2000	16, 18, 23 25, 30	6		853, 902, 1020 856, 1290	1080	
2001		20, 21, 25, 27	1, 3, 9		904,901,891,824	735, 684, 543

DOLORES	DATE OF ELECTROFISHING		FLOW IN CFS	
Big Gypsum	July		July	
2000	11, 12, 13, 18, 19, 20, 27		52, 53, 55, 58, 53, 53, 52	
2001	16, 17, 18, 19, 23		66, 68, 68, 53, 50	

Waterline Surveys

One hindrance to using sonar to map the channel bottom involved the equipment's minimum depth limitation. In order for the sonar to get a reading off the bottom of the channel, the transducer had to have at least half a meter of water underneath it. The transducer was located approximately 15cm underwater to allow for the pitch and roll of the boat and to minimize air entrainment under the transducer head. Thus, the minimum depth to gather sonar data was 75 cm.

In areas that were too shallow for data collection by the boat-mounted GPS/sonar method, additional topographic data was collected using RTK GPS in what we referred to as the “walking method”. In this method, the Javad RTK GPS was mounted on a range pole and individual RTK GPS positions were recorded with a Psion data collector running Field Face software. After 2001, a TDS Ranger was used for collecting individual survey points.

Reference Sites

Data collected in the 15-mile reach of the Colorado River were geographically referenced to the Mesa County GPS Survey System (www.co.mesa.co.us, GIS section). Aerial photography of the 15-Mile Reach was purchased from Mesa County to aid in identification of landmarks and waterline boundaries.

The web page of the Mesa County Dept. of Public Works Engineering Division/Survey Section showed the locations of the county markers. Using the latitude and longitude of the brass marker at the intersection of 31 and C Road as a known reference point, we placed secondary rebar survey pins at two places along the 15-Mile Reach. One pin was placed near river mile 175. This pin was used as the reference point for the entire Corn Lake survey. The other pin, located on a bluff just upstream of the 32 Road Bridge on property owned by the Meso County Highway Department, was used for the Clifton surveys.

On the Yampa and Dolores, initial surveys markers were placed using only uncorrected GPS coordinates. Base pins located by the GPS were then used for all subsequent surveys at each of the sites.

Corn Lake, Colorado River

The Corn Lake site was mapped during a seven-day period beginning June 27th and ending July 7th. Flows were generally between 8,000 and 10,000 cfs. About 38,880 usable bathymetric survey points were collected along a 4.0-km reach. Water edge shots were obtained in October 1999 and July and August, 2000 using the walking method.

Clifton, Colorado River

The Clifton site is located 0.4 km upstream of Corn Lake and is 4.25 kilometer in length. A total of 45,000 usable bathymetric survey points were collected using the GPS/sonar method on May 31, and June 1, 2, 4 and 5, 2000. Flows during this period varied between 10,000 and 13,000 cfs. Waterline/water surface measurements were made by the walking method on August 1, 2 and 3, 2000; January 23, 24, 25 and 26, 2001; and (the final set) June 18,19 and 20, 2001.

Duffy, Yampa River

Bathymetric data was collected along a 2.25 km section of the Yampa River near the Duffy Tunnel using the GPS/sonar method during the period of July 9th to July 11th, 1999. From July 27th through July 29th 1999, the walking method was used to survey waterlines and shallow riffles.

Sevens, Yampa River

On July 12, 1999, bathymetric data were collected using the GPS/sonar technique along a 1.3-km section of the Yampa River at the Sevens study section. The length of this site was believed to be to short given the nature of the associated fish data and the habitats represented in this reach. The Sevens site was enlarged on June 23, 2000, by surveying another 1.3 km immediately upstream and overlapping the site mapped the previous year. These surveys used the same boat and GPS/sonar equipment. To compare bed and water surface elevations between years, three longitudinal profiles were obtained in the 1999 site and water lines and were recorded for the entire 2.6 km station. Collection of bathymetric data was hampered in 2000 by the low and unusually short runoff period.

The base pin established in 1998 was used as the reference position for both the 1999 and 2000 surveys. Shoreline and water surface shots were made using the walking method. Waterline shots for the entire reach were surveyed on October 30 and 31, 2000. Another series of water edge/surface shots were made in June 26 & 27 and July 5 & 6 2001.

Lily Park, Yampa River

Bathymetric data were collected using the GPS/sonar technique along a 3.3-km section of the Yampa River at Lily Park on June 12, 13 and 14, 2000. Collection of bathymetric data was hampered in 2000 by the low and unusually short runoff period. There was a large, wide and shallow riffle near mid-station that could not be surveyed by boat. Therefore, walking method was employed to survey shallow riffles on August 8 and 9 and again on October 19 and 20, 2000. Waterline shots were made on June 27 and 28, 2001, and at a lower flow on July 31 and August 1.

Big Gypsum, Dolores River

Over a three-day period, May 16, 17, and 18, 2000, bathymetric data was collected using the GPS/sonar methodalong a 3-km section of the Dolores River in the Big Gypsum Valley. As was the case with the Yampa River, the lower than normal runoff flows made data collection using sonar more difficult. Also, certain parts of the river were too shallow for the sonar. Several days were spent in June and July 2000 logging additional points by the walking method. Waterline/water surface shots were made on July 6 and 7, 2000, and on June 13 and 14, 2001.

Velocity Measurements

To calibrate modeled data, it is necessary to have obtained field measurements of depth and velocity at known flows. While depth can be gathered using the same technologies that are used in determining bathymetry, velocity measurements require another set of instruments. Two different technologies were used for measuring velocities in this project.

In 1998, a Marsh McBirney Flo-Mate Portable Flowmeter was used in conjunction with the total station to determine point velocities. The Marsh McBernie had a published accuracy of 1.5cm/s +/- 2 percent. This flowmeter was based on the electrical principle known as Faraday's Law. Here the flow rates were determined by passing a conductive fluid through a magnetic field. A wading rod that held the meter head was placed at a depth chosen to represent average velocity (usually 0.6 of total depth). Locations were recorded by shooting the point with the total station and then recording the average of three 10-second averages. After 1999, locations were recorded by locating the position with the RTK GPS and then recording the velocity of that point.

At high flows it is often not practical to use a wading rod to measure velocities. In May of 2000, a 3MHZ Sontek River Surveyor Acoustic Doppler Profiler (ADP) was used to gather calibration data at the 15-mile reach. The ADP measured the velocity of water using a physical principle called the Doppler shift. This principle stated that if a source of sound was moving relative to the receiver, the frequency of the sound at the receiver was shifted from the transmit frequency. By determining the Doppler shift using three beams, it was possible to determine the relative speed and direction of the flow. Using the Doppler shift from the river bottom to determine the boat speed and direction, we computed absolute velocity and direction. The ADP measured velocities in 15 cm vertical increments down to the river bottom. These velocities were averaged over a specified time interval.

Data Reduction and Preparation

The GPS/sonar technique produced a large number of data in a short amount of time. It generally was not possible to perform any quality control as the data was being collected. Data reduction and quality control were accomplished using an Excel- macro that stripped out non-sensible or incomplete points so only points that met a set of standard criteria were used in the final survey. The Excel-macro eliminated all non-RTK hits as indicated by the GGA string. This eliminates false spikes in the sonar data sometimes caused by fish or woody debris. Spikes were identified by making a running average of the six nearest sonar pings (three prior and three after). An individual depth reading was marked as "bad" if the difference in between the moving average and the individual ping was greater than 15 cm. If an RTK GPS reading had a "bad" sonar ping recorded directly before or after it, that GPS reading was ignored. For those RTK GPS signals with "good" sonar recordings before and after them, the depth for that GPS position was determined through a linear interpolation of the sonar data based on the time tags. Topographic data were also visually examined by creating Triangular Irregular Networks (TIN).

HYDRAULIC SIMULATION

In the first two years of the project, hydraulic simulation and 2-D flow modeling was contracted with the Earth Resources Department of Colorado State University (CSU). Greg Stewart, a CSU graduate student, collected and input the data to the RMA2-hydraulic model. He performed the analysis during the time period June 1998 to June 2000. Stewart (2000) gives details on hydraulic methods, problems and innovations used for making flow simulations at 15-Mile Reach (Corn Lake) and the Duffy Tunnel site.

Stewart performed most of the installation and operation of technical equipment and data handing for the 2-D modeling. Following his departure, no 2-D modeling was performed until a new contractor was found. In 2002, a new contract was finalized with Utah State University. Dr. Craig Addley, contract administrator for 2-D modeling at Utah State University (USU), supervised modeling for the remaining four sites and some new modeling on Corn Lake. The USU lab used a 2-dimensional, quasi-3-dimensional model developed by Jonathan Nelson of the USGS. The technical description of this model and underlying equations can be found in Nelson (1996), Thompson et al. (1998), Nelson et al. (1995), McLean et al. (1999), Topping et al. (2000).

The 2-D model flow simulations for the Yampa River were meant to cover the range of flow typical in the base flow period, which typically varies between 125 and 200 cfs. Flows simulations at Sevens and Lily Park were produced at 40, 60, 80, 100, 125, 150, 200, 250, 300, 400, 500 and 600 cfs by USU. The Duffy site modeled by Stewart was at flows of 60, 80, 100, 125, 150, 200, 250, 300, 400, 500 and 600 cfs. On the Colorado River base flow was typically much higher than on the Yampa and did not commonly fall below 600 cfs. Stewart ran flow simulations at Corn Lake at 600, 700, 800, 900, 1000, 1200, 1400, 1600, and 1800 cfs. The same flows were modeled for the Clifton site by USU, with additional simulation at flows of 200, 250, 300, 350, 400, 450, 500 and 2000 cfs. Some follow-up modeling was done on the Colorado River so that both sites were modeled down to 100 cfs. Flows on the Dolores River ranged from a low at 10 cfs and a high of 500 cfs.

Site Characterization

Length, mean width and wetted area for each simulated flow were determined for each site using the two-dimensional modeling output data. Station lengths were measured along the channel thalweg. Widths were determined by dividing the wetted channel area at 600cfs (100cfs for Big Gypsum) by the station length. Longitudinal profiles were generated in ArcInfo by sampling channel bathymetry at two-meter intervals along the channel thalweg.

HABITAT QUANTIFICATION

A primary objective of this study was to objectively quantify changes in meso-habitat composition over a range of flows at each site. Meso-habitat is defined at the reach level and includes pools, runs, riffles and rapids. Pools have low velocity, runs have moderate velocity, riffles are swift areas and rapids have the fastest current. For modeling purposes pools were given a velocity of zero to 0.15 m/sec, runs ranged from 0.15 to 0.6 m/sec, riffles had velocity ranging from 0.6 to 1.5 m/sec and rapids had velocities over 1.5 m/sec (Table 4).

Habitat suitability for fish was also a function of depth. Very shallow areas were of high value to small fish, but they had no habitat value to large fish. Pools and runs had five depth categories, riffles had four and two depths categories for rapids (Table 4).

Using only depth and velocity, we defined 16 different non-overlapping meso-habitat types for use in this study. These 16 meso-habitat types provided a general representation of habitat diversity that was inclusive for a fish community composed of a variety of size-classes and species. These 16 meso-habitat types were then mapped using data provided by the 2-D flow models. In each case, solution files (2-D model output) were imported into ArcInfo and then linearly interpolated into 1 x 1-meter grids representing depth and velocity for a given flow. Depth and velocity grids were then sampled to create 1x1-meter meso-habitat grids. The abundance of meso-habitat was determined by counting the number of grids of each meso-habitat type. Surface maps of meso-habitat were created either in ArcView or by importing 2-D plotfiles into SMS (the 2-D modeling package by Boss International).

DEVELOPMENT OF MESO-HABITAT SUITABILITY

Meso-habitat suitability was developed using the fish sampling data. The electro-fishing data was summarized for individual electro-fishing sub-reaches (polygons). The total density and biomass calculated over the entire station did not indicate how fish were distributed within a station, whereas the electro-fishing sub-reaches provided much more detail on fish distribution within the stations. Electro-fishing sub-reaches had the same starting and end locations between passes and years and were digitized on the aerial photos of the study stations using ArcView. The sum of the area and fish from all electro-fishing sub-reaches equaled 100% of the entire station.

Table 4. Depth and velocity criteria used to define meso-habitat types.

	Habitat Types	Depth	Velocity
		(m)	(m/s)
1	Wetted-pool	0.01 – 0.2	< 0.15
2	Shoal-pool	0.2 - 0.5	< 0.15
3	Shallow-pool	0.5 - 1.0	< 0.15
4	Medi–pool	1.0 - 2.0	< 0.15
5	Deep-pool	> 2.0	< 0.15
6	Wetted-run	.01 - 0.2	0.15 - .6
7	Shoal-run	0.2 - 0.5	0.15 - .6
8	Shallow-run	0.5 to 1.0	0.15 - .6
9	Medi-run	1.0 to 2.0	0.15 - .6
10	Deep-run	> 2.0	0.15 - .6
11	Shallow-riffle	< 0.2	0.6 - 1.5
12	Riffle	0.2 to 0.5	0.6 - 1.5
13	Deep-riffle	0.5 to 1.0	0.6 - 1.5
14	Very-deep-riffle	> 1.0	0.6 - 1.5
15	Shallow-rapid	< 0.5	> 1.5
16	Deep-rapid	> 0.5	> 1.5

The meso-habitat suitability analyses used the 2-D hydraulic modeling simulation runs to determine physical attribute metrics for each polygon. This included surface area, mean depth, mean velocity, maximum depth and maximum velocity. Species density and biomass data were calculated based on the percent of fish captured in each sub-reach times the total-reach estimate. Polygons with zero biomass were considered unusable habitat. Polygons that supported high biomass indicated higher habitat quality. Biomass was determined for the flannelmouth sucker, bluehead sucker and roundtail chub over 20 cm in length.

The polygon data was used to create four functional meso-habitat types for bluehead and flannelmouth suckers. The biomass and mean depth, and mean velocity data was imported into Sigma Plot and then smoothed using a running median function. The result was a regular matrix showing estimated polygon biomass as a function of mean depth and mean velocity. The biomass data were graphed using Sigma Plot software at the scale of 0.1 m, which was used for both axes. For example, bluehead sucker had low biomass in the cell with a depth of 0.6 m and 0.3 m/s, but higher biomass for the cell with 0.6 depth and 0.7 m/s. The data was validated by regression analysis of projected biomass versus observed biomass.

Four levels of suitability were determined from the polygon biomass. Polygons with zero biomass were called Unusable habitat. Unsuitable, Marginal and Optimal were the other meso-habitat types. Each contained roughly about one-third of the total sample size. The lower third or Unsuitable polygons represented about 15% of the total biomass. Marginal represented about 25% Optimal contained about 60% of the total biomass of the total electro-fishing station.

Biomass data for the Colorado River was also examined as a function mean depth and velocity from the electro-fishing done along the shoreline. Shoreline sampling was done in 2000 and 2001 to determine species composition of the shoreline habitats. Shoreline habitats are typically shallow and low velocity and very adult flannelmouth and bluehead sucker were captured from shoreline habitats. The shoreline electro-fishing results were similar to the criteria for Unusable habitat determined by the Sigma Polt analysis.

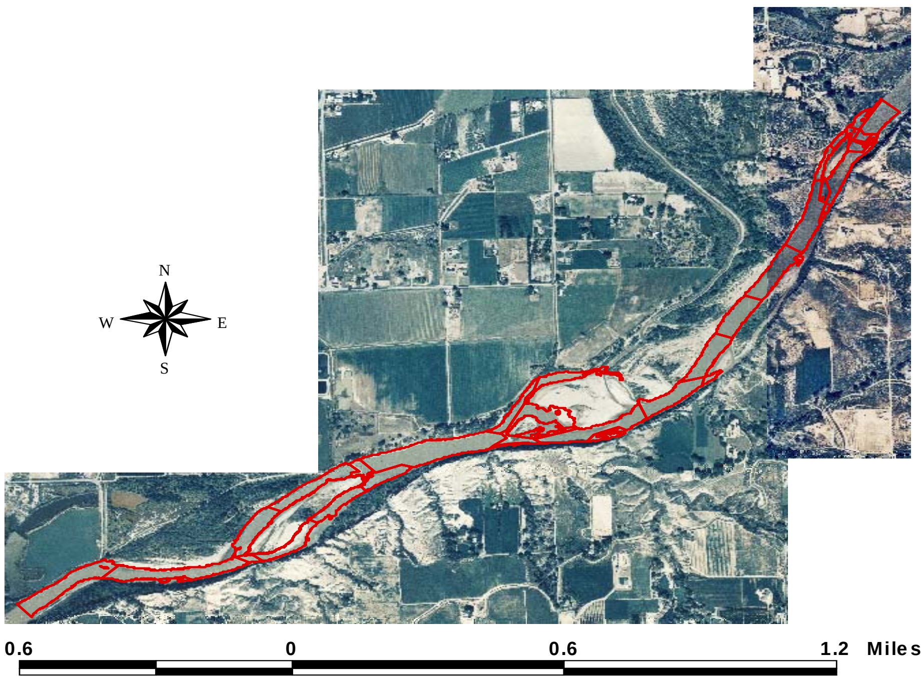

Figure 6. Example of digitized polygons or electro-fishing areas (photo of Clifton site).

DETERMINATION OF HABITAT AVAILABILITY

Once meso-habitat biomass (suitability) criteria for each species of interest were determined, habitat surface area for each of the four meso-habitat types (Unusable, unsuitable, marginal and optimal) was calculated with ArcInfo using the same process as described for the 16-meso habitat types. The surface area of unusable, unsuitable, marginal and optimal habitat was multiplied by the observed mean biomass to give a biomass estimate for both bluehead and flannelmouth suckers for each of the simulated flows.

RESULTS

FISHERY QUANTIFICATION

To determine the role flows have on fish community structure it is necessary to quantify both the fishery and habitat availability and then to establish the relationship between habitat and flow. The fishery was characterized by three different attributes for each of the study sites: 1) species composition, 2) size distribution and 3) density and biomass estimation. Since a complete summary of the fish data was in the job progress report, Anderson (2002), not all fish data is presented in this report.

In general, each annual progress report compares species composition, size and density data to the prior year's data. Length frequency histograms for each station sampled in 1998 and 1999 are available in Anderson and Stewart (2000). Histograms for the 2000 sample are given in Anderson and Stewart (2001) and histograms for the 2001 sampling are in Anderson (2002). Length data can also be obtained from the author in spreadsheet format. Seining data is presented in Anderson and Stewart (2000) and Anderson (2002).

Data for the Yampa River was organized by two periods, the first two years (1998 and 1999) had above normal base flows, while base flows during 2000 and 2001 were well below normal. Differences in the fishery between these two periods probably were attributable to differences in base flows. At the Duffy station, fish population sampling was done in a 4.5-mile reach (Long Reach), but only the upper 1.8 miles of the long reach was modeled for habitat composition (habitat reach). The Long Reach fish data was used for making comparisons between years.

Fish Over 15-cm in Length

Native species composition was highly consistent between years at the Sevens station with native fish comprising 73% (four-year mean) of the fish over 15 cm. The four-year mean for flannelmouth-sucker composition at Sevens was 49% with a range of 46% to 53%. The four-year mean for bluehead sucker was 19% and it was 4% for roundtail chub (Table 5). Colorado pikeminnow were rare or absent at Sevens for the four-year period. The greatest inconsistency for a native species at Sevens was a drop in bluehead and a small increase in flannelmouth composition in the 2001 sample compared against the three prior years (Table 5).

Native fish species were uncommon to rare at Duffy, averaging only 13% of fish over 15 cm for the four years. The data showed a downward trend in native fish at Duffy with highest native fish composition in 1998 (15%) and the lowest in 2001 (10%) (Table 5). Flannelmouth suckers were consistently at 5% in the first three years, but were only 2% in 2001. Bluehead suckers comprised about 4% and roundtail chub were 3% over the study period. Colorado pikeminnow were uncommon at Duffy. They comprised between 0.6 to 1.5% of the total catch.

Lily Park had by far the largest sample size for fish over 15 cm, and also the largest variation between years (Table 5). Flannelmouth was the most common species found at Lily Park. Its composition was 68% in 2001 and 48% in 2000 (Table 5). The 2001 data was probably a more accurate description of species composition at Lily Park because of the extraordinary number of catfish caught in 2000 decreased the relative abundance of other species that year. Bluehead sucker, roundtail chub and Colorado Pikeminnow composition were similar between years (2001 versus 2000) at Lily park: (9% versus 7%), (0.02% versus 0.03%) and (0.1% versus 0.0%) respectively (Table 5).

Within-station native fish species composition on the Yampa River was quite consistent over the four years of sampling. The differences observed were likely related to either sampling variability between years or difference in flows between years. There were large differences in species composition between stations. Flannelmouth composition was about 50% at Sevens, 5% at Duffy and 70% at Lily Park. Bluehead sucker composition was about 20% at Sevens, 4% at Duffy and 8% at Lily Park. Roundtail chub composition was at 4% at Sevens, 3% at Duffy and 0% at Lily Park.

Nonnative fish comprised 85 to 90% of the fish captured at Duffy Tunnel. White sucker and hybridized white sucker averaged 71% of the catch for the first three years (Table 5). The white sucker group dropped to 50% in 2001. At Sevens, the white sucker group was consistent at 15% of the population for the four years. White sucker or hybrids were very rare at Lily Park at 0.03%. Statistics indicate that the white sucker was better suited to conditions upstream of Sevens and native suckers were better competitors at the lower two sites.

There are three non-native predator species in the Yampa River that influence species composition independent of habitat availability. The northern pike was fairly commonly caught during the first two years of sampling (1998 and 1999) at Sevens and Duffy, but were uncommon in the last two years (Table 5). The trend for smallmouth bass was the reverse with the highest composition occurring in the last year, 2001 (Table 5). The most dramatic shift in smallmouth bass was at the Duffy site, from 10% in 2000 to 33% in 2001.

Channel catfish were non-native predators that had a low composition at Sevens (5%) and Duffy (4%). However at Lily Park, channel catfish composition was 40% in 2000 and 18% in 2001 (Table 5). Low flows were identified as problematic for channel catfish migration in 2000, inflating their numbers relative to normal flow years. A composition of 18% for catfish was a more likely representation for this species. In 2000, smallmouth bass comprised only 0.8% of the fish over 15 cm, but in 2001 smallmouth bass were 5 percent (Table 5).

Table 5. Species composition for fish over 15 cm from all study sites. Composition is from total number of fish measured.

YAMPA RIVER	SEVENS	SEVENS	SEVENS	SEVENS	MEAN	MEAN
Species	1998	1999	2000	2001	98,99,00	4 years
Flannelmouth Sucker	48%	46%	50%	53%	48%	49%
Bluehead Sucker	23%	18%	22%	13%	21%	19%
Roundtail Chub	5%	4%	4%	3%	4%	4%
Colo. Pikeminnow	0.20%	0.20%	0.25%	0.00%	0%	0.2%
White S. + Crosses	11%	15%	17%	16%	14%	15%
Channel Catfish	7%	7%	2%	5%	5%	5%
Carp	4%	5%	4%	4%	4%	4%
Smallmouth Bass	1.0%	2.5%	0.5%	5.0%	1%	2%
Northern Pike	1.3%	1.9%	0.2%	0.3%	1%	1%
Sample size	1391	1026	807	676		
YAMPA –REACH	DUFFY	DUFFY	DUFFY	DUFFY	MEAN	MEAN
Species	1998	1999	2000	2001	98,99,00	4 years
Flannelmouth Sucker	5%	5%	5%	2%	5%	4%
Bluehead Sucker	4%	6%	4%	4%	5%	4%
Roundtail Chub	3%	3%	4%	3%	3%	3%
Colo. Pikeminnow	1.5%	0.6%	0.8%	0.6%	1%	1%
White S. + Crosses	69%	72%	73%	50%	71%	66%
Channel Catfish	3%	4%	3%	4%	3%	4%
Carp	3%	1%	1%	2%	2%	2%
Smallmouth Bass	8%	6%	10%	33%	8%	14%
Northern Pike	2.8%	2.3%	0.9%	1.1%	2%	2%
Sample size	1653	2092	1294	856		
YAMPA RIVER			Lily Park	Lily Park		MEAN
Species			2000	2001		2 years
Flannelmouth Sucker			48%	68%		58%
Bluehead Sucker			9%	7%		8%
Roundtail Chub			0.02%	0.03%		0.03%
Colo. Pikeminnow			0.1%	0.0%		0.1%
White S. + Crosses			0.3%	0.2%		0.3%
Channel Catfish			40%	18%		29%
Carp			2.1%	2.1%		2.1%
Smallmouth Bass			0.8%	5%		3.0%
Northern Pike			0.2%	0.2%		0.2%
Sample size			4058	2989		
COLORADO RIVER		CORN L.	CORN L.	CORN L.		MEAN
Species		1999	2000	2001		3 years
Flannelmouth Sucker		38%	31%	40%		36%
Bluehead Sucker		35%	36%	38%		36%
Roundtail Chub		3%	4%	3%		3%
Colo. Pikeminnow		0.10%	0.04%	0.03%		0.06%

Razorback Sucker		0.20%	0.30%	0.06%		0.19%
White S. + Crosses		6%	5%	6%		6%
Channel Catfish		4%	6%	5%		5%
Carp		11%	14%	6%		11%
Sunfish (all species)		0.9%	1.5%	0.7%		1.0%
Trout (all species)		0.0%	0.1%	1.4%		0.5%
Bullhead		1.3%	0.6%			1.0%
Sample size		3499	2784	3463		
COLORADO RIVER		CLIFTON	CLIFTON	CLIFTON	MEAN	MEAN
Species		1999	2000	2001	2 Years	3 years
Flannelmouth Sucker		33%	33%	42%	37%	36%
Bluehead Sucker		23%	41%	27%	34%	30%
Roundtail Chub		7%	5%	6%	6%	6%
Colo. Pikeminnow		0.50%	0.03%	0.09%	0.06%	0.21%
Razorback Sucker				0.04%	0.04%	0.04%
White S. + Crosses		5%	4%	4%	4%	4%
Channel Catfish		14%	5%	6%	5%	8%
Carp		16%	12%	14%	13%	14%
Sunfish (all species)		0.9%	1.2%	1.1%	1.2%	1.1%
Trout (all species)		0.5%	0.1%	0.2%	0.2%	0.3%
Bullhead		0.5%	0.2%	0.4%	0.3%	0.4%
Sample size		575	3276	4485		
DOLORES RIVER			BIG GYP	BIG GYP	MEAN	MEAN
Species			2000	2001		2 years
Flannelmouth Sucker			16.0%	57.5%		36.8%
Bluehead Sucker			2.2%	5.8%		4.0%
Roundtail Chub			54.9%	24.5%		39.7%
Channel Catfish			15.8%	8.3%		12.1%
Carp			3.4%	1.7%		2.6%
Green Sunfish			2.0%	1.4%		1.7%
Bullhead			5.2%	0.6%		2.9%
Sample size			501	636		

Native species composition was also consistent between years for the Colorado River stations. At Corn Lake, native fish comprised 76% (three-year mean) of the fish over 15 cm with an even split of 36% for flannelmouth and bluehead suckers (Table 5). The three-year mean for roundtail chub was 3% (Table 5). Colorado pikeminnow were very rare at 0.06 percent. All razorback sucker caught were stocked fished. The greatest inconsistency for a native species at Corn Lake was for flannelmouth sucker composition in 2000. This was probably resulted from a different sampling effort that year.

In 1999, a two-pass effort was made at the Clifton station to see if marked fish from Corn Lake would be recaptured outside the site (Anderson and Stewart 2000). This data allowed for three years of species composition data to be collected on the Clifton reach. At Clifton, native fish comprised 76% (two-year mean) of the catch.

Flannelmouth composition averaged 36%, bluehead 30%, and roundtail chub 6 percent. Colorado pikeminnows were very rare at 0.2 percent.

Both Colorado River sites had 76% native fish and 36% flannelmouths. Clifton had a lower abundance of bluehead, but higher numbers of roundtail chub, suggesting subtle habitat differences for these species between these two sites.

Relative abundance of flannelmouths, blueheads and roundtail chub remained stable over three years at the two Colorado River sites. Minor fluctuations in community composition between years were well within the range of sampling error. They, therefore, probably do not reflect any real change in species composition. Sampling efficiency was influenced by a number of factors including flow, water clarity, effort and ability of netters. Flow conditions during sampling were fairly similar in 2000 and 2001, but were much higher in 1999. In 2000, sampling after thunderstorms or during periods of reduced water clarity was more common. There were fewer passes made in 2000 than in 1999 and 2001. Also, shoreline habitats received proportionally more effort in 2000 than in the other years.

Nonnative fish comprised 24% of the fish community over 15 cm at the two sites in the 15-Mile Reach. Common carp was the most frequently occurring nonnative species collected at both sites. The three-year mean for carp was 11% at the Corn Lake site and 14% at Clifton (Table 5). Carp displayed the most movement between stations based on recapture locations. Carp composition was much higher in the Colorado River that in the Yampa River, suggesting the Colorado River has better carp habitat.

The mean composition of white suckers, plus white sucker hybrids with flannelmouth and bluehead suckers, was 6% at Corn Lake and 4% at Clifton in 2001 (Table 5). The white sucker catch was much higher in backwater habitats than in the main channel. On the Yampa River, white sucker was a main channel species in the Duffy and Sevens sites while white sucker were very rare at Lily Park (0.3%). The other common nonnative fish in the 15-Mile Reach was the channel catfish, which was 5% at both stations. Unlike the Yampa River, there appears to be local reproduction of catfish in the 15-Mile Reach.

The Dolores River site at Big Gypsum was sampled in 2000 and 2001. Species composition differed greatly between the two years. In 2000, flannelmouth sucker represented 16% of fish over 15 cm. That rose to 58% in 2001 (Table 5). Roundtail chub represented 55% in 2000 and 25% in 2001 while bluehead sucker was 2% of the sample in 2000 and 6% in 2001. Native fish comprised 73% of the fish population in 2000 and 86% in the 2001 sample. The most common non-native fish in 2000 was channel catfish at 16%, but represented 8% in 2001.

The Big Gypsum stations had the highest composition of roundtail chub of all sites and the highest composition of native fish in general. However, there was instability in species composition between years at Big Gypsum. This instability was probably related to the much different flow conditions between years, with lower flows in 2001.

Even though native fish composition was high at the Big Gypsum site, other fishery factors indicate that the habitat conditions at this site were severely degraded.

Fish Less Than 15 cm in Length

The speckled dace and the mottled sculpin, two small-bodied native species that are associated with riffles or swift current habitats, were commonly observed at the Duffy station in 1998 (13%; 19%) and 1999 (8%; 27%). Conversely, both species were very rare in 2000 (1.2%; 5%) and 2001 (0.2%; 0.8%). The reduced number coincided with reduced flows in 2000 and 2001.

A large increase in young-of–year (YOY) smallmouth bass composition was observed in 2000 and 2001 (lower flow years). Species composition for YOY smallmouth bass at the Duffy station was 45% in 1998 and 42% in 1999. In these higher flow years, most YOY smallmouth bass were collected from shoreline habitats. YOY smallmouth bass composition was 84% in 2000 and 98% in 2001. Also during those years, YOY smallmouth bass occupied riffles as well as the shoreline habitats. The shift from speckled dace to YOY smallmouth bass in riffle habitats was also observed at Sevens in 2000 and 2001. This suggested the shift occurred river-wide.

Shoreline seining done in 1999 and 2001 gave a more quantitative count of fish less than 15 cm. The number of speckled dace collected by seine in 1999 at Duffy was 538 for 24% of the total, whereas seining in 2001 collected zero speckled dace (Table 6). The number of white suckers collected in seines in 1999 was 497 (22% of the total catch), but only 11 (1%) white suckers were caught in 2001. Smallmouth bass numbers were 35 (1.5%) in 1999 and 540 (67%) in 2001. Increases in YOY smallmouth bass during 2001 appeared to be related to the low flow conditions during that year as compared to higher base-flow conditions in 1999.

Low densities or abundance of speckled dace and mottled sculpin were also observed at Sevens. Speckled dace species composition (n) in 1998, 1999, 2000 and 2001 was 38% (123), 13% (10), 2% (11) and 2% (3) respectively, and for mottled sculpin, 5% (16), 0%, 0%, and 0% respectively (Table 6).

Speckled dace appeared to be very common during sampling on the Colorado River. Since other agencies were doing concurrent fish sampling in the 15-Mile Reach, no special effort was made to sample small-bodied fish. Miller et al (2003) made a density estimate of 2.36 dace per square meter for riffles and 0.50 in runs. Based on habitat availability, Miller et al. (2003) estimated speckled dace at 34,000 dace per km in the 15-Mile Reach.

In addition, no special effort was made to quantify non-native cyprinds (NNC; red shiner, sand shiner and fathead minnows) since this fish group was not involved in instream flow recommendations. These species were very abundant in shoreline and backwater habitats (Valdez 1999, Bundy and Bestgen et al. 1999, and McAda et al. 1997, and other annual ISMP reports).

Table 6. Species composition from seine hauls at the Sevens and Duffy sites in 1999 and 2001, Yampa River.

STATION	SEVENS	SEVENS	DUFFY	DUFFY
YEAR	**1999**	**2001**	**1999**	**2001**
TOTAL (n)	2165	2026	2272	803
	% (n)	% (n)	% (n)	% (n)
Flannelmouth sucker	1.1 (23)	5.4 (109)	1.0 (23)	0
Roundtail Chub	1.4 (34)	2.2 (45)	34 (733)	1.4 (11)
Speckled Dace	3.8 (83)	1.9 (39)	24 (538)	0
Sand Shiner	57 (1241)	82 (1662)	13.9 (315)	29.5 (237)
White Sucker, &crosses	27 (588)	4.3 (88)	21.9 (497)	1.2 (11)
Smallmouth bass	0.4 (9)	1.5 (30)	2.5 (57)	67 (540)
Fathead minnow	3.6 (77)	2.5 (50)	0.4 (10)	0.1 (1)
Carp	4.3 (93)	0	1.5 (35)	0.2 (2)
Stickleback	0.7 (16)	0.1 (3)	0.4 (9)	0
Redside shiner	0.05 (1)	0	0.04 (1)	0
Plains Killifish	0.05 (1)	0	0	0

All small green sunfish sighted were netted, and most were captured in backwater habitats. Removal of sunfish species was attempted in 2001 and 2000, but not in 1999, since the Recovery Program was conducting centrachid removal in some of the same backwaters during that time. In general, green sunfish numbers were higher during years of lower flow (2001) than during the high year (1999). However, the magnitude of flows observed during the study period did not appear likely to give sunfish species a competitive advantage in the Colorado River as was observed on the Yampa River.

YOY and juvenile flannelmouth and bluehead suckers and roundtail chubs were collected in the Colorado River in all years indicating that suitable habitat was available and that predation was not problematic for younger life stages. In contrast, YOY and juvenile flannelmouth and bluehead suckers were very rare on the Yampa River.

The sample size for fish less than 15 cm was highest in 2001. This could reflect increased sampling efficiency in backwaters and shorelines or an actual increase in small fish numbers. Small fish numbers can increase during low flow conditions because of increased habitat and water temperatures. A longer growing season and more primary productivity is usually associated with higher water temperatures. Flow conditions in both 2000 and 2001 may have been more conducive for small fish than in 1999.

Table 7. Species composition for fish greater and less than 15 cm at the Big Gypsum site on the Dolores River, July 2001.

	Big Gypsum 2001	**Big Gypsum 2000**	**Big Gypsum 2001**	**Big Gypsum 2000**
Species	**>15 cm**	**>15 cm**	**<15 cm**	**<15 cm**
Flannelmouth Sucker	57.5%	16.0%	9.9%	5.2%
Bluehead Sucker	5.8%	2.2%	14.2%	0.0%
Roundtail Chub	24.5%	54.9%	16.5%	48.0%
Channel Catfish	8.3%	15.8%	0.4%	1.4%
Carp	1.7%	3.4%	0.0%	0.2%
Green Sunfish	1.4%	2.0%	1.5%	5.7%
Pumpkinseed	0.0%		0.5%	
Brown trout		0.6%		
Black Bullhead	0.6%	5.2%	0.5%	0.2%
Speckled Dace	0.0%		17.5%	33.8%
Mottled Sculpin				
Red Shiner	0.0%		36.3%	5.2%
Sand Shiner	0.0%		2.3%	0.2%
Fathead minnow	0.0%		0.5%	0.2%
Native species	87.9%	73.1%	58.1%	87.0%
Sample size	636	501	2159	577

The number of fish less than 15 cm was much higher in 2001 (2,159) than in 2000 (577) in the Dolores River (Table 7). Many more red shiners were observed in 2001. This was the most common species at 36% in the less than 15-cm group. Speckled dace was the next most common fish under 15 cm at 18 percent. Young flannelmouth suckers, bluehead suckers and roundtail chub were also common in the small fish group at 10%, 14% and 17% respectively in 2001. Native fish comprised 58% of the less than 15-cm fish sample in 2001 compared to 87% in 2000 (Table 7).

Size Structure for Native Fish

Length frequency histograms for each station sampled in 1998 and 1999 are available in Anderson and Stewart (2000). Length frequency histograms for the 2000 sample are given in Anderson and Stewart (2001) and histograms for the 2001 sample are found in Anderson (2002). There are no length frequency histograms given in this report, but summaries presented herein are based on data from the progress reports. Readers can refer to these progress reports for comparison between stations and between years. Some histograms from 2000 at Sevens are incorrect (bluehead, flannelmouth and catfish) or not included (Lily Park, smallmouth bass). Corrected histograms are found in Anderson (2002).

The Yampa site Sevens had a decrease in mean size of the bluehead sucker in 2000 and 2001 compared to 1998 and 1999 (higher flow years). Both mean length and sample size were smallest in 2001 at Sevens (Table 8). The 30.0-cm mean length was the smallest mean size for any site on the Yampa and Colorado. Duffy was the only site where mean lengths were not significantly different between years (Table 8). Bluehead suckers under 34 cm were rare at Duffy, likely due to predation. The bluehead's mean length of 36 to 38 cm was the highest for any site on the Yampa or Colorado River (Table 8). At Lily Park, bluehead under 28 cm were rare in both years and the means were similar (Table 8).

The length frequency for bluehead suckers on the Colorado River contained juvenile and adult–size fish. Mean length of the bluehead sucker was 33 to 35 cm (Table 8).

Mean lengths of the bluehead sucker on the Dolores River were noticeably different from all other sites with no collected bluehead sucker being over 28 cm in either sampling year. A very high number of yearling (325) bluehead sucker were caught at Big Gypsum in 2001, but no fish in that size-group was collected in 2000 (Table 8). About the same number of fish between 19 cm and 28 cm were collected in both years (11 in 2000, 18 in 2001).

Table 8. Mean lengths of bluehead sucker captured during the study period (1998 to 2001), Yampa, Colorado and Dolores Rivers.

	1998,a	1999,b	2000,c	2001,d
	Mean length of bluehead sucker in cm			
Sevens	33.5,cd	33.6,cd	31.3,abd	30.0,abc
Duffy	36.5	37.9	37.6	36.2
Lily Park			34.4,d	33.5,c
Corn Lake		36.5,cd	33.3,bd	34.8,bc
Clifton			31.8,d	33.5,c
Dolores			23.6	12.1
	Total number in sample - Number less than 15 cm			
Sevens	314 - 0	187 – 0	180- 0	89 – 0
Duffy	56 – 0	102- 0	45 – 0	41 – 3
Lily Park			347 – 3	212 – 0
Corn Lake		1212 –3	1010 –16	1283 –31
Clifton			1374 – 51	1228 – 35
Dolores			11-0	343-308

*a, b, c, d following a mean length indicates significant difference (2 tail test) at @=0.5.

The length frequency histograms and mean sizes were very similar for the flannelmouth sucker for the first three years at Sevens. But, their size decreased in 2001 compared to prior years. The mean length (43.8 cm) was significantly lower (Table 9).

Because the number of flannelmouth was low at Duffy in 2001 (n = 17) (Figure A8), the 2001 mean lengths (47.5 cm) were not significantly different from prior years (Table 9). The mean lengths of flannelmouth at Sevens (46 cm) and Duffy (49 cm) (Table 9) were high because there were no juvenile fish at these sites. This was most likely a result of predation. At Lily Park, mean length was significantly less in 2001 (38.4 cm) than in 2000 (41.5 cm) (Table 9) due to more fish less than 29 cm in 2001 (153) than in 2000 (4).

At Corn Lake, mean length of the flannelmouth was 39 to 41 cm (Table 9). The size structure of flannelmouth in the Colorado River ranged from 7 to 55 cm with modes representing all age groups. This suggested abundant habitat and no predation or competition.

On the Dolores River only three adult flannelmouth sucker were collected in 2001. The low mean length was representative of a population that had either poor habitat or limited forage availability for adult size fish. There was apparently very good reproductive success among flannelmouth in the Dolores River, since the vast majority of fish were between 9 and 19 cm in 2001. In 2000, most flannelmouth were between 16 to 26 cm in 2000.

Size structures of roundtail chub at Sevens and Duffy in 2001 were very similar (not significantly different) to prior years, but sample sizes were less at both sites (Table 10). The small decrease in mean lengths in 2001 (Table 10) was due to only one or two additional small fish in the sample, not a shift in size distribution. The high mean lengths at Sevens (38 to 40 cm) and at Duffy (43 to 44 cm) for the study period were due to few yearling and juvenile fish in the sample. Only one chub was collected at Lily Park in 2000 and in 2001. On the Colorado River, both large and small roundtail chub were present in 2000 and again in 2001 at Corn Lake and at Clifton. Mean lengths were not significantly different between Corn Lake (23.5, 20.9 cm) and Clifton (25.0, 22.1 cm) in the same year, but the differences were significant between 2000 and 2001 at both sites. On the Dolores River, roundtail chub ranged in size from two cm to 27 cm with only one large chub at 40 cm.

The length frequency data contained a lot of information about these fish populations. When smaller fish appeared as modes on the graph it was an indication of successful reproduction and survival of younger year-classes. On the Yampa River at Sevens and Duffy very few fish were collected in the size range of 15 to 35 cm, but fish larger than 40 cm were common. This indicates that predators in the Yampa River, primarily northern pike, have had a heavy impact on 15 to 35 cm fish. On the Colorado River, lengths were evenly distributed and showed the presence of multiple year-classes. The lack of predation in the Colorado River apparently allowed a natural length distribution to develop that was based on limits set by habitat availability.

Table 9. Mean lengths of flannelmouths captured during the study period (1998 to 2001), Yampa, Colorado and Dolores Rivers.

	1998a	1999b	2000c	2001d
	Mean length of flannelmouth sucker in cm			
Sevens	45.7,d	46.5,d	45.8,d	43.8,abc
Duffy	48.9	49.0	49.8	47.5
Lily Park			41.5,d	38.4,c
Corn Lake		41.2,cd	38.9,bd	40.6,bc
Clifton			38.3	38.8
Dolores			18.8d	14.2c
	Total number in sample - Number less than 15 cm			
Sevens	668 –0	476 – 0	404 – 1	359 – 0
Duffy	90 – 0	79 – 0	65 – 0	17 – 0
Lily Park			1,935 – 0	2,022 – 0
Corn Lake		1,384 –46	928 – 65	1,495 – 39
Clifton			1,106 – 55	1,934 – 53
Dolores			110 – 30	580 – 271

- a, b, c, d following a mean length indicates significant difference (2 tail test) at @=0.5 for those years.

Table 10. Mean lengths of roundtail chub captured during the study period (1998 to 2001), Yampa, Colorado and Dolores Rivers.

	1998a	1999b	2000c	2001d
	Mean length of roundtail chub in cm			
Sevens	39.0	40.0,d	39.2	37.9,b
Duffy	43.5	44.5	44.2	43.4
Lily Park			40.3	18.0
Corn Lake		23.3,d	23.5,d	20.9,bc
Clifton*		28.9	25.0,d	22.1,c
Dolores			14.1,d	10.9,c
	Total number in sample - Number less than 15 cm			
Sevens	73 –0	39 – 0	31 – 0	23 – 0
Duffy	55 – 1	44 – 0	46 – 0	27 – 1
Lily Park			1 – 0	1 – 0
Corn Lake		188 – 78	145 – 26	193 – 89
Clifton*		47 – 4	196 – 29	446 – 186
Dolores			275 – 277	145 – 367

* a, b, c, d following a mean length indicates significant difference (2 tail test) at @=0.5 for those years.

The Dolores River displayed yet a third pattern in length frequency. In the Dolores River, small fish (<15 cm) were abundant, but large fish (> 25 cm) were very rare. The Dolores does not have obvious predation impacts. The channel catfish was the only non-native predator species and typically small sized fish disappeared by predation. The lack of large fish was likely a function of a lack of habitat. The Dolores River appeared to be a model of small fish having the advantage in the shallower pools and runs of this site. The Colorado River was a model of larger fish occurring in big the deeper and faster habitats typical of this river.

Density and Biomass Estimation

The biomass estimate included both size and density and was the best measurement of fish productivity for a river reach. Species composition and length frequency analysis provided necessary information about factors that may be influencing the biomass estimate. It was assumed that the carrying capacity (potential biomass) of a community and for individual species was set by a combination of habitat and forage availability. Other factors that reduced a particular species biomass below the habitat potential included predation, competition and hybridization as were described above for each site. Native fish biomass on the Colorado, Dolores Rivers and the Lily Park (Yampa River) was likely a good estimated of carrying capacity. The Sevens site was found to be less impacted by predation and hybridization than Duffy. The other primary variable in the carrying capacity equation was forage availability. Riffles were the most productive habitats for aquatic invertebrate production. Therefore, riffle habitat availability may also have influenced fish biomass. Given these background variables, biomass (fish productivity) at each site was used to indicate habitat potential for native fish between years and between sites.

In 1998 and 1999 at the **Duffy** Reach, total fish density and biomass estimates were similar at 378 and 403 fish/km and 73 and 65 kg/ha respectively (Table 11). Density estimates were not significantly different (alpha = .05) for 1998 and 1999. The 2000 density estimate of 316 was significantly lower (alpha = .05) than prior years. The total biomass estimate at Duffy in 2000 was 49 kg/ha. It was 42 kg/ha in 2001. Density and biomass estimates were down for all species except smallmouth bass in 2000 and 2001 (A-Table 1 and 2). The base flows during 2000 and 2001 were much less than in 1998 and 1999. Reduced fish biomass during the low flow years was also found at the other Yampa River sites. This was consistent with reduced carrying capacity in those years.

The density estimate for both white sucker and hybrids in 2001 was the lowest of the study period and was significantly different from the three prior years (A-Table 1). At **Duffy** large-bodied species decreased in density in 2001 compared to years with higher base flows. The only species to increase in density and biomass in 2001 was the smallmouth bass, a smaller bodied species that can utilize shallow habitats.

Total density estimates at **Sevens** were similar in 1998 (1,147 km) and 1999 (1,115/km) (Table 11). Biomass was 183 and 162 kg/ha in those years (Table 12). The density estimates dropped in 2000 (778/km) and 2001 (653/km). The biomass estimate in 2000 was 102 kg/ha. It was 79 kg/ha in 2001 (Table 12). The lower biomass was again associated in the years with the lower base flows, an indication of reduced carrying capacity at the flows of those years. Also consistent with Duffy is the lower estimate for northern pike in 2000 and 2001. That suggests the risk of predation by this species was higher in 1998 and 1999.

Flannelmouths were the most common fish greater than 15 cm collected in all four years at **Sevens.** This species had the highest density estimates except in 2000. Flannelmouth sucker estimates were similar for 1998 and 1999, and similar for 2000 and 2001, but the periods differed from each other. The lowest numbers of bluehead were caught in 2001, but the estimate was not significantly different than in other years because of the lower number of recaptures (higher variance). The electro-fishing effort was roughly equal between years at Sevens and, based on effort, it appeared bluehead suckers were more scarce in 2001. The same applied to roundtail chub. Sample size was small for roundtail chub in all years and recapture rates were not high enough to produce tight confidence intervals. In 2001, fewer fish were caught given a similar sampling effort, but it was not statistically significant. The fact that total fish and native sucker density was less in 2000 and 2001 at both Sevens and Duffy indicates a common cause (likely flows) at both locations.

Lily Park was added to the study in 2000 so data is not available for the higher base flow years. The two years (2000 and 2001) of data were strikingly different. Anderson (2002) explained that channel catfish and flannelmouth sucker estimates were highly biased in 2000 as a result of very low summer flows and that the 2001 data was better for comparing density and biomass with other stations.

In 2001, **Lily Park** had by far the highest total fish density of 3,168 fish/km (Table 11) at the three Yampa Sites. Total biomass (kg/ha) at Lily Park was 3.7 times higher than at **Sevens** and 7.0 times higher than at **Duffy** (Table 12). These data strongly indicated that Lily Park had higher total productivity than the upstream sites. Lily Park was only ten river miles downstream of Sevens, suggesting similar temperature and water quality attributes. Also, there appeared to be a larger predator population of northern pike and smallmouth bass at Lily Park (Table 11). Most of the differences in fish density between Lily Park and Sevens were likely habitat related.

Flannelmouth biomass at **Lily Park** was 3.6 times higher and bluehead sucker density was 3.9 times higher than **Sevens**. The 37% decrease in bluehead density at **Lily Park** between 2000 and 2001 indicated reduced abundance between years. Roundtail chub density for fish over 15 cm was highest at Sevens. The near zero chub density at Lily Park (Table 11) indicated a lack of habitat there. It seemed more likely spawning or YOY habitat was missing for chub at Lily Park. Hybridization at **Duffy** did not allow for comparing native sucker density and biomass to other sites. Also predation at Duffy may have been reducing the density and biomass estimates below the potential for this site.

In spite of the problems identified with the 2000 **Lily Park** density data, the sampling effort was beneficial for documenting habitat used at this location. Many flannelmouths were collected from deep eddies and pools on September 13, 2000, at 114 cfs (Lily Park gage). But, on subsequent passes at higher flows (September 27, October 3 and 5) flannelmouth were not captured from those backwaters, but in runs with suitable depths. These observations directly showed that flannelmouths occupied habitats at low flows (100 cfs) that were not used at higher flows (over 120 cfs). This

Table 11. Density and biomass estimates in **fish per kilometer** and **kilograms per kilometer** for each study site.

	no./km	no./km	no./km	no./km	kg/km	kg/km	kg/km	kg/km
YAMPA RIVER	**SEVENS**							
Species	1998	1999	2000	2001	1998	1999	2000	2001
Total Fish	1147	1115	778	**653**	1136.7	1004.5	633.1	491.9
Flannelmouth Sucker	395	376	296	**263**	413.4	411.6	361.4	227.7
Bluehead Sucker	274	238	309	**120**	110.5	93.5	26.0	30.1
Roundtail Chub	73	41	54	**29**	43.8	26.6	13.6	14.9
LONG REACH	**DUFFY**							
Species	1998	1999	2000	2001	1998	1999	2000	2001
Total Fish	387	403	316	430	509.6	453.8	340.5	291.9
Flannelmouth Sucker	25	15	11	5	34.2	19.3	15.6	6.1
Bluehead Sucker	24	23	16	19	14.0	9.5	10.1	12.1
Roundtail Chub	12	25	5	10	12.0	26.6	5.1	9.6
MAPPED REACH	**DUFFY**							
Species	1998	1999	2000	2001	1998	1999	2000	2001
Total Fish	435	343	467	716				
Flannelmouth Sucker	13	5	9	9				
Bluehead Sucker	21	10	12	3		2.6	4.1	2.1
Roundtail Chub	16	7	7	3		3.1	1.2	0.5
YAMPA RIVER			**Lily Park**				**Lily Park**	
Species			2000	2001			2000	2001
Total Fish			**6279**	**3168**			2369	1760
Flannelmouth Sucker			**2238**	**1667**			1316	801
Bluehead Sucker			**552**	**346**			195	114
Roundtail Chub			**2**	**2**			3.0	0.1
COLORADO RIVER		**CORN LAKE**				**CORN LAKE**		
Species		1999	2000	2001		1999	2000	2001
Total Fish		3962	3417	4007		2761	2854	2605
Flannelmouth Sucker		1550	999	1662		1261	1269	1281
Bluehead Sucker		1573	1182	1272		806	504	596
Roundtail Chub		192	357	171		57	68	41
COLORADO RIVER		**CLIFTON**				**CLIFTON**		
Species			2000	2001		1999	2000	2001
Total Density estimate			3766	4547			3207	3341
Flannelmouth Sucker			1822	1563			1280	1075
Bluehead Sucker			1138	1164			452	496
Roundtail Chub			437	357			100	94
DOLORES RIVER			**Big Gypsum**				**Big Gypsum**	
Species			2000	2001			2000	2001
Total Density estimate			196.6	231.7			259.0	49
Flannelmouth Sucker			35.8	105.9			89	1.5
Bluehead Sucker			3.0	12.7			7.0	0.3
Roundtail Chub			81.0	65.1			14.9	4.5

Table 12. Density and biomass estimates in **fish per hectare** and **kilograms per hectare** for each study site.

	no./ha	no./ha	no./ha	no./ha	kg/ha	kg/ha	kg/ha	kg/ha
YAMPA RIVER	**SEVENS**							
Species	1998	1999	2000	2001	1998	1999	2000	2001
Total Fish	185.2	180.0	125.6	105.4	183.5	**162.1**	**102.2**	**79.4**
Flannelmouth Sucker	63.8	60.7	47.8	42.5	66.7	**66.4**	**58.3**	**36.7**
Bluehead Sucker	44.3	38.4	49.8	19.4	17.8	**15.1**	**4.2**	**4.9**
Roundtail Chub	11.8	6.6	8.6	4.7	7.1	**4.3**	**2.2**	**2.4**
LONG REACH	**DUFFY**							
Species	1998	1999	2000	2001	1998	1999	2000	2001
Total Fish	55.3	57.7	45.3	61.4	72.9	64.9	48.7	41.7
Flannelmouth Sucker	3.6	2.1	1.6	0.7	4.9	2.8	2.2	0.9
Bluehead Sucker	3.5	3.3	2.3	2.7	2.0	1.4	1.4	1.7
Roundtail Chub	1.7	3.6	0.7	1.4	1.7	3.8	0.7	1.4
MAPPED REACH	DUFFY	DUFFY	DUFFY	DUFFY				
Species	1998	1999	2000	2001				
Total Fish	85.9	67.8	92.3	141.4				
Flannelmouth Sucker	2.6	1.1	1.8	1.7				
Bluehead Sucker	4.1	1.9	2.3	0.7				
Roundtail Chub	3.1	1.3	1.4	0.7				
YAMPA RIVER			**Lily Park**				**Lily Park**	
Species			2000	2001			2000	2001
Total Fish			1047.6	528.5			395.2	293.7
Flannelmouth Sucker			373.3	278.1			219.5	133.7
Bluehead Sucker			92.1	57.7			32.5	19.0
Roundtail Chub			0.3	0.3			0.5	0.0
COLORADO RIVER		**CORN LAKE**				**CORN LAKE**		
Species		1999.0	2000.0	2001.0		1999	2000	2001
Total Fish		765.1	659.9	773.8		533.2	551.2	503.1
Flannelmouth Sucker		299.4	192.9	320.9		243.6	245.1	247.3
Bluehead Sucker		303.8	228.3	245.7		155.7	97.4	115.1
Roundtail Chub		37.0	68.9	32.9		11.1	13.1	8.0
COLORADO RIVER			**Clifton**				**Clifton**	
Species			2000	2001			2000	2001
Total Density estimate			600	724			511	532
Flannelmouth Sucker			290	249			204	171
Bluehead Sucker			181	185			72	79
Roundtail Chub			70	57			16	15
DOLORES RIVER			**Big Gypsum**				**Big Gypsum**	
Species			2000	2001			2000	2001
Total Density estimate			116.3	137.1			153.2	28.8
Flannelmouth Sucker			21.2	62.6			52.5	0.9
Bluehead Sucker			1.8	7.5			4.2	0.2
Roundtail Chub			47.9	38.5			8.8	2.6

habitat-switching pattern was also observed in 2001 when flows were dropping. Flannelmouths did not occupy the eddies and pools when flow was above 120 cfs (August 22, 2001), but they were captured in these habitats as flows dropped to near 100 cfs on August 29th and September 5th, 2001.

Smallmouth bass was the only species in **Lily Park** to increase in 2001 (A-Table 1). This increase was believed to reflect a true increase in abundance, as all three Yampa sites displayed bass increases in lower-flow years. The bass density estimate at Lily Park in 2001 (501/km) was the highest of any of the sites on the Yampa River (Table 11).

The Colorado River **Clifton** site was added in 2000 because of differences in channel morphology compared with the Corn Lake site. Total density and total biomass estimates for fish/km and kg/km were similar between Corn Lake and Clifton in both years. But because Clifton was wider, the number of fish per hectare was less than Corn Lake. The total area at Clifton was 27.4 hectares compared to Corn Lake's 20.7 hectares. Both sites had a common flow of 1000 cfs. Clifton and Corn Lake were separated only by 0.2 km. So, it was possible to pool data from the sites and get larger sample sizes for testing estimates there between 2000 and 2001.

The **Clifton** site had the highest estimate of any site for total fish density per kilometer (4007/km) and biomass (3498 kg/km) (Table 11), but **Corn Lake** had the highest density 773/ha and 551 kg/ha biomass estimates by area (Table 12). The mean total fish biomass for both sites in the **15-Mile Reach** was 486 kg/ha. Biomass in the15-Mile Reach was much higher than the Yampa River, except for the Lily Park section where it was 1.4 times higher in 2001. Biomass in the 15-Mile Reach was three to five times higher than at **Sevens** and seven to ten times higher than at **Duffy**.

The **Corn Lake** estimate in 1999 for bluehead sucker was higher than in 2000 and 2001. The density estimate for bluehead and flannelmouth suckers were very similar between Corn Lake and Clifton in 2001. Bluehead sucker density was 1,272/km at **Corn Lake** and 1,206/km at **Clifton**. Flannelmouth-sucker density was 1,662/km at Corn Lake and 1,619/km Clifton (Table 11).

Bluehead-sucker density and biomass estimates were higher in the 15-Mile Reach than in the Yampa and Dolores River. The bluehead sucker's mean kilogram per hectare in the **15-Mile reach** was 3.6 times higher than blueheads at **Lily Park,** 5.5 times higher than **Sevens,** and 22 times greater than **Big Gypsum** (2000 data).

Flannelmouth-sucker density estimates per hectare were higher at **Lily Park** than the **15-Mile Reach.** But, because fish were smaller at **Lily Park**, **Corn Lake** had a higher biomass/ha. These data indicated that flannelmouth sucker habitat at **Lily Park** was nearly as good as the 15-Mile Reach. Flannelmouth sucker biomass at Lily Park was three times higher than **Sevens** and about four times higher than **Big Gypsum**.

Roundtail chub density estimates per kilometer were lower at Corn Lake (171/km), than at Clifton (370/km) (Table 11).

The largest difference between Corn Lake and Clifton in 2001 was in carp abundance (Table 11 and 12). Carp were found to be more mobile than other species between sampling trips. Near the end of sampling in 2001 when flow was lowest, habitats that formerly had a large number of carp at Corn Lake were vacant of carp and it appeared relatively more carp were found in Clifton. In spite of minor differences in density for carp, catfish and white suckers, productivity was very similar between the Corn Lake and the Clifton Stations.

Total fish density and biomass were very different between years at the **Big Gypsum Site** on the **Dolores River.** Base flows were similar between 2000 and 2001 (50 to 60 cfs), but there was a large difference in spring flows. Runoff flows were mild in 2000 with a peak flow of 1170 cfs on May 1, 2000, and peak flow was 533 cfs in 2001. The mean flow for the period April 17 though May 30 was 522 cfs in 2000, but was only 170 cfs in 2001. Reduced spring flows probably caused the lower biomass in 2001.

Dolores River density estimates for native fish >15 cm were low compared to the Colorado and Yampa (Table 11 and 12). The bluehead-sucker estimate was higher in 2001 (13 fish/km) than in 2000 (3 fish/km) due to a higher number of yearling fish in 2001. The Dolores had the lowest bluehead-sucker density estimate of all sites in 2000, but was higher than Duffy in 2001.

Flannelmouth density at Big Gypsum was significantly higher in 2001 at 106/km than 2000 at 36/km (Table 11). The higher flannelmouth abundance in 2001 resulted from a strong yearling group (13 - 18 cm), which was not as high the year before. The low density of adult size native fish in the Dolores River did not appear to be due to lack of recruitment, since juvenile fish were extremely abundant.

It appeared that the Dolores river was a much higher availability of YOY and yearling habitat than it had habitat for adult-sized (>28 cm) fish. Density estimates of roundtail chub were less in 2001 (65/km) than in 2000 (81/km). In 2000, there was a very high number of yearling chub (12 – 19 cm) collected, but the number of yearling fish caught in 2001 was much lower. Either there was poor survival of yearling chub or zero growth in chub since the number of larger fish did not increase.

HABITAT QUANTIFICATION

General Site Description

The Clifton reach on the Colorado River was the longest of the sampling sites followed by Corn Lake, Big Gypsum, Lily Park, Sevens and Duffy Tunnel (Table13). The Clifton reach had a riffle run morphology with a mean slope of 0.2%. An abandoned diversion dam, in the lower part of the site, backed up sediment and created an astomosting channel morphology through much of the Clifton site. Downstream of the dam, the channel was straight and narrow where it entered the Corn Lake reach. The mean width at Clifton was 59 m at 600 cfs (Table 13).

The Corn Lake Reach was located immediately downstream of the Clifton Reach on the Colorado River. Corn Lake had the same riffle run morphology, but was narrower and more constrained than the Clifton Reach. The slope of the Corn Lake was 0.15 percent. The site had the highest mean velocity of all sites. Aerial photograph analysis of the entire 15-mile reach revealed that Clifton site was slightly wider than most of the 15-Mile Reach while the Corn Lake site was slightly narrower. Mean width of Corn Lake was 48 meters at 600 cfs (Table 13)

The Duffy Tunnel on the Yampa River was the widest station with a mean width of 68 m at 600 cfs. Diffy had a low gradient riffle run / pool riffle (slope 0.06%) (Table 13). A significant feature of the Duffy Tunnel Reach was the "Duffy Tunnel" itself, a water diversion in the middle of the sampling reach. Large boulders were located in the channel just downstream of the diversion. In this area the channel widened considerably into an island complex. The Duffy Tunnel Reach was comprised of four runs and three riffles, each riffle being associated with an island complex.

The Sevens site had a mean width of 60 m at 600 cfs, with a slope of 0.05 percent (Table 13). Sevens mirrored the same low gradient riffle run / pool riffle morphology as Duffy Tunnel. The Sevens Reach had a single-thread channel with the upper portion of the channel consisting of tightly spaced pools and riffles (~7.5 channel widths between riffles). The lower 900 meters was one large run.

Lilly Park was steeper, faster, and narrower (Table 13) than the other Yampa River sites and had a characteristic change in morphology between the upper and lower sub-reaches. The upper portion of the reach was shallow with riffle-run morphology. Half way through the reach was a large bend. Below that point the river had tightly spaced pool-riffle sequences (~5 channel widths between riffles).

Mean bed slope was determined from the longitudinal profiles for each site. Negative slopes on the profile occurred in riffles and runs. Positive or up-slopes occurred in glides or in the tail out of pools. The Corn Lake and Clifton longitudinal profile see Appendix-Figures 1 and 2. Lily Park has the highest bed slope and the highest standard deviation suggesting higher variability at this station (A-Figure 3). Longitudinal profiles for Sevens, Duffy and Big Gypsum are presented in (A-Figure 4, 5 and 6 respectively).

Habitat Composition and Habitat Diversity

The surface area of the 16 meso-habitats types was used to determine habitat composition at each site for each simulated flow. The 16 meso-habitat types were composed of five pools, five runs, four riffles and two rapids (Table 4). The flow at the time of fish sampling was used to compare habitat composition and diversity between rivers. For the Colorado River this flow was 1000 cfs. Only about 7% of the habitat was in the pool category (Table 14). Clifton had about 17% pool and backwater at 1000 cfs. Lily Park was 19% pool habitat at 250 cfs (Table 14). At 250 cfs Lily Park, Sevens and Duffy were dominated by run habitats. Pools were common in the main channel (Table 14).

Table 13. Physical attributes of each study site (mean velocity, length, mean width, surface area at modeled flows).

	Big Gyp	Clifton	Corn Lake	Duffy	Lilly	Sevens
*Mean Velocity (m/s)	0.28	0.44	0.54	0.39	0.51	0.38
Length (km)	3.3	4.2	3.9	2.1	3.1	2.9
*Width (m)	22	59	50	68	57	60
Percent Slope	0.15%	0.20%	0.16%	0.06%	0.20%	0.05%
Flow (cfs)	Area (ha)					
10	6.0					
20	6.3					
30	6.5					
40	6.7				12.9	11.8
50	6.8					
60	6.9			10.8	12.9	13.1
80	7.0			11.2	12.9	13.7
100	7.1	16.4	11.2	11.6	13.1	14.3
125				11.9		
150		18.5	15.5	12.2	14.4	15.1
200	7.6	19.6	16.3	12.6	14.9	15.6
250		20.6	17.0	12.9	15.1	15.9
300	7.8	21.3	17.7	13.2	15.1	16.2
350		21.9	18.1			
400	8.0	22.4	18.5	13.6	16.7	16.7
450		22.9	18.8			
500	8.2	23.3	19.2	13.9	17.0	17.1
600		24.2	19.8	14.2	17.6	17.4
700		25.3	20.2			
800		26.0	20.7			
880						18.1
900		26.8	20.4			
1000		27.4	20.7			
1200		28.5	22.1			
1400		29.3	22.7			
1600		30.2	23.3			
1800		31.0	23.8			
2000		31.8				

Velocities and mean width calculated at 600cfs, except for Big Gypsum which were calculated at 100cfs

Meso-habitat composition varied with discharge, since meso-habitats were defined by depth and velocity criteria. At Corn Lake and Clifton, pool composition was highest (40% and 60%) at the lowest modeled flow of 100 cfs and quickly decreased as flows increased to 800 cfs (A-Figures 11a and 11c). At 1000 cfs, Corn Lake had the highest composition of riffle habitat at 53% while Clifton had 39% (Table 14, and A-Figures 11a and 11c). At 250 cfs, the Yampa River had a low amount of riffle habitat compared to the Colorado River. Lily Park had more riffle habitat at 250 cfs (10%) than Sevens (2%) and Duffy (6%) (Table 14, A-Figures 12a, 12c, 13a).

Table 14. Meso habitat availability per kilometer at a reference flow typical of the base flow period.

	Habitat Types	Depth	Velocity	CLIFTON 4.2 km	Corn Lake 3.9 km	Lily Park 2.9 km	Sevens 2.9 km	Duffy 2.4 km	Big Gypsum 4.0 km
#		(m)	(m/s)	1000 cfs	1000 cfs	250 cfs	250 cfs	250 cfs	60 cfs
1	Wetted Sand	0.01 - 0.2	< 0.15	0.71	0.09	0.61	0.72	0.17	0.21
2	Shoal	0.2 - 0.5	< 0.15	0.44	0.12	0.30	0.77	0.61	0.26
3	Shallow pool	0.5 - 1.0	< 0.15	0.45	0.12	0.27	0.59	0.43	0.36
4	Medi -pool	1.0 - 2.0	< 0.15	0.23	0.03	0.13	0.30	0.27	0.16
5	Deep pool	> 2.0	< 0.15	0.12	0.00	0.09	0.00	0.05	0.01
6	Wetted area	.01 - 0.2	0.15 - 0.6	0.54	0.18	0.58	0.16	0.26	0.13
7	Shoal-run	0.2 - 0.5	0.15 - 0.6	0.90	0.43	1.67	1.35	1.97	0.29
8	Shallow run	0.5 to 1.0	0.15 - 0.6	1.07	0.54	1.17	1.63	1.20	0.12
9	Medi-run	1.0 to 2.0	0.15 - 0.6	1.03	0.96	0.45	0.58	0.14	0.01
10	Deep run	> 2.0	0.15 - 0.6	0.15	0.08	0.08	0.00	0.00	0.00
11	Shallow riffle	< 0.2	0.6 - 1.5	0.25	0.05	0.11	0.01	0.04	0.04
12	Riffle	0.2 to 0.5	0.6 - 1.5	0.80	0.61	0.39	0.09	0.25	0.05
13	Deep riffle	0.5 to 1.0	0.6 - 1.5	1.53	1.41	0.05	0.02	0.01	0.00
14	Extra deep riffle	> 1.0	0.6 - 1.5	0.73	0.60	0.00	0.00	0.00	0.00
15	Shallow rapid	< 0.5	> 1.5	0.10	0.07	0.01	0.00	0.00	0.00
16	Deep rapid	> 0.5	> 1.5	0.10	0.08	0.00	0.00	0.00	0.00
	Total surface area per kilometer			9.15	5.37	5.92	6.22	5.39	1.63
	Shannon Weaver diversity index								
	POOL			1.9 (21%)	0.4 (7%)	1.4 (24%)	2.4 (38%)	1.5 (28%)	1.0 (61%)
	RUN			3.7 (40%)	2.2 (41%)	4.0 (67%)	3.7 (60%)	3.6 (66%)	0.6 (34%)
	RIFFLE			3.5 (39%)	2.8 (53%)	0.6 (10%)	0.1 (2%)	0.3 (6%)	0.1 (6%)

Base flows on the Dolores River at the time of electro-fishing were about 50 to 60 cfs. Habitat composition at this flow was 51% pools and only 5% riffle (Table 14, A-Figure 13c).

The lowest of amount of riffle habitat per kilometer was at the Big Gypsum Site. The highest amount of riffle habitat was at Clifton (2.58 ha) (Table 14). These two sites also had the lowest (Big Gypsum, 259) and the highest (Clifton, 3,440) total fish biomass (kg/km). The R-square value for a simple linear regression between riffle area and total fish biomass was 0.85 (Table 15). Riffle habitat at the Duffy site was intermediate to Sevens and Lily Park. Yet, total fish biomass was much less at Duffy. Fish biomass at Duffy was likely reduced by higher predation rates. Habitat data there suggested a higher total fish biomass potential than was observed.

Table 15. Correlation between riffle meso habitat and total fish biomass

		Clifton	Corn	Lily Park	Sevens	Duffy	Big Gypsum
Riffle		2.58	2.08	0.55	0.12	0.30	0.09
Total biomass		3440	2740	2064	1071	482	259
R Square	0.847535						

Deep pools were found to be uncommon habitats in all sites. At low flows velocities are low. At high flow when depths are higher, low velocity areas are confined to backwaters. Deep pools seemed to be used primarily by larger fish including larger predators. Small fish tended to occupy shallow pools or shorelines. Species that appeared to require deep pools and runs (over 1-meter depth) included mostly channel catfish, carp and white suckers. The Clifton station, with the most deep-pool and deep-run habitat, also had the greatest combined biomass of catfish, carp and white suckers (Table 16). The R-square value for this regression was 0.89.

Table 16. Correlations between pool habitat and biomass for carp, white sucker and catfish.

	Clifton	Corn	Lily Park	Sevens	Duffy	Big Gypsum
Deep pool & deep run	1.53	1.07	0.76	0.88	0.46	0.17
tot biomass	1581	767	740	492	373	95

R Square 0.8854

The bluehead sucker is a native fish and one of the primary species of interest for this study. Habitat requirements of this fish indicate a relationship between bluehead sucker biomass and deep-riffle meso-habitat availability. The Colorado River sites had much greater deep-riffle meso-habitat than either the Yampa and Dolores Rivers. The R-square value for deep-riffle habitat and total bluehead biomass was 0.92 (Table 17). It appeared that a lack of deep and swift habitat (deep-riffle) in the Yampa River explained why blueheads tended to be smaller at Lily Park. The Duffy site had lower bluehead sucker biomass relative to the other Yampa River sites and relative to riffle habitat availability. This was explained by hybridization with the white sucker.

Table 17 Correlation between deep riffle habitat and bluehead sucker biomass

		Clifton	Corn	Lily Park	Sevens	Duffy	Big Gypsum
Deep riffle		1.53	1.41	0.05	0.02	0.01	0.00
Bluehead biomass		497	550	195	102	12	7
Bluehead	R Square	0.9158					

Habitat diversity based on the 16 meso-habitat compositions varied greatly among sites. The Shannon Weaver diversity at the base flow representative of the fish surveys was highest at Clifton followed by Corn Lake, Big Gypsum, Lily Park, Sevens and Duffy (Table 14). A visual display of habitat diversity for each simulated flow is given in Appendix Figures 11, 12 and 13.

The maximum Shannon-Weaver value for 16 meso-habitats was 2.776. Habitat diversity (Shannon-Weaver) peaked at 1000 cfs at Clifton (2.47) and at 1200 cfs at Corn Lake (2.23), which were typical of flow conditions during the fish-sampling period. Since flows were not modeled above 600 cfs for the Yampa River, the flow that habitat diversity peaked was not identifiable. However, at 600 cfs Lily Park had the greatest habitat complexity according to Shannon-Weaver diversity (2.22) followed by Sevens (1.92). Duffy was the least complex (1.73). This order of habitat complexity matches the order of fishery diversity found on the Yampa River.

Habitat Suitability

We used the finer scale (Polygon) method to determine fish habitat suitability criteria based on how fish distributed themselves within the study site. Polygons were sub units of a study site and possessed both electro-fishing and habitat data. The polygon analysis referred to the process where biomass was used to identify suitable and non-suitable habitats. Habitat suitability for bluehead and flannelmouth suckers was calculated at Corn Lake, Clifton, Lily Park and Sevens (A-Table 3, 4, 5, and 6 respectively). Polygon data from Duffy was not included due to the very low occurrence of native suckers there (A-Table 7). Polygon data from the Big Gypsum site was not included because the 2-D model simulations were not available when this analysis was performed. Inclusion of the Big Gypsum data would likely not alter results because at 50 to 60 cfs the Big Gypsum site lacked both habitat and biomass diversity.

In 2000 and 2001, shoreline electro-fishing was done at Corn Lake and Clifton to sort out bank habitat from mid-channel habitat. Very few adult bluehead and flannelmouth suckers were collected along from the shoreline making it unnecessary to keep shoreline polygons for these fish. The adult bluehead and flannelmouth sucker did not occupy bank habitat. This was another indication that these fish avoid areas with depths less than 0.3 m and velocities less than 0.35 m/s.

The polygon analysis found that bluehead sucker biomass increased in polygons with higher velocities (A-Tables 3, 4, 5, 6 and 7; A-Figure 14a). Polygons that had velocities over 0.6 m/s had much higher biomass than polygons with velocities less than 0.5 m/s. There were no polygons with a mean velocity over 0.6 m/s on the Yampa River.

All polygons with higher velocity criteria were on the Colorado River data. The bluehead sucker Sigma plot (A-Figure 14a) also showed mean depths of 0.5 to 1.0 m having higher biomass than shallower depths.

The sigma plot for flannelmouths showed these fish were more abundant in polygons with mean velocities over 0.5 m/s and depths over 0.6 m (A-Figure 14b).

The sigma plot representation was simplified into four functional meso-habitat types based on depth and velocity characteristics. The poorest habitat for blueheads was classified as **Unusable** (Figure 7) and represented the river areas that blueheads did not occupy. Polygons with the highest biomass were used to indicate **Optimal** habitat conditions (depths and velocities). Optimal polygons accounted for about 60% of the total bluehead biomass. The mean biomass for all optimal biomass polygons was found to be about 243 kg/ha (Figure 7). **Marginal** habitat represented about 25% of the total biomass. The mean biomass for polygons in the marginal category was 116 kg/ha. The remaining 15% of the total biomass represented the **Unsuitable** category (Figure 7). Unsuitable habitat had a biomass value of 31 kg/ha.

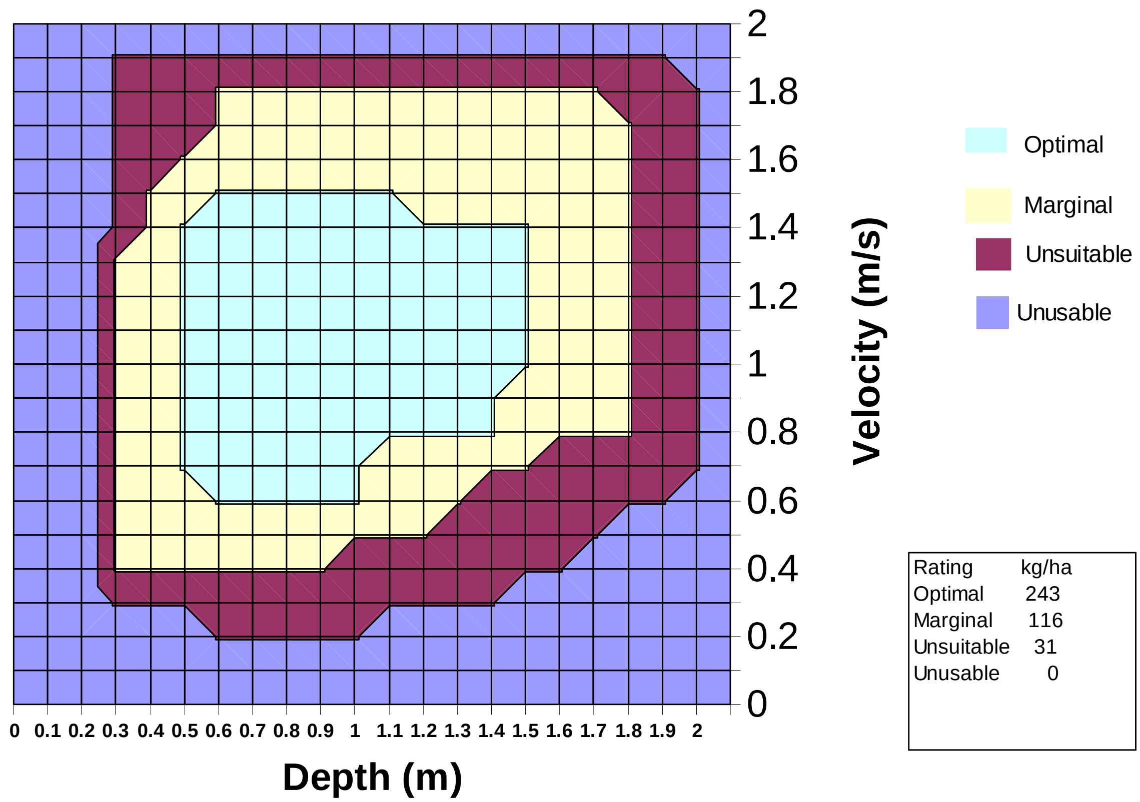

Figure 7. Depth and velocity criteria used to model bluehead habitat availability.

Habitat suitability criteria for flannelmouths were also developed using the above-described polygon analysis approach. The sigma plot for flannelmouths showed biomass associated with mean depths and velocities for that polygon (A-Tables 3, 4, 5, 6, and 7). Very few flannelmouth were observed from habitats with velocities less than (0.3 m/s) (A-Figure 14b). **Unusable** habitat for flannelmouths represented the river areas where they were not found. **Optimal** polygons accounted for about 60% of total biomass. The mean biomass for all optimal biomass was found to be about 496 kg/ha (Figure 8). **Marginal** habitat represented about 25% of the total biomass and was 253 kg/ha. **Unsuitable** was about 15% of the total biomass and was a value of 123 kg/ha.

The higher biomass for flannelmouths resulted primarily from their larger body size. Larger flannelmouths were more frequent in the Colorado River than in the Yampa. Also flannelmouth and bluehead densities were fairly similar in the Colorado River. But, in the Yampa River flannelmouths had much greater density than the bluehead.

Development of biologically based habitat suitability criteria made it possible to determine the relationship between flow and habitat availability. The suitability criteria were validated by the high R-square value for the regression between observed and predicted biomass values for the bluehead (0.91) and flannelmouth (0.93).

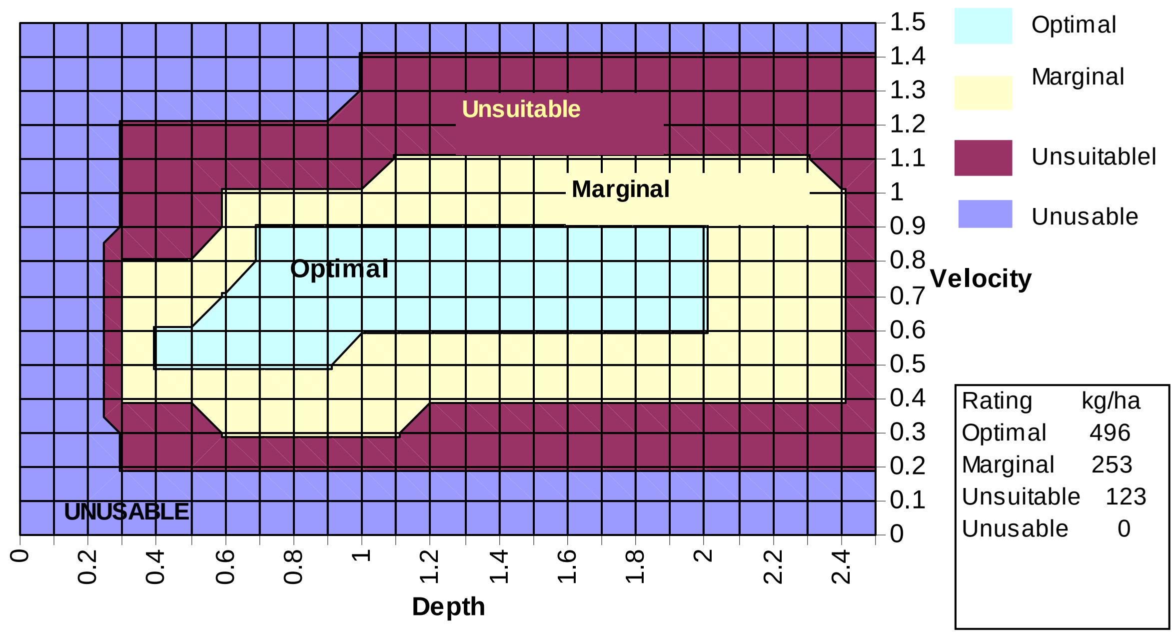

Figure 8. Flannelmouth sucker depth and velocity criteria used to model bluehead habitat availability.

HABITAT AVAILABILITY VERSUS FLOWS

Habitat availability for each of the four functional meso-habitat types (Optimal, Marginal, Unsuitable and Unusable) was calculated using the 2-D flow model data for simulated flows at each site. The habitat suitability graphs were the final product in the Meso-Habitat methodology and showed how total habitat was related to flow. The functional meso-habitat graphs were for adult (>20 cm) bluehead and flannelmouth suckers. Optimal habitat represented about 60% and Marginal habitat represents about 25% of the total biomass. The Unsuitable habitat represented about 15% of the biomass and Unusable supported zero biomass. At low flows, Unusable habitat always increased the area and percentage of blueheads and flannelmouths since both depths and velocities decreased.

– Bluehead sucker

Flows modeled at **Corn Lake** ranged from 100 to 1800 cfs. Unusable habitat decreased rapidly from 150 to 800 cfs and was fairly constant from 1000 to 1800 cfs. Optimal habitat increased with increasing flow upt to 1200 cfs. Above 1200 cfs optimal habitat increased at a slower rate. Both marginal and unsuitable peaked at near 500 cfs (Figure 9).

The range of flows modeled at **Clifton** ranged from 100 to 2000 cfs. Clifton had more total surface area than Corn Lake. There was about four ha more of the Unusable habitat at Clifton than at Corn Lake. The wider channel and higher amount of pool habitat at Clifton did not to translate to increased habitat or abundance of blueheads. The Unusable area peaked at 16 ha, remaining high at 10 ha at 1500 cfs (Figure 10). Optimal habitat increased linearly from 300 to 1800 cfs. At 1000 cfs, Optimal habitat was near six ha while Marginal habitat was also near six ha, similar to Corn Lake. Marginal habitat had an inflection point at 700 cfs. Unsuitable habitat had an inflection point at 300 cfs (Figure 10).

Flows modeled at **Lily Park** ranged from 40 to 600 cfs. At the start of the project we believed that 600 cfs would be high enough to be inclusive for making instream flow recommendations. Nonetheless, relationships between flow and the functional meso-habitat types would have been clearer if flows had been modeled up to at least 1000 cfs. Unusable habitat decreased fairly linearly from 40 (12.5 ha) to 600 cfs (six ha). Unsuitable habitat peaked at about 250 cfs and was fairly constant above this flow. Below 250 cfs, Optimal habitat availability was very low. At 600 cfs, Optimal habitat increased to two ha, which was very similar to availability on the Colorado River (three ha at Corn Lake and two ha at Clifton). Marginal habitat was near zero at 100 cfs and increased to five ha at about 500 cfs (Figure 11), which was also similar to the two Colorado River sites.

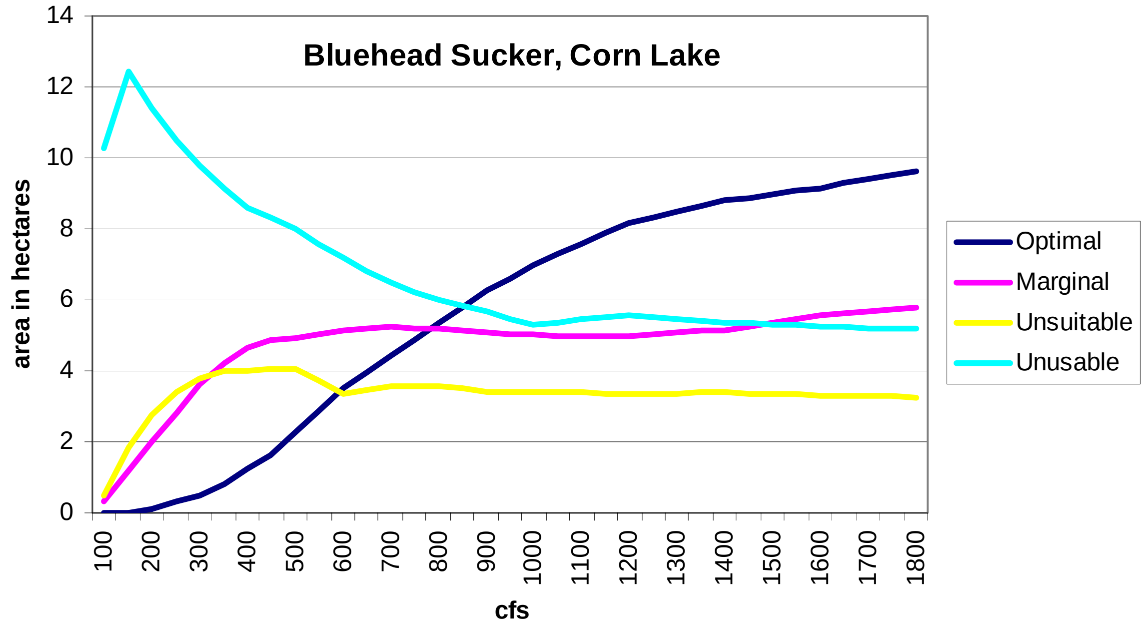

Figure 9. Bluehead sucker habitat availability at Corn Lake, Colorado River.

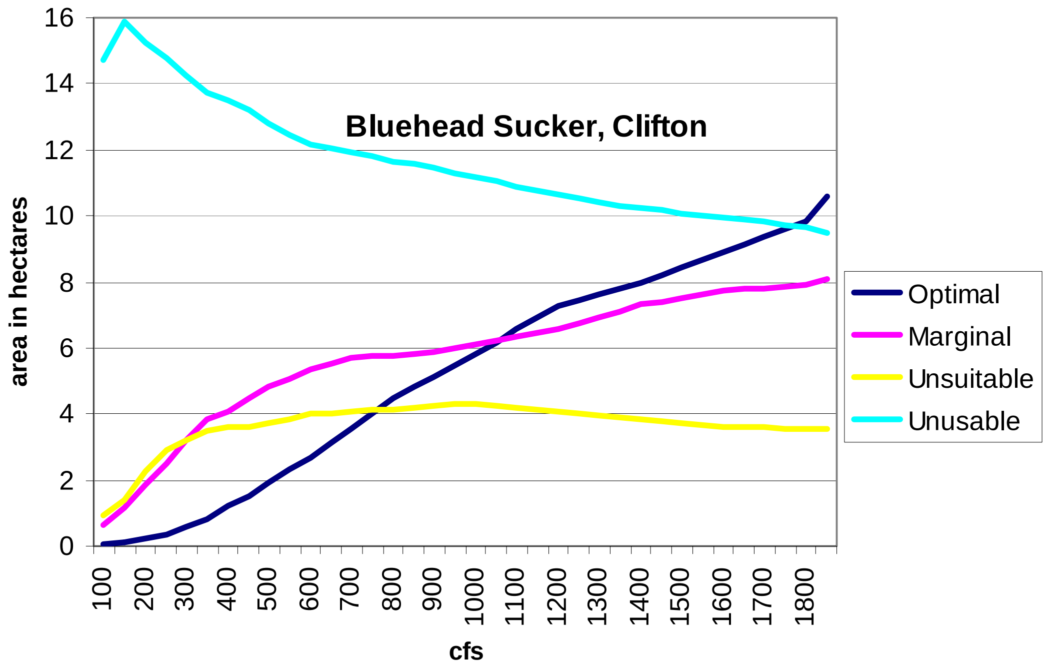

Figure 10. Bluehead sucker habitat availability at Clifton, Colorado River.

Flows modeled at **Sevens** ranged from 40 to 880 cfs. At flows less than 100 cfs nearly 100% of the river was in the Unusable habitat category. Unusable habitat was about six ha at 550 cfs. Marginal habitat peaked near 5.5 ha at 550 cfs (Figure 12). Optimal was only one ha at 600 cfs, about half that found at Lily Park and the Colorado River sites. Optimal habitat availability increased to over four ha at the highest modeled flow of 880 cfs and the rate of increase was faster above 600 cfs. The rapid increase in Optimal habitat indicated that depths and velocity increased more quickly above 600 cfs than below 600 cfs. Flows less than 250 cfs produced a very low amount of adult bluehead sucker habitat in the Marginal and the Optimal categories (Figure 12)

Flows modeled at **Duffy** ranged from 40 to 600 cfs. At 600 cfs, marginal habitat was at 3.9 ha and Optimal was less than 1 ha. Like Sevens, Duffy has a flat slope and did not appear to have high potential for a large bluehead-sucker population at flows less than 250 cfs. Unusable habitat at Duffy peaked at 125 cfs and was the most common habitat type until flows reached 500 cfs (Figure 13).

Flows modeled at **Big Gypsum** ranged from 10 to 500 cfs. These ranges appeared adequate to bracket curve breaks for both higher and lower base flows. Curve breaks for Unusable, Unsuitable and Marginal were all near 200 cfs (Figure 14). Flows less than 80 cfs provided less than 0.6 ha Optimal habitat. Wetted width at Big Gypsum was less than half that of the Yampa and Colorado rivers, so hectare per unit discharge was less.

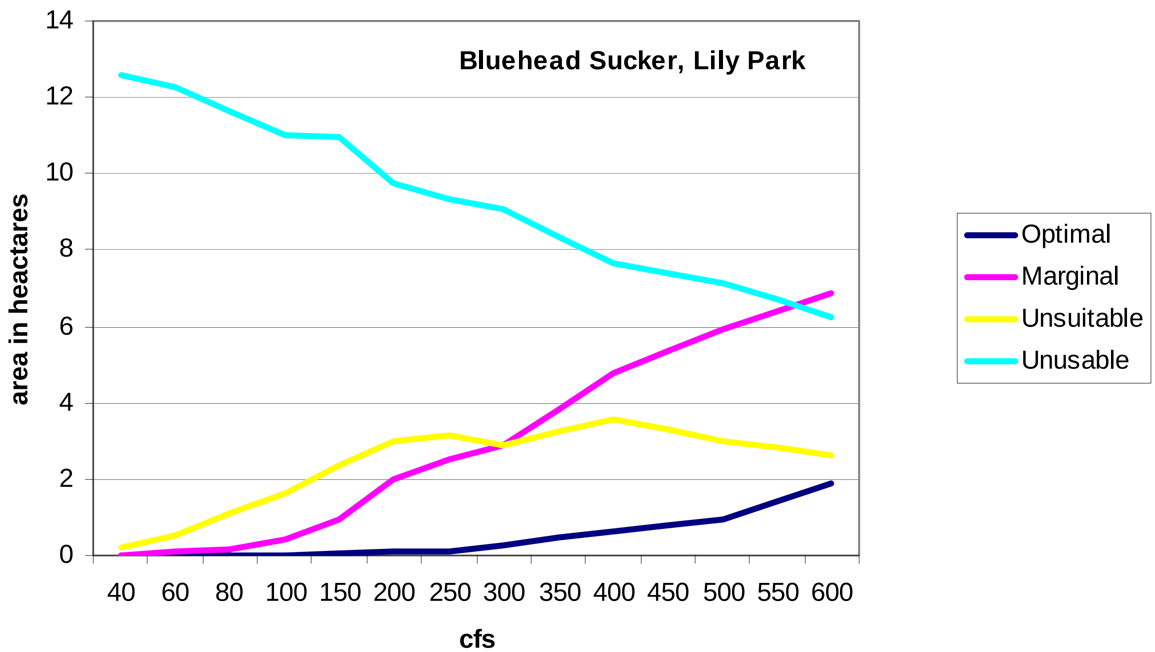

Figure 11. Bluehead sucker habitat availability at Lily Park, Yampa River.

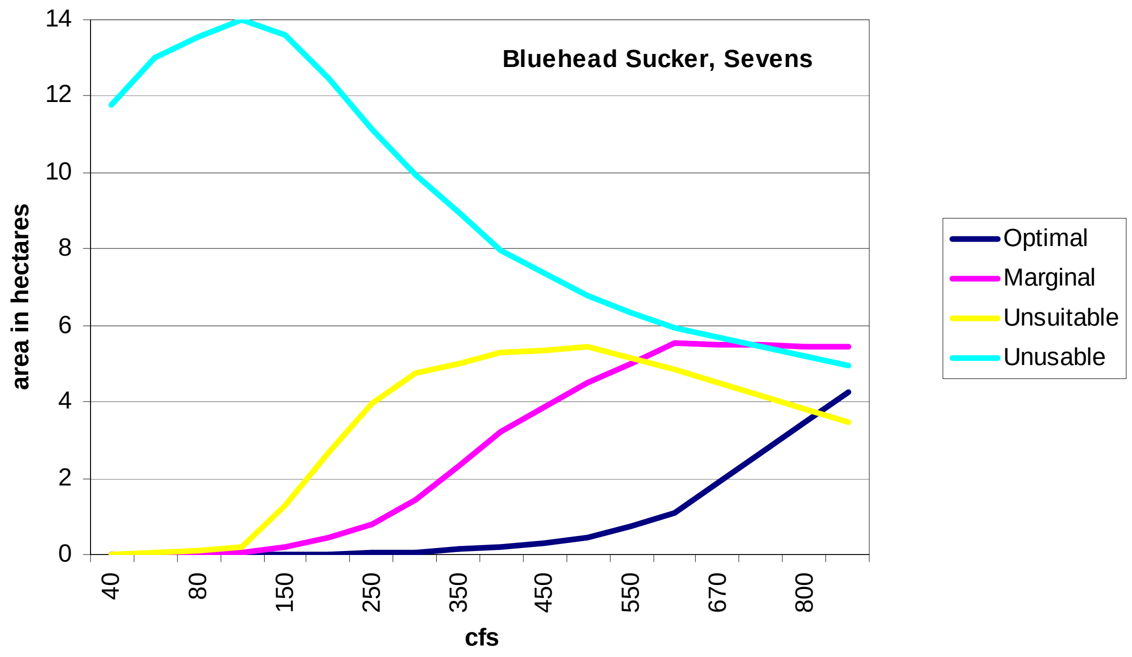

Figure 12. Bluehead sucker habitat availability at Sevens, Yampa River.

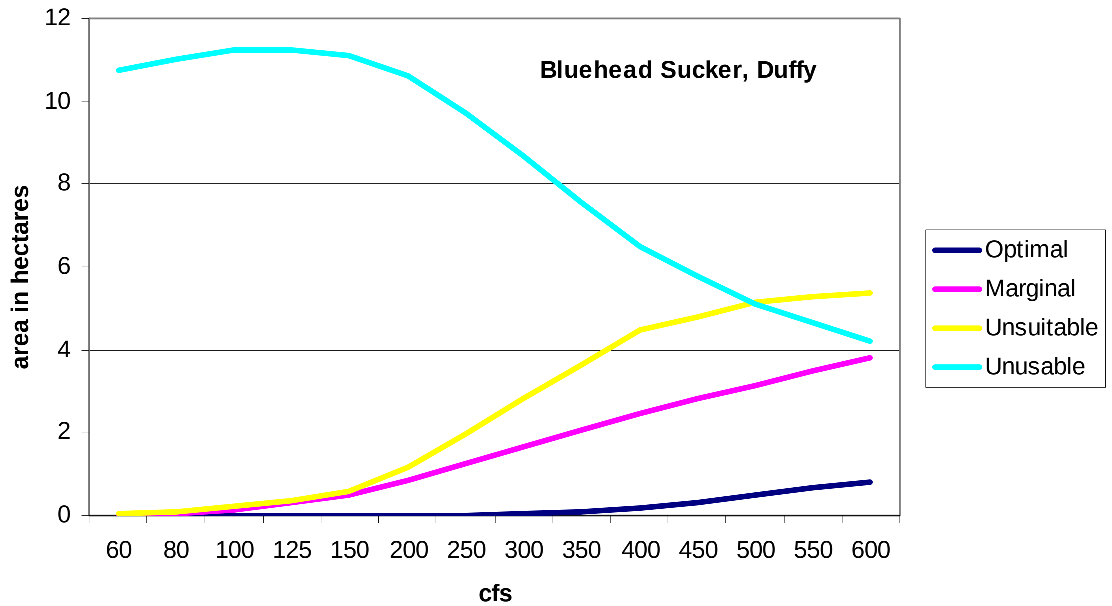

Figure 13. Bluehead sucker habitat availability at Duffy, Yampa River.

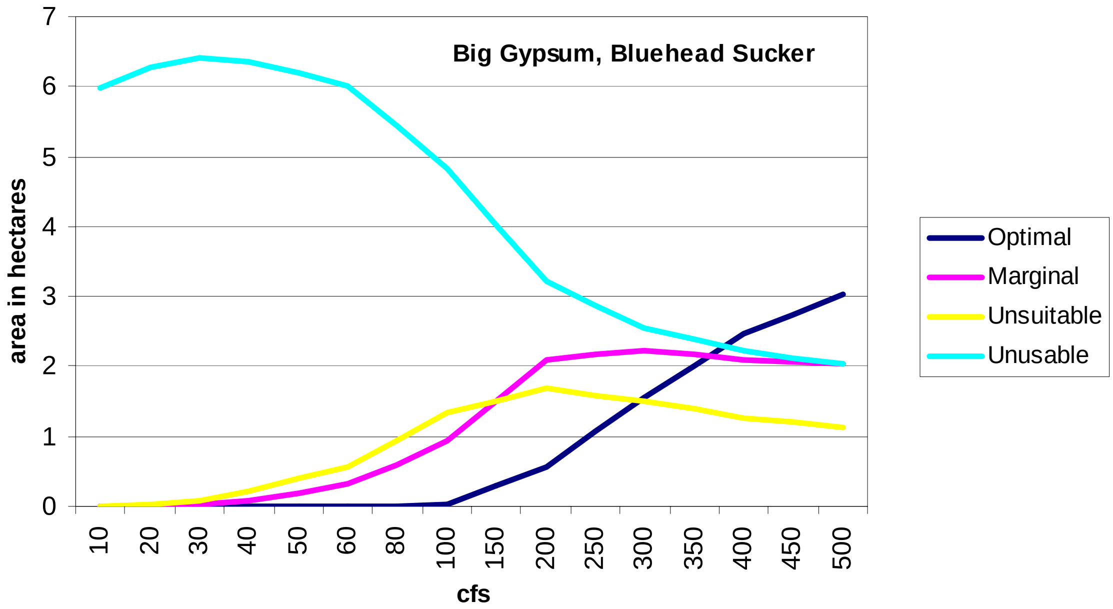

Figure 14. Bluehead sucker habitat availability at Big Gypsum, Dolores River

When habitat availability (Figures 9 to 13) in hectares is multiplied by the mean biomass associated with each habitat type (Optimal, Marginal and Unsuitable) the product represents a biomass projection for each simulated flow. The mean biomass for blueheads was zero in Unusable habitat (polygons), 31 kg/ha for Unsuitable polygons, 116 kg/ha in Marginal and 243 kg/ha in Optimal polygons (Figure 7). The biomass projection curve was therefore a composite of the four functional meso-habitat types, which simplified comparisons of habitat availability between sites.

The Big Gypsum site had higher projected biomass at lower flows than the other sites (Figure 15). Big Gypsum had a much narrower wetted width (18.5 m) and a fairly high bed slope of 0.15%. The smaller channel meant suitable depths and velocities were achieved at lower flows. Big Gypsum also had the highest projected bluehead biomass of 121 kg/ha at 500 cfs (Figure 15). There was a curve inflection in the Big Gypsum projection curve at 80 cfs and another at 200 cfs. Below 80 cfs, bluehead biomass was computed to be less than 5 kg/ha, which was near the flow and biomass observed during data collection.

The Corn Lake site had the highest projected biomass for flows over 250 cfs for the large rivers (Figure 15). Corn Lake has a narrowest stream width (48 m) of the Colorado and Yampa River sites and a higher bed slope of 0.15%. Since discharge equalled width x depth x velocity, the narrower width at Corn Lake produced higher mean depth and/or velocity values for the higher range of flows. The Corn Lake bluehead biomass curve had its steepest slope below 600 cfs. At base flows of near 1000 cfs, biomass at Corn Lake was projected to be near 115 kg/ha. Corn Lake was sampled during three years and bluehead biomass was observed to be near 110 kg/ha at base flows of near 900 to 1000 cfs.

Lily Park had the highest projected biomass of blueheads at flows less than 250 cfs (Figure 15). The higher mean bed slope (0.2%) accounted for more biomass potential at lower flows than at Corn Lake. The projected biomass curves at Lily Park and Corn Lake were very similar, which meant physical habitat was very similar for these two sites. The most obvious physical difference between these two sites was the level of their base flows. Given similar base-flow scenarios, the two sites were expected to have similar bluehead population characteristics. The deeper and faster habitats and larger-sized bluehead suckers, common at Corn Lake, were lacking at Lily Park. In 2001 the bluehead biomass estimate was about 32 kg/ha at Lily Park.

The Clifton site had the third highest predicted bluehead biomass for flows from 100 cfs to 600 cfs among the large rivers studied. Wetted width (60 m) and mean bed slope (0.2%) were also high at Clifton. Even though bluehead population characteristics were nearly identical between Clifton and Corn Lake, biomass projections were less at Clifton because of higher total surface area there. The greater amount of off-channel or backwater habitat at Clifton was found to be unusable habitat for adult blueheads. Figure 15 indicates that at a flow of 600 cfs, bluehead biomass was expected to be very similar for Clifton, Sevens and Duffy.

Sevens and Duffy had similar wetted widths of 60 m and 68 m respectively and the lowest mean bed slopes (0.05% and 0.06% respectively) of the six study sites. The flatter nature of the two sites was reflected in a reduced amount of bluehead potential. At 400 cfs, the bluehead biomass was projected to near 35 kg/ha. It quickly dropped to six kg/ha at a flow of 150 cfs for both sites (Figure 15).

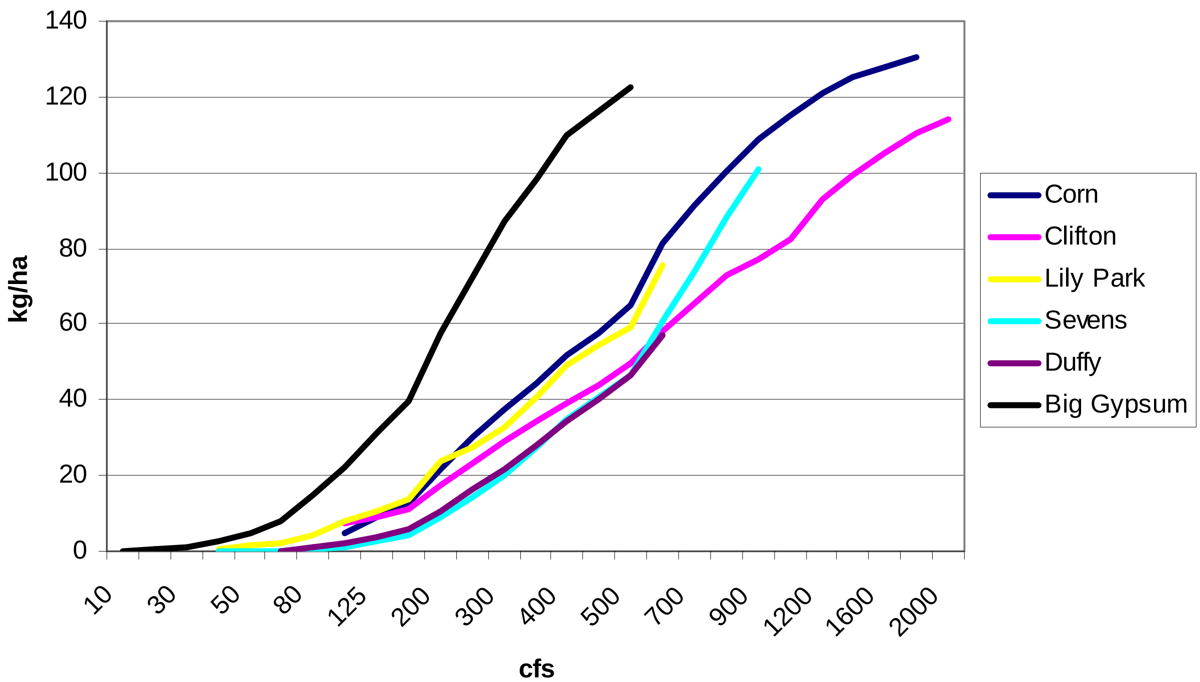

Figure 15. Projected biomass (kg/ha) of blueheads based on habitat availability over a range of simulated flows.

The projected adult bluehead biomass was regressed against the measured biomass for all stations with data except for Duffy. Duffy was excluded because non-hybridized blueheads were very rare at that site, a condition amplified by predation and not due strictly to habitat availability. Measured biomass was the kg/ha of blueheads determined by fall electro-fishing. To make the comparison between measured and predicted biomass, it was necessary to select a flow that represented the base flow for that year's sample. Some years have higher base flows than others, but the minimum flow likely does not set carrying capacity for the entire year since it only occurs for a singe day (Table 19). The median flow (177) had an even number of days above and below this level (Table 19). The 60-day low-flow was selected as the flow to use for the comparison between measured and projected biomass. The 60-day low-flow day meant there were 59 days in the water year with less flow and 305 days with higher.

Table 18. The 1, 10, 20, 40, 60, 100 and 177 low-flow days for the Maybell, Lily Park, Palisade and Bed Rock gages for years with fishery biomass data.

1998	1	10	20	40	60	100	177
Maybell	115	170	194	280	350	500	808
Lily Park	157	210	241	340	433	540	802
1999	1	10	20	40	60	100	177
Maybell	110	176	212	247	290	362	469
Lily Park	110	210	226	274	327	400	490
Palisade	435	710	1190	1380	1510	1720	1970
2000	1	10	20	40	60	100	177
Maybell	30	50	67	113	199	275	352
Lily Park	30	70	99	125	196	303	364
Palisade	581	694	749	901	1090	1620	1880
Bed Rock	25	33	37	48	52	54	59
2001	1	10	20	40	60	100	177
Maybell	50	70	94	123	160	210	255
Lily Park	67	95	126	160	201	240	280
Palisade	477	580	690	828	927	1080	1340
Bed Rock	26	32	36	38	42	45	52

The R square value for the project versus measured biomass of 0.91 indicated that this analysis gave a good reflection of the measured data (Figure 15). The highly significant relationship was due to the wide range of flow conditions used in development of the Meso-habitat model. Flows less than 800 cfs during the base flow period were not common on the Colorado River and base flows were generally less than 300 cfs on the Yampa River. Additional data for this validation approach will become available when fish sampling is conducted at the Colorado and Yampa River sites in 2003 and when a site on the Gunnison River is added in 2005.

– Flannelmouth sucker

Flannelmouth habitat data was analyzed in the same manner described for bluehead sucker. In general, flannelmouths were found to prefer habitats with somewhat less velocity and greater depths than blueheads. Flannelmouth and bluehead density estimates were similar for the Colorado River, but biomass estimates for flannelmouths were higher because these fish achieve a larger body mass. On the Yampa River, flannelmouths had higher density and biomass estimates than bluehead sucker at all three sampling sites.

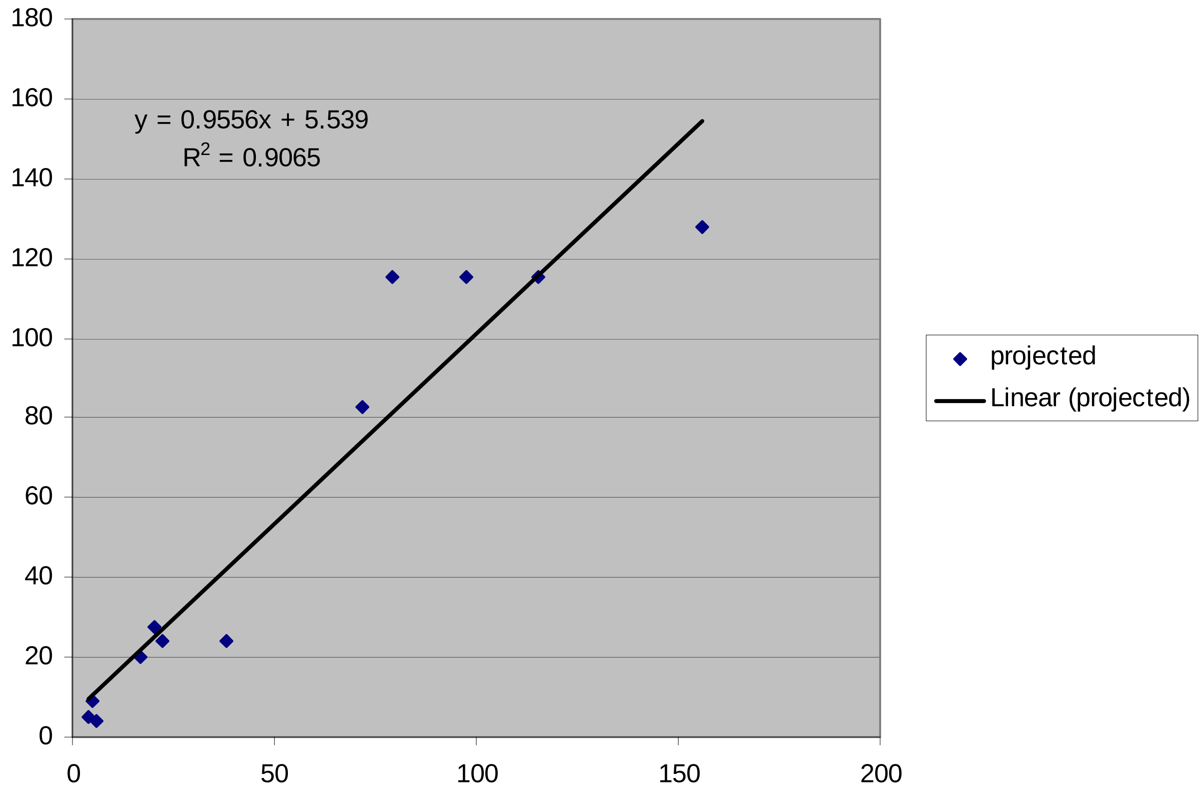

Figure 16. Projected versus observed bluehead biomass for five study sites.

The flows modeled at **Corn Lake** ranged from 100 to 1800 cfs. Unusable flannelmouth habitat was minimized near 5 ha in the flow range of 800 to 1000 cfs. Sampling on the Colorado River in 2000 and 2001 was performed at flows in the 900 to 1000 cfs ranges. These flows appeared to provide near maximum habitat for flannelmouths. Flows over 1200 cfs do not improve habitat availability for flannelmouths. Optimal habitat was highest at about 5.5 ha (1000 cfs), while Marginal habitat peaked at 7 ha at 1200 cfs. There was an inflection of the Marginal habitat curve at 500 cfs indicating a rapid decline in flannelmouth habitat when flows drop below 500 cfs (Figure 17).

The flows modeled at **Clifton** ranged from 100 to 2000 cfs. Clifton had about 4 to 5 ha more of the Unusable category than Corn Lake at similar flows. Unusable area peaked at 15 ha at 100 cfs and was at its minimum, 10 ha, at a flow of 800 cfs (Figure 22). Optimal habitat increased linearly from 10 to 1100 cfs. At flows of 1200 to 1500 cfs, flannelmouth habitat was maximized at the Clifton station. At 1500 cfs, both Marginal and Optimal habitats were near 7 ha. Marginal habitat had an inflection point at 700 cfs and Unsuitable habitat had an inflection point at 300 cfs (Figure 18).

Flows modeled at **Lily Park** ranged from 40 to 600 cfs. Unusable habitat decreased fairly linearly from 40 (12 ha) 600 cfs (5 ha). Unsuitable habitat peaked from

250 cfs to 400 cfs. The maximum optimal habitat likely occurred at a flow higher than 600 cfs. At 600 cfs, Optimal was four ha and Marginal was five ha. At 600 cfs Lily Park was very similar in habitat availability to both Colorado River sites. Below 200 cfs, Marginal habitat decreased and Optimal habitat became rare. Below 100 cfs Marginal habitat was very poor and Optimal was near zero (Figure 19).

Flows modeled at **Sevens** ranged from 40 to 880 cfs. At flows less than 100 cfs, nearly all habitat was in the Unusable category at 12 to 14 ha. Unusable habitat was below four ha at flows over 600 cfs. Marginal habitat peaked near 6 ha at 600 cfs (Figure 20). Only one ha of Optimal habitat occurred at 450 cfs. There were less than 3 ha at 600 cfs. At flows over 600 cfs, Optimal habitat increased at a faster rate and was about 6 ha at the highest modeled flow of 880 cfs. At flows less than 200 cfs, very little river area was in either the Marginal or Optimal categories for flannelmouths.

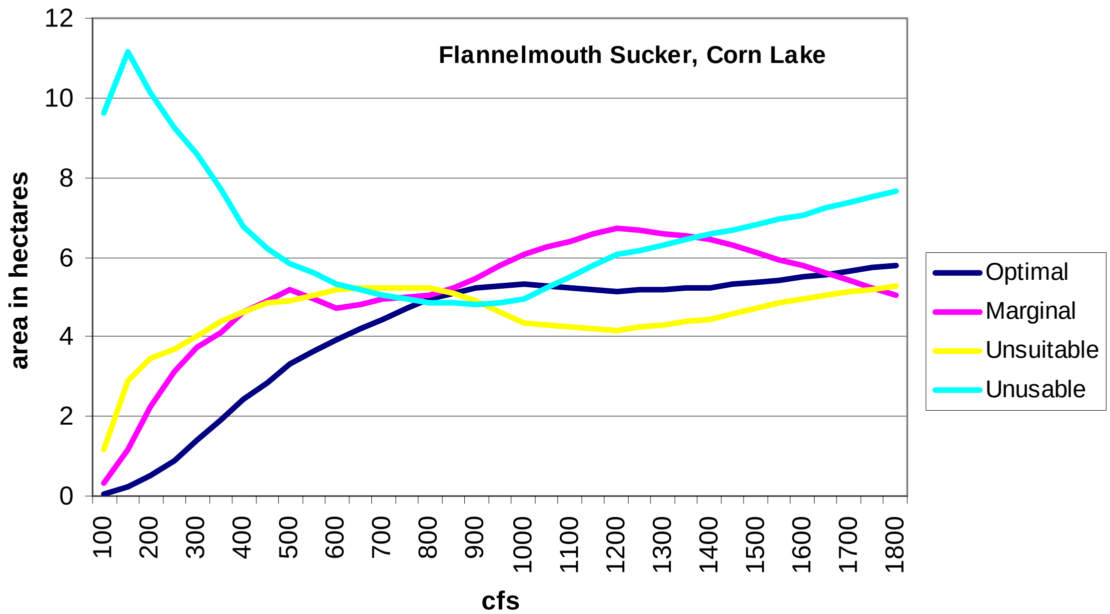

Figure 17. Flannelmouth sucker habitat availability at Corn Lake, Colorado River.

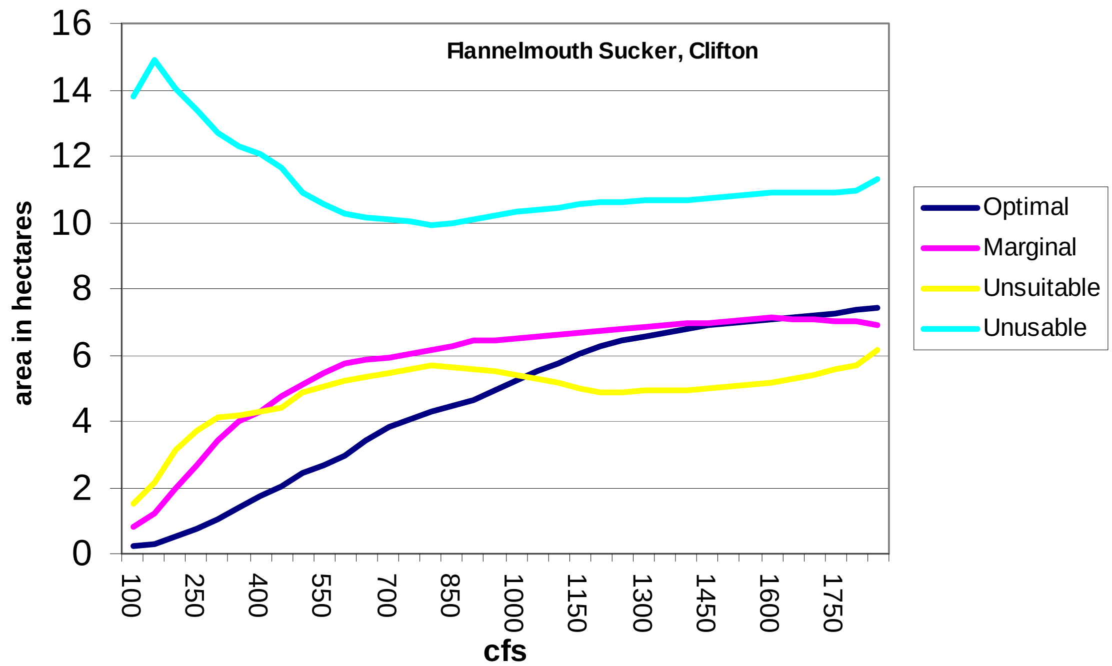

Figure 18. Flannelmouth sucker habitat availability at Clifton, Colorado River.

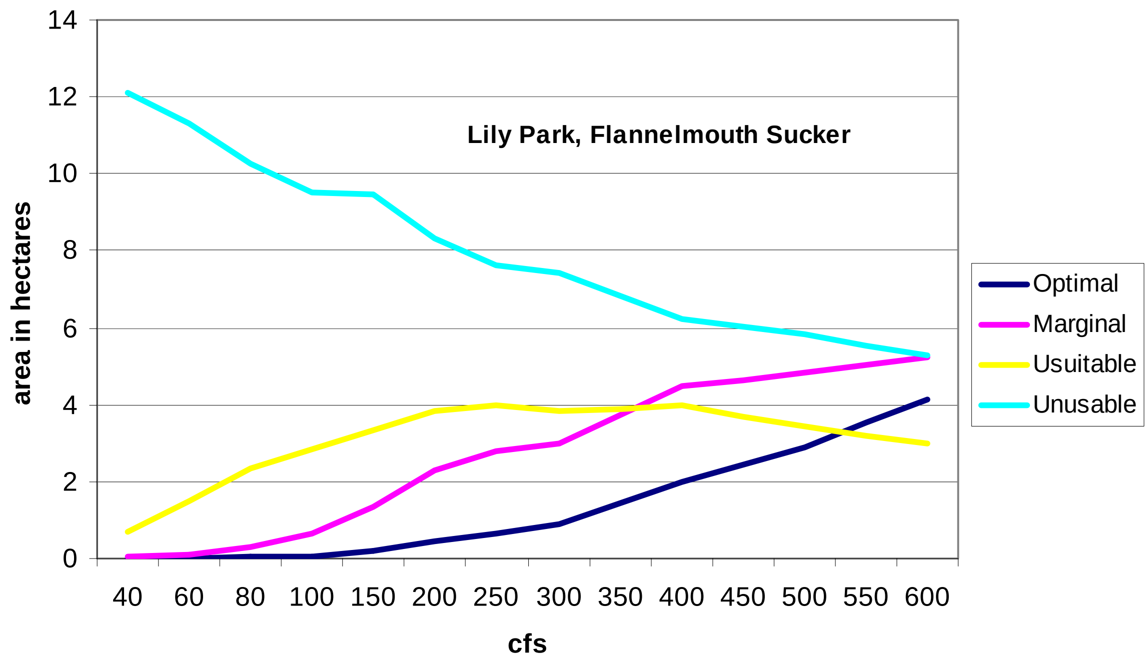

Figure 19. Flannelmouth sucker habitat availability in ha at Lily Park, Yampa River.

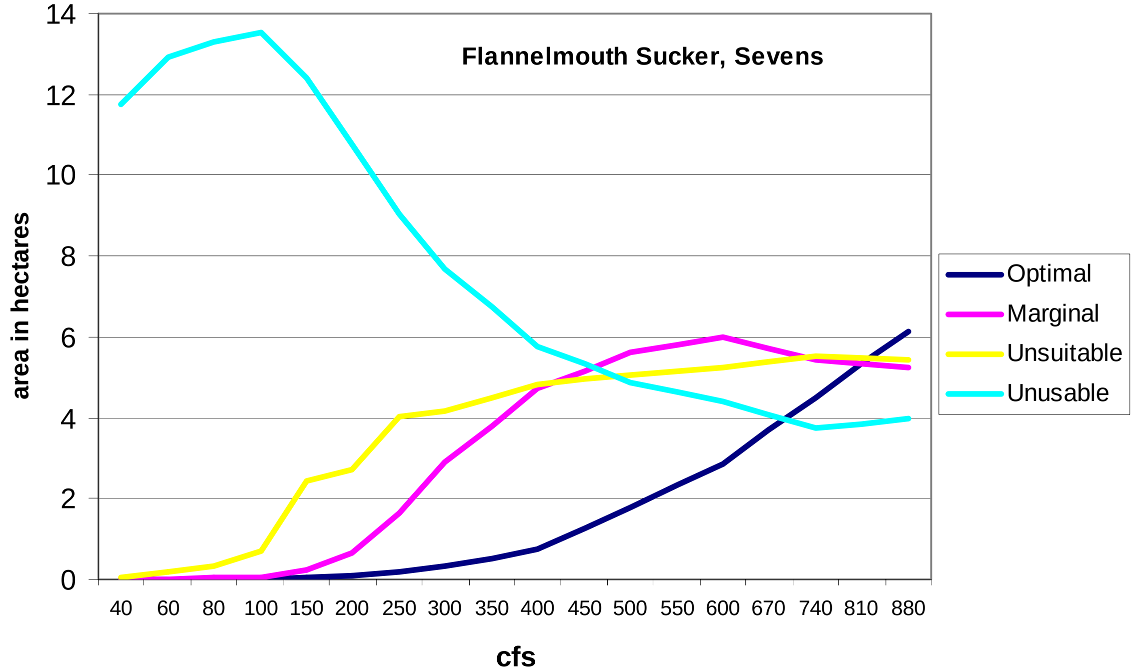

Figure 20. Flannelmouth sucker habitat availability in ha at Sevens, Yampa River

Flows modeled at **Duffy** ranged from 40 to 600 cfs. Unusable habitat at Duffy peaked at about 11 ha at 100 cfs and was the most common habitat type until flows reached 400 cfs (Figure 21). At 600 cfs unusable habitat was less than 3 ha. Unsuitable habitat was highest at 400 cfs. Marginal habitat increased slowly from 60 to 300 cfs. Optimal habitat was about 1.5 ha at 600 cfs. Duffy appeared to have the least amount of flannelmouth sucker habitat of the study sites in the lower ranges of flows

Flows modeled at **Big Gypsum** ranged from 10 to 500 cfs. Unusable habitat dropped from a high of 6 ha to about 1.7 at 150 cfs. Optimal habitat increased steadily from 100 to 550 cfs (Figure 22). Flows over 150 cfs did not improve marginal habitat. Flows less than 80 cfs did not provide optimal flannelmouth habitat. Flows less than 40 did not provide marginal habitat. The Big Gypsum station was sampled at a flow near 60 cfs, but flows can get well below 60 cfs in some years.

Adult flannelmouth (>20 cm) biomass was projected for each simulated flow by multiplying habitat availability (ha) times the mean biomass for each type. Unusable habitat had a zero biomass value. Unsuitable had a mean biomass of 123 kg/ha. Marginal had a mean biomass of 253 kg/ha Optimal was 496 kg/ha. The projected biomass curve was a composite of these four functional meso-habitat types.

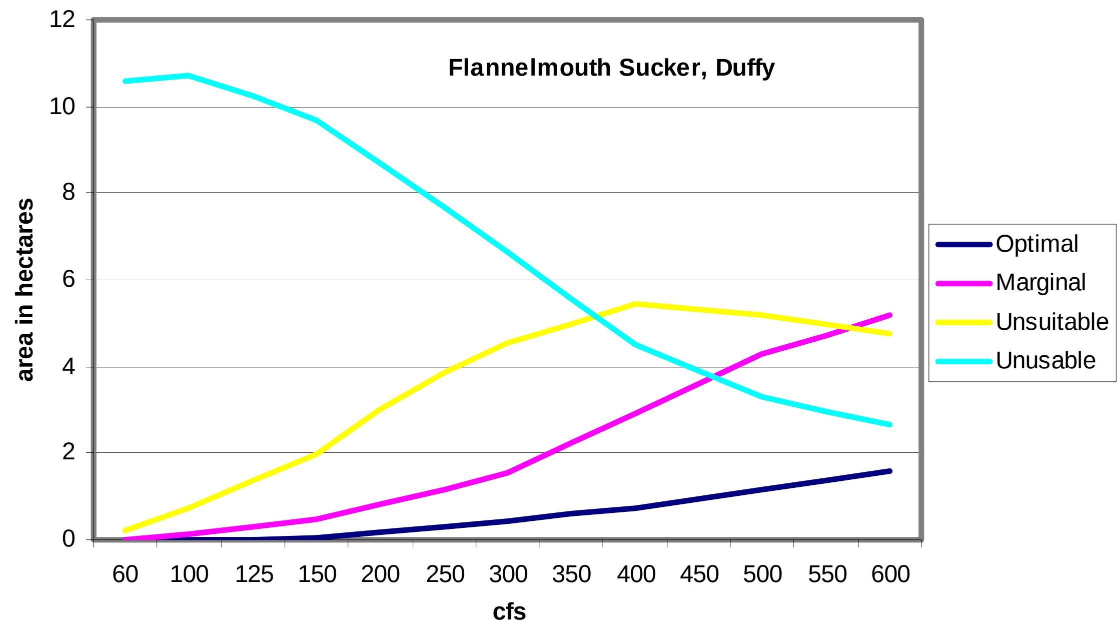

Figure 21. Flannelmouth sucker habitat availability at Duffy, Yampa River.

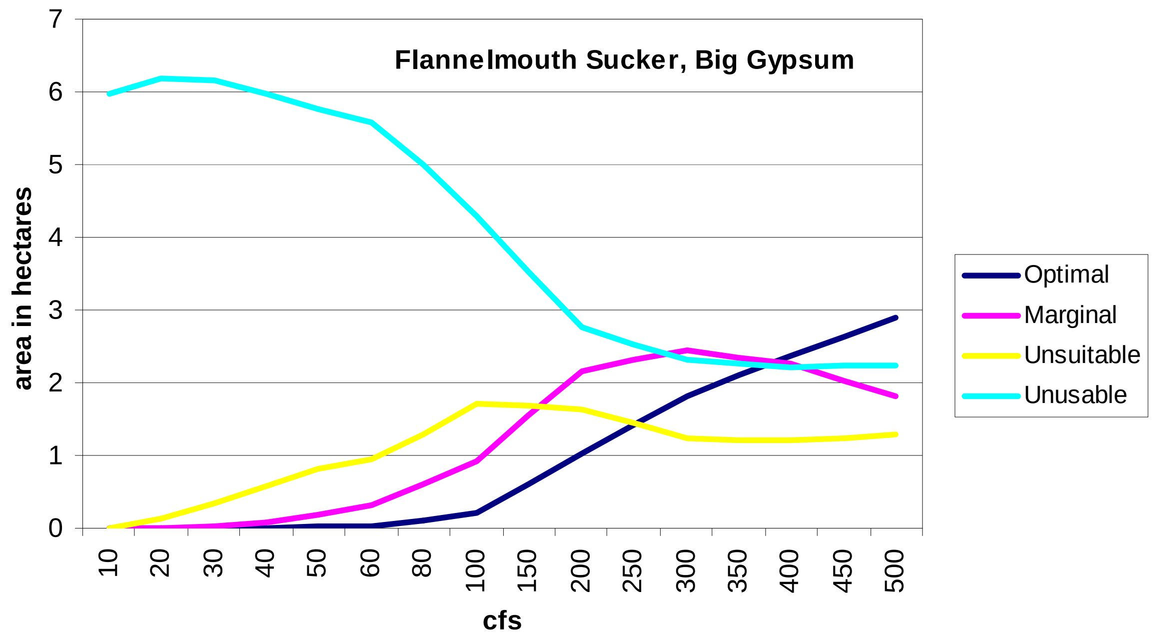

Figure 22. Flannelmouth sucker habitat availability at Big Gypsum, Dolores River.

Big Gypsum had a higher total biomass per hectare for all sites at a given flow due to its smaller channel. The slope of the flannelmouth biomass increased slowest from 10 to 60 cfs and the increase was fastest from 60 cfs to 150 cfs. At 150 cfs, the adult flannelmouth biomass was 150 kg/ha (Figure 23). Below 80 cfs the Big Gypsum site had less than 5 kg/ha. Big Gypsum had a higher projected flannelmouth biomass than the Colorado River. At 400 cfs, the projected biomass at Big Gypsum was 250 kg/ha, compared to 225 kg/ha and 200 kg/ha at flows of 1800 cfs at Corn Lake and 2000 cfs at Clifton respectively. Typically base flows are less than 60 cfs on the Dolores River. At 60 cfs, flannelmouth biomass was about 31 kg/ha and about 23 kg/ha at 50 cfs.

Corn Lake had the highest projected biomass for flows between 250 cfs and 500 cfs (Figure 23). At base flows of near 1000 cfs, biomass at Corn Lake was projected to be near 210 kg/ha. There was an inflection of the biomass curve at Corn Lake at 500 cfs. Above 500 cfs the biomass curve increased at a lower rate.

The **Clifton** site had the lowest adult flannelmouth biomass curve for flows over 300 cfs (Figure 23). Flows over 1000 cfs did not increase habitat potential for adult flannelmouths. The adult flannelmouth biomass curve for the entire 15-Mile Reach was likely intermediate to that found for Corn Lake and Clifton. Corn Lake was found to have a below-average mean width and Clifton had an above-average mean width. We defined Mean width as a geomorphic feature influencing velocities. Velocity strongly influenced habitat suitability. Corn Lake represented the upper limit and Clifton the lower limit regarding to flannelmouth habitat potential in the 15-Mile Reach.

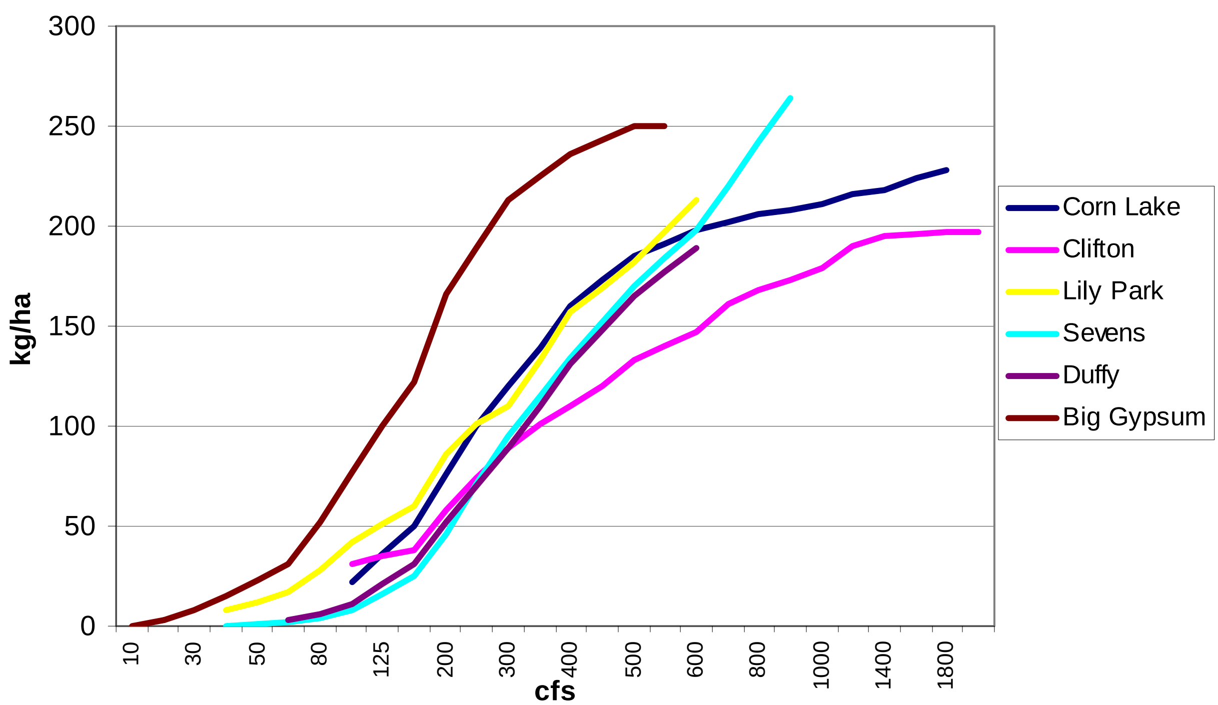

Figure 23. Project flannelmouth biomass as a function of flow for all study sites.

The **Lily Park** site had the highest potential for flannelmouth habitat at flows less than 200 cfs (Figure 23). The geomorphic characteristics that stood out at Lily Park were the narrower channel, higher bed slope and larger sediment size. The narrower channel and higher bed slope resulted in higher depths and velocities at lower flows. Corn Lake had a very similar projected biomass compared to Lily Park at flows from 150 to 500 cfs, indicating similar geomorphic characteristics between the sites. These data also suggested that given similar flow scenarios, the flannelmouth populations would be similar for these sites.

Sevens and **Duffy** have nearly identical flannelmouth curves for projected biomass (Figure 23). The geomorphology of these sites was similar with a lower bed slope and a wider wetted width in the lower flow range (>600 cfs). At about 600 cfs, biomass potential, based on the availability of the four functional meso-habitat types was nearly identical at the Sevens, Duffy, Lily Park and Corn Lake sites. At flows over 600, optimal velocities were being exceeded at Corn Lake and the curves flattened out. But at Sevens and Duffy, it appeared that flows of 400 cfs to 600 cfs were required to achieve the velocities that produced optimal habitat.

The projected biomass for the 60-day low flow was regressed against the measured biomass for all stations for which data was available except for Duffy. Duffy was excluded because pure flannelmouths are very rare at this site, a condition due to hybridization and predation, not due to habitat availability.

DISCUSSION

Habitat Modeling, Flow Needs for Native Sucker

This study established baseline fishery data at six study sites and used this data to develop habitat suitability criteria and model validation. Another value of the fishery data was that it established consistency in the fish community through time. Consistency in community structure within each site strongly suggested a dynamic relationship among the sites' habitats. Consistency in fishery characteristics also promoted confidence that habitat modeled in one year not only represented both the geomorphic and fishery aspects for that time period, but that it also represented conditions through time.

The 2-D flow modeling quantified habitat conditions at each study site so that habitat availability could be directly correlated to fish biomass. The main variable of habitat availability was flow. Differences in habitat appeared to explain several differences in fish community composition and biomass among sites and between rivers. A significant correlation was found for the six study sites between habitat availability and abundance of the native blueheads and flannelmouths. The two sites in the 15-Mile Reach had the highest base flows, the highest optimal habitat availability and the highest density and biomass of total fish and native fish. Lower base flows and lower native sucker habitat and biomass were found at Sevens, Duffy and Big Gypsum.

Both blueheads and flannelmouths were found to have strong preferences for habitats with minimum velocities of above 0.5 m/s. In the Colorado River, habitats with currents over 0.5 m/s were abundant in the flow range of 800 to 1000 cfs. In the Yampa River base flows were typically less than 250 cfs and lower velocity runs were the dominant habitat between flows of 150 to 250 cfs.

Because a significant relationship was found between available habitat and bluehead and flannelmouth biomass, species abundance was used as a relative indicator of the habitat abundance. In the 15-Mile Reach, blueheads and flannelmouths had similar species composition and similar amounts of habitat availability. In the Yampa River flannelmouth biomass and habitat was much higher than it was for blueheads.

Bluehead population estimates made in 2000 and 2001 in the 15-Mile Reach were near 1200 fish per km and 100 kg/ha. Anderson (1997) reported fishery population data for three sites upstream of the 15 Mile-Reach. Species composition (30 to 37%), length-distribution and density estimates (90 to 97 kg/ha) made for blueheads near Una and Parachute were very similar to that in the 15-Mile Reach. Generally, flows during the irrigation season (April to November) were considerably higher upstream of the Roller Dam due to the amount of water that was being diverted (1200 to 1600 cfs). Bluehead sucker standing stocks were similar above and below the Roller Dam. That indicated similar habitat quality despite less flow in the 15-Mile Reach. The 2-D habitat analysis found only minor increases in bluehead habitat availability when flows increased above 1400 cfs.

Osmundson (1999) reported catch rates of blueheads (fish per minute of electro-fishing) in the Colorado River from samples made in 1994 and 1995. The catch rate in the 15-Mile Reach, Strata 9 (2.2 fish/min) was higher than upstream of the Roller Dam at Strata 10 near Una Bridge (0.8 fish/min) and at Strata 11 at Parachute (1.5/min). Osmundsons' fishery data indicated blueheads were more numerous in the 15-Mile Reach. This suggested bluehead habitat availability was also greater, even with reduced flows compared to above the Roller Dam.

The flannelmouth estimates made in 2000 and 2001 in the 15-Mile Reach were approximately 1600 fish per km and 220 kg/ha. These estimates were very similar to Anderson's (1997) reported density estimate of about 1750 flannelmouth / km at Parachute in 1994 and 1995. The flannelmouth biomass of 185 kg/ha (Anderson 1997) was lower than found in this study because it was calculated using mean channel width and not wetted width. Species composition of flannelmouths in the 15-Mile Reach was also similar to Parachute (34 to 40%) (Anderson 1997). The 2-D modeling found increasing flannelmouth habitat with increasing flows up to about 1200 cfs. Therefore, much higher flows at Parachute apparently have not resulted in a much larger population size of the flannelmouth.

Fish sampling data in the Colorado River from 1994 and 1995 by Osmundson (1999) found flannelmouth catch rates were highest in the 15-Mile Reach. Flannelmouth catch rates in Strata 9 or the 15-Mile Reach were about 1.6 fish/min compared to about 0.5 fish/min at Strata 10 (Una Reach) and about 1.2 fish/min at Strata 11 (Parachute) (Osmundson 1999). Osmundson's fishery data was fairly consistent with Anderson's (1997) and corroborated the 2-D modeling data that found that maximum flannelmouth habitat was provided by flows of 800 to 1200 cfs.

The 2-D habitat modeling showed that the 15-Mile Reach appeared to be near the carrying capacity of habitat for adult blueheads and flannelmouths in the flow range experienced during the study period (800 to 1000 cfs). The fishery data showed an abundance of juvenile blueheads and flannelmouths indicating habitat for smaller fish (<15 cm) was also available. Both the habitat modeling and the fishery data indicated that habitat for these native fish was not limiting or problematic.

Pitlick and Cress (2000) found that the Colorado River near Una and Parachute had a slope and bankfull width very similar to the 15-Mile Reach. Given similar channel morphology (width and slope) at particular sites, modeled habitat availability was also similar. Therefore the meso-habitat curves and flow recommendations determined for blueheads and flannelmouths in the 15-Mile Reach most likely were transferable to above the Roller Dam, since channel characteristics were similar.

Discharge (Q) equalled width x mean depth x mean velocity, so the same flow in a narrower channel meant either depths or velocities were increased. This was obvious at the Big Gypsum site, which had the narrowest stream width and was able to provide higher optimal bluehead habitat at lower flows. For the large rivers, Corn Lake had the narrowest width for flows less than 600 cfs and had the highest percent of optimal bluehead habitat in the lower end of the modeled flows.

Other geomorphic features such as bed slope directly influenced mean depths and velocities. Sevens and Duffy had the lowest bed slopes of the study sites and the highest percentage of Unusable native sucker habitat at flows less than 400 cfs. Lily Park had the highest bed slope and maintained habitats with swifter currents at lower flows than did Sevens and Duffy. Higher bed slope and a narrower width likely explained the higher fish productivity at Lily Park compared to Sevens and Duffy.

The 2-D habitat model showed that Sevens and Duffy required a flow of 400 cfs to yield an equal amount of bluehead habitat as Corn Lake at a flow of 250 cfs. This was partially due to Sevens and Duffy being wider than the Colorado River sites. The Colorado River was a larger river than the Yampa in terms of drainage area and mean annual flow. The drainage area at the Cameo gage (Colorado River) was 8050 square miles. Mean annual flow was 3897 cfs and median peak flow was 17900 cfs (68 years). For the Yampa River Maybell gage (86 years), the drainage area was 3837 square miles, the mean annual flow was 1568 cfs and the median peak was 9880 cfs (86 years).

Piktlick (1999) reported the Colorado River channel had narrowed slightly and was more or less in equilibrium with the present flow and sediment transport regimes. Pitlick (1999) also found that, in general, base flows in the Colorado River were somewhat higher than natural base flows. The Yampa River likely had the reserve conditions. The channel upstream of Cross Mountain appeared to be unstable as indicated by a poor riparian zone along most of the river. Also current base flows were greatly reduced, primarily for irrigation use, compared to pre-development flows (CWCB report, htpp://cdss.state.co.us)

The 2-D habitat model appeared to be in sync with fishery data collected under a variety of flow conditions. The Yampa River represented fishery data from a community exposed to lower flow conditions than in the 15-Mile Reach. The Lily Park site had similar channel widths and slopes as the 15-Mile Reach, so differences in habitat availability were mainly due to the flow differences. Also, the first two years of fishery data at Sevens and Duffy were collected when summer flows were near 250 cfs (1998 and 1999), but flows were noticeably less during the second two years (2000 and 2001).

Sevens and Duffy had about 20% of the bluehead habitat at a flow of 250 cfs. Sevens had about 21% of the biomass of the 15-Mile Reach (900 cfs). Lily Park (250 cfs) had about 28% of the projected habitat availability and had 39% of bluehead biomass as the 15-Mile Reach (900 cfs). The 2-D model for Duffy (250 cfs) indicateed that bluehead habitat availability was much higher than reflected by the existing biomass, which was likely depressed by predation and hybridization (Anderson 2002). The 2-D modeling results indicated that bluehead sucker biomass in the 15-Mile Reach would decrease to about 20 to 40% of the current conditions if 250 cfs were to become the long-term mean flow.

At Lily Park, the flannelmouth density estimate was very similar to the 15-Mile Reach (near 1670/km), but Lily Park's flannelmouth biomass was 64% of that at Corn Lake. It appeared that the higher gradient at Lily Park was beneficial for maintaining flannelmouth numbers at the lower flows. Biomass was less at Lily Park because large flannelmouths were less frequently captured at Lily Park. At Lily Park, 42% of flannelmouths were larger than 40 cm and 3% were over 45 cm, but at Corn Lake 73% were larger than 40 cm and 30% were over 45 cm. Apparently, the shallower and slower habitats at Lily Park were not suitable for supporting the larger-sized adult flannelmouths.

The difference in size structure was even more pronounced at the Dolores River site, where the largest flannelmouth collected was 31 cm. This differential in size was also observed for both blueheads and roundtail chubs with there being high numbers of larger-sized fish at Corn Lake, fewer larger fish in the Yampa and even fewer in the Dolores River. Differences in fish size were observed at Sevens between the higher and lower flow periods for blueheads. During the relatively high flow year of 1999, 83% of blueheads were over 30 cm and 29% were over 35 cm. This was 45% over 30 cm and 9% over 35 cm during the low-flow year of 2001. Mean lengths of blueheads were high at Duffy because fish under 35 cm were likely removed by predation during the study period (Anderson 2002).

The lack of larger-sized (>35 cm) fish in a population was probably due to lack of adult fish habitat, which was likely an attribute of poor flow conditions. The fish community of the Dolores River in 2001 consisted mostly of blueheads and flannelmouths sucker less than 20 cm. The lack of adult-sized fish clearly indicated a lack of adult fish habitat for these species.

Habitat Composition and Diversity

Regressions between habitat and fish productively were significant among the six study sites. In general it appeared that sites with high amounts of riffle habitat had higher total fish biomass and higher bluehead biomass. Riffles were the primary meso-habitat for most aquatic macroinvertebrates. The availability of riffle habitat was a good indicator of general productivity of a river.

Sites with higher amounts of deep-run and deep-pool habitats had higher amounts of catfish, carp and white suckers. Not all species, however, displayed a direct relationship between biomass and a meso-habitat type (roundtail chub). Also, with only six study sites in the project, sample size was rather small for an in-depth analysis. Other factors such as variability in predation and hybridization rates between sites could not be included in a regression analysis. But even given these factors the analysis indicated habitat was a major influence on native fish biomass and composition.

The Shannon-Weaver diversity index provided a means of comparing habitat complexity at each study site, with higher habitat diversity suggesting improved conditions for maintaining fish community diversity. Habitat diversity (Shannon-Weaver) peaked at 1000 cfs at Clifton and at 1200 cfs at Corn Lake. Maximum meso-habitat diversity occurred in the same flow range that produced maximum habitat for adult native suckers. Flows of 1000 to 1200 cfs were also the near the flows when fish were sampled, and numerous age-0 and age-1 native suckers, roundtail chub and speckled dace were collected. These collections of young fish also indicated 1000 to 1200 cfs resulted in suitable habitat all life stages.

Since flows were not modeled above 600 cfs for the Yampa River the flow associated with peak habitat diversity was not identified. However, at 600 cfs Lily Park had the greatest habitat complexity (2.22) followed by Sevens (1.92) and Duffy which had the least complex habitat (1.73). This order of habitat complexity matched the order of fishery diversity found on the Yampa River. The consistency in species composition and size structure observed at Sevens and Duffy from 1998 to 2000 was not maintained in 2001 when flows and habitat complexity were less.

Field Observations, Flow Needs of Native Fish

There were some field observations made at Lily Park during electro-fishing that confirmed some of the 2D habitat modeling results for the Yampa River. In 2000 there was a large difference in flows between field trips (Anderson 2001). During trips when flow was less than 120 cfs, flannelmouths were collected from backwater habitats that were not occupied at flows above 120 cfs (Anderson 2002). These observations showed that flannelmouths were compelled to occupy non-preferred habitats when flow was less than 120 cfs. The electro-fishing raft had to be dragged in Lily Park at flows less than 120 cfs and during these occasions it was observed that fish were confined to the deepest remaining water pockets. The concentration of large numbers of fish in shallow and confined habitats made them highly vulnerable to capture by us, avian and terrestrial predators.

Anderson (2002) reported a dramatic decline in two native fish species in the Yampa River fish community in 2001. The speckled dace and the mottled sculpin were both common in 1998 and 1999 at Duffy and Sevens. Both are small-bodied fish that occupy shallow habitats. Small-bodied fish should be less susceptible to population crashes during low flow events, and these fish likely could have maintained viable populations if low flows were the only factor. The Dolores River population was comprised mostly of native species, but the vast majority were small, less than 20 cm length. The Dolores River did not have the same burden of nonnative predators as the Yampa River.

The disappearance of dace and sculpin in the year 2001 was concurrent with an increase in the number of smallmouth bass. Anderson (2002) considered the shifts in these species to be connected. As flows fell below a certain threshold (as experienced in both 2000 and 2001), velocities were reduced in virtually all riffles making them suitable habitat for YOY smallmouth bass. YOY bass were not observed in riffles during the field surveys in 1998 and 1999. This shift in species composition occurred during years when stream flow was less than 120 cfs for most of the summer. When riffle habitats were unsuitable to maintain small-bodied fish like speckled dace, they become unusable for large-bodied fish bodied like blueheads.

Speckled dace on the Colorado River were found to comprise 72% of the catch from shallow riffles (Miller et al. 2003). The next most common fish in riffles were sand shiners at 9%, juvenile flannelmouths 6% and juvenile blueheads were 3 percent (Miller et al. 2003). Miller et al. (2003) made density and biomass estimates for small-bodied fish in the 15-Mile Reach using depletion sampling. Their estimate for speckled dace was 2.36 dace per meter square of riffle. This value multiplied by the area of riffle meso-habitat from the 2-D modeling at 1000 cfs for Corn Lake and Clifton resulted in a projected speckled dace density over 15000 dace/km in the 15-Mile Reach. If 2.36 dace/km is somewhat valid for the Yampa River riffles, based on riffle habitat area at 200 cfs, the projected speckled dace numbers 4500/km at Duffy, 1200/km at Sevens, and 4000/km at Lily Park. The speckled dace population dropped at 100 cfs to 856/km, 218/km and 1300/km for Duffy, Sevens and Lily Park respectively. Speckled dace numbers for 60 cfs were projected only for 196/km, 23/km, and 196/km at Duffy, Sevens and Lily Park respectively.

The roundtail chub was another large-bodied native fish that we attempted to model by determining its meso-habitat suitability. Significant correlations were not found between roundtail chub biomass and a meso-habitat type that could be defined by depths and velocities. Roundtail chub was a predator that occupied deep pools during the day and moved through several habitats to forage in the evening (Byers 2001). The roundtail chub, therefore, was a multi-habitat species that was found in the habitat it occupied at the time of the fish sampling. Stewart (2000) proposed an approach to characterize an analysis of adult chub habitat using habitat complexity indices such as richness and evenness. The approach was still under investigation at the time of this report, and will be examined further in the next project cycle.

The fish community of the Dolores River appeared to be highly stressed. Species composition of native fish was high, but most fish were small. Roundtail chub was the most common species and biomass was very low. These attributes appeared to be habitat and flow related. The lack of runoff flows in 2000 and 2001 may have negatively impacted productivity. Riffles and runs had large silt deposits and both forage and habitat potential seemed unnaturally low. If the Colorado River data can be used as an example of a high-quality habitat and fishery, the Dolores River data can be useful as an example of very poor quality habitat conditions. The lack of non-native piscivores, like smallmouth bass, apparently allowed young and small fish survival, but clearly there was a lack of habitat for larger individuals. Even the channel catfish was affected.

Since the construction of McPhee Reservoir, the spring runoff flows have been greatly modified. Mean monthly flows from 1985 to 2001, from the Bedrock gage, for May and June were about half of flows during the period prior to 1985. The loss of spring runoff flows, as in the Dolores River below McPhee Reservoir, appeared to be causing channel downsizing and heavy siltation deposits. A more natural native fish community would be possible in the Dolores River if a natural shape was restored to the hydrograph.

Non-Native Fish Versus Flows

The 2D habitat modeling data suggested a relationship between habitat availability, and composition and of abundance of nonnative fish. On the 15-Mile Reach common carp were the most prevalent nonnative species and channel catfish and white suckers were fairly uncommon at about 5 to 6% of the total fish over 15 cm. Common carp and white sucker were collected, primarily in backwater and deep shoreline habitats, suggesting that faster mid-channel habitats were not suitable for these species.

On the Yampa River, white sucker and roundtail chub were very rare at Lily Park. This may have resulted from a lack of reproductive and nursery habitats in this high gradient site. White suckers were very common in the Yampa River upstream of Maybell. Elmblad (2003) reported that ISMP sampling found 50% of the catch at Maybell were white suckers. This species was 62% of the catch in the Juniper area. At Duffy about 70% of the fish collected were white suckers prior to 2001. The slow flowing (pool) habitats of Duffy appeared to be ideal for all life stages of this species. In contrast, the Dolores River is an example of a river with primarily slow flowing habitats, but has no white suckers. Without white suckers in the Yampa River, native sucker species could likely maintain a much stronger presence.

White suckers and its hybrids with flannelmouths and blueheads were examined on the Yampa River in the mid 1970's. About half of the white suckers examined in the field were identified as hybrids with native sucker species (Prewitt (1977). White x flannelmouth and white x bluehead hybrids were more successful than pure native suckers in the river upstream of Maybell. This may have been a function of habitat or possibly the white sucker hybridization imparted better predation defenses, as it co-evolved with the nonnative piscivores present in the Yampa River.

Results of the four years of sampling on the Yampa and 3 years on the 15-Mile Reach strongly indicated that the magnitude of base flows was critical for maintaining a strong native fish community. It was established that native fish prefer higher velocity habitats and that nonnative fish exhibit a preference for lower velocity habitats. Backwater and shallow pool habitats had higher composition during low flow. Sunfish and white sucker populations were increased during lower base flow years. The negative impacts of smallmouth bass were less in 1998 and 1999, the years that had higher base flows. Smallmouth bass had a much higher presence at Duffy and Lily Park in 2001 than at Sevens. The lower numbers of bass at Sevens suggested that habitat was less suitable for smallmouth bass at that site.

Flows during the irrigation season may be more important for minimizing non-native nuisance species than flows during the runoff. Large numbers of smallmouth bass YOY were observed in 1998 and 1999 when runoff flows were near 10,000 cfs. It appeared that normal high runoff flows did not negatively impact this species. It will take more years sampling to provide empirical data that will help determine the relative importance of base flows versus peak flows.

Anderson (2002) speculated that Cross Mountain Canyon was a barrier to fish passage at the flows observed in the summer of 2000. Fish passage in Cross Mountain Canyon could be problematic for migrating species, e.g., channel catfish and Colorado pikeminnow at flows of less than 100 cfs.

Hawkins et al. (1997) found a low occurrence of nonnative fish in the Little Snake River during a period when flows were near zero, but did not provide data about species composition during normal flow years. Hawkins et al. (1997) suggested that native species may be more tolerant of drought flows and therefore had an inherent advantage under such condition over non-native species. The fishery data from the Little Snake and Dolores Rivers appeared to be similar. There was a high native fish composition during very low flows. The Dolores River fish community appeared to be highly stressed and unnatural. In the Yampa River, native fish versus nonnative composition varied among sites. This indicated habitat availability was also important for non-native species as well as natives.

On the Colorado River, the Clifton site had more total area than Corn Lake, but it was entirely in pool and backwater habitat. The higher availability of pool and backwater habitat was primarily utilized by nonnative species (largemouth bass, green sunfish, carp) and somewhat by juvenile native fish (i.e. roundtail chub), but not by adult native fish. Reduced flows in the 15-Mile Reach increased unusable habitat for native fish and suitable habitat for nonnative species.

Flows for Endangered Fish

Flow recommendations by the Recovery Program were much different for the Yampa and Colorado Rivers. The Recovery Program recommended a mean monthly flow of 1243 cfs during the irrigation season for an average year for the 15-Mile Reach to maintain habitat for adult Colorado pikeminnow (Osmundson 1996). The flow recommendation for the Yampa River was to maintain 93 cfs at the historic frequency observed at the Maybell gage (Modde et al 1999), i.e., the frequency of flows less than 93 cfs were not to increase compared to gage records. The contrast in flow recommendations was quite dramatic given that life history and habitat needs of endangered fish should be similar regardless of the specific river.

The fishery data and the 2-D modeling results did not indicate habitat problems for non-endangered native species in the 15-Mile Reach. The 2-D modeling found that similar flows provided similar habitat availability for adult native suckers in the Colorado and Yampa Rivers. We interpret these results to indicate that habitat availability for adult endangered species was not likely problematic in the 15-Mile Reach. The availability of prey fish (10 - 30 cm) appeared high in the 15-Mile Reach suggesting that forage availability was not lacking for adult Colorado pikeminnow (Osmundson 1999). In spite of seemingly good habitat and forage, the numbers of endangered fish collected in this study and by recent recovery program efforts have been very low in the 15-Mile Reach.

Catch rate and population estimate data suggested that Colorado pikeminnow had similar population sizes in the Colorado and Yampa Rivers during the period of 1987 to 2000 (McAda 2002 and Osumndson 2002). The fact that Colorado pikeminnow densities were similar for the Colorado and Yampa River further suggested that neither habitat nor forage availability has limited pikeminnow abundance in the 15-Mile Reach. The bottleneck for Colorado pikeminnow and razorback sucker in the Colorado River was most likely related to reproduction and recruitment (Osmundson and Kaeding 1991). Colorado pikeminnow reproduction occurred during the descending limb of the hydrograph and lack of recruitment was linked with predation of larvae (Bestgen 1997). Data from this study indicated that YOY smallmouth bass appeared to be an efficient predator of fish larvae in the Yampa River. If YOY smallmouth bass become prevalent in Dinosaur Canyon, this could have a major impact on survival of Colorado pikeminnow larvae.

FLOW RECOMMENDATIONS

The intent of this project was to develop flow recommendations that would be adequate to provide suitable flows for maintaining existing populations of native fish. The first three years of the project were spent documenting the status of existing native fish populations in the 15-Mile Reach of the Colorado River, the Yampa River and the Dolores River. The fish population data was necessary to create the habitat suitability criteria and also to provide baseline population data given existing habitat conditions.

The habitat analysis found several similarities in channel morphology, suitability curves and flow/habitat relationships between the Yampa and Colorado Rivers. The data also strongly suggested the Yampa and Colorado Rivers would have similar native sucker populations given similar instream flow scenarios. Flow recommendations for these two rivers, however, were not similar because of large differences in historical flows and water availability.

Colorado River

The base flows in the 15-Mile Reach in 2000 (900) and 2001 (1000) were found to be near optimal in providing suitable for habitat for native suckers and in maintaining habitat diversity. Neither the fish sampling data nor the habitat modeling results gave indications that flows above 1200 cfs would improve habitat conditions or biomass of native sucker species. Base flows observed in the Colorado River in 2000 and 2001 appeared suitable to maintain the existing native fish population for the long term.

The 2-D habitat model showed that bluehead habitat and projected biomass falls rapidly when flows drop below 600 cfs, and at 200 cfs or less habitat availability and predicted biomass is very low compared to current estimates. Base flows of 600 to 800 cfs appear sufficient to maintain the bluehead sucker population size found during the study period.

Pitlick (1999) reported that base flows in the Colorado River were slightly higher than native flow. For the historic record, flows less than 800 cfs have been uncommon in the 15-Mile Reach (Osmundson and Keading 1991), establishing a history of near optimal habitat conditions. We recommend that optimal habitat be sustained. The 2-D habitat modeling data indicated that a mean monthly flow of 650 cfs during the late irrigation season (July 1 to October 31) would likely maintain native sucker species at or very near the existing population size. A mean monthly flow of 650 cfs would be achieved if flows exceed 400 cfs for 100% of the month, exceed 525 cfs for 25% of the month and exceed 650 cfs for 50% of the month. To simplify the recommendation to a single flow, 600 cfs should be considered the instream flow recommendation for the Colorado River in the 15-Mile Reach.

Yampa River

The Tennant Method (Instream Flow Council 2002) calculates a minimum flow of 465 cfs as a recommendation for the Yampa Rivers' mean annual flow of 1552 cfs. Base flows over 300 cfs have been uncommon in the Yampa River during the irrigation season even though 300 cfs seems fairly low for a river the size of the Yampa. The median minimum flow for the Maybell gage was only 121 cfs. Both fish observations and habitat modeling identified that flows less than 120 cfs do not provide enough habitat to adequately support native fish.

The goal for flow management on the Yampa River is to provide enough flow to avoid degraded habitat (unsuitable depths and velocities in riffles and runs). The fish sampling data found conclusively that summer flows during 2000 and 2001 had negative impacts on the native fish populations of the Yampa River. The recovery time frame of native fish (speckled dace, mottled scuplin and bluehead sucker) is unknown at this time since flows in 2002 were even lower. Base flows of 1998 and 1999 were found to sustain native fish. It is recommended that the flow conditions of these years be used to model instream flow scenarios in the future.

Compared to the Colorado River the Yampa River upstream of Cross Mountain Canyon appears overly-wide and the channel is unstable. Improved riparian management and activities that promote bank stabilization and a more natural-sized channel would have long term benefits for native fish in the Yampa River. Also, base flows on the Yampa River are much reduced compared to native flow.

The 2-D meso-habitat model found that flows below 200 cfs appear to be highly problematic for blueheads on the Yampa River. It appears that base flows need to be over 400 cfs to have a significant improvement in bluehead habitat at all three sites. In regard to blueheads, it appeared flows less than 200 cfs should be avoided.

A minimum flow of 200 cfs is necessary to maintain native fish at the levels observed in 1998 and1999. A monthly average of 200 cfs would likely avoid severely degraded conditions. To achieve this standard it is recommended that flows exceed 120 cfs for 100% of the month, exceed 150 cfs for 25% of the month and exceed 200 cfs for 50% of the month. If a single flow is desirable then the instream flow recommendation is 175 cfs.

Dolores River

The Dolores River was found to have a high species composition of native fish, but very poor size structure and biomass. In fact, the fishery of the Dolores River in Big Gypsum was so poor it has become an example of a fish community representative of extremely altered flows and habitat. The Dolores River has the potential to be an important river for native fish management given adequate instream flows. Habitat modeling found that flows of 200 cfs would maintain riffle habitats. Base flows of this magnitude would likely result in a fish density and biomass similar to estimates in the 15-Mile Reach. However, it does not appear likely that flows of 200 cfs are available.

Perhaps an even larger problem than base flows is the change in runoff flows. There has also been a lack of peak or flushing flows in the Dolores River during the study period. The lack of flushing flows appears to have severely reduced productivity of this river. The 2-D modeling suggests an instream flow of at least 80 cfs. The field data suggests a runoff flow of near 1200 cfs, but more modeling is needed for this river.

SUMMARY

Four years of fish population characteristics were summarized at Sevens and Duffy on the Yampa River. Density, biomass and size structure in the first two years 1998 and 1999 were higher than in 2000 and 2001. We examined the fish data at Lily Park in 2000 and 2001. We attributed the observed changes in the fishery at Sevens and Duffy to poorer flow and habitat conditions in 2000 and 2001. Low flows appeared to be responsible for negative impacts to blueheads, speckled dace, mottled scuplin, flannelmouths, white suckers and channel catfish. Smallmouth bass and sand shiners appeared to respond positively during the lower flow years on the Yampa.

Three years (1999, 2000 and 2001) of fish population characteristics were summarized at Corn Lake in the 15-Mile Reach and two years (2000 and 2001) of fish data were collected at the Clifton site. Density, biomass and size structure of the native fish community appeared to be at carrying capacity and representative of an ideal population.

Two years (2000 and 2001) of fish population characteristics were summarized at the Big Gypsum site on the Dolores River. Although native fish species composition was high in both years, fish density, biomass and size structure were considered to be fair in 2000 and very poor in 2001. The Dolores River fishery appeared to have a highly stressed and unnatural fish community and served as an example of a population in a highly degraded habitat.

We observed two-dimensional habitat modeling at all sites with fishery data. We developed meso-habitat suitability curves based on fish distribution within each site. Meso-habitat suitability were validated and used to project habitat availability for a range of simulated flows. Geomorphic characteristics were similar for the Yampa River and Colorado in the range of flows modeled. Habitat for flannelmouth and bluehead suckers were maximized or optimal at flows near 1000 to 1200 cfs for the Colorado. The 1000 to 2000 cfs flows were likely the optimal flows in the Yampa River, but the flows were not modeled over 600 cfs. Flows less than 400 cfs provided significantly reduced habitat for flannelmouth and bluehead suckers. Nearly 100% of available habitat was in the unusable category for flannelmouth and bluehead suckers at flows of 100 cfs and less.

We made instream flow recommendations based on the 2-D meso-habitat modeling and observations made during the fish sampling. To maintain the existing population in the 15-Mile Reach instream flows should exceed 600 cfs. A instream flow target for the Yampa River is 200 cfs and flows less than 120 cfs need to be avoided to prevent loss of riffle-habitats. Instream flows of 60 to 80 cfs may be sufficient to maintain a native fish community in the Dolores River, as long as runoff flows are provided in the spring. The lack of spring flows in the Dolores River appears to have severely reduced the fishery potential there.

CONCLUSIONS

- 2-D habitat modeling found that flows of the same magnitude provide about the same amount of habitat availability for both the Colorado and Yampa Rivers.

- 2-D habitat modeling found the Yampa River had a larger stream width at flows less than 600 cfs even though the Colorado River had the larger drainage area and mean annual flow.

- Flows (900 to 1000 cfs), habitat availability and the non-endangered native fish community in the 15-Mile Reach documented during the study period were all found to be representative of near ideal conditions.

- Flows above 1200 cfs on the Colorado River do not enhance habitat availability for adult native suckers.

- Flows below 400 cfs will likely result in significant reductions in density and biomass of flannelmouths and blueheads in the 15-Mile Reach.

- The present flow management strategy for the 15-Mile Reach is to maintain historic flows and optional habitat conditions. Flows of 600 to 800 cfs will provide suitable habitat to maintain the existing native fish population in the 15-Mile Reach.

- Flows, habitat availability and the non-endangered native fish communities in the Yampa River documented during the study period were poor compared to their potential and to the 15-Mile Reach.

- Flows less than 120 cfs do not provide suitable habitat for adult native suckers and should be avoided.

- Flows of 300 to 400 cfs are required to provide suitable habitat for a healthy native fish population at the Yampa River.

- The flow management strategy for the Yampa River is to avoid severe habitat degradation. An instream flow of 200 cfs should be considered the minimum flow for the Yampa River.

- The Dolores River was sampled under similar base flow for two years, but the fish population was much degraded in the second year. Lack of peak flows appears to have caused the negative impact on the native fish population of this river.

- For the Dolores River an instream flow of 80 cfs and a minimum runoff flow of 1200 cfs are recommended. Further study is required on the Dolores River.

RECOMMENDATIONS FOR FUTURE FLOW RESEARCH

1. Reform model flows for the Yampa River 2D sites up to 2000 cfs as was done for the 15-Mile Reach. This is needed to complete modeling habitat suitability and habitat diversity.

2. Continue working with Dr. Richard of Mesa State College to determine channel geomorphology. Conduct a channel geomorphic study for the Yampa River to determine bankfull flows and channel stability. Also, summarized flow records are needed to determine the scale in reduction of base flows on the Yampa River.

3. Survey the floodplain of the Dolores River study site and determine bankfull flows at the Big Gypsum site. Determine the rate of channel narrowing through contract work with Dr. Richard of Mesa State.

4. Continue to sample the fish sites on the Yampa and 15-Mile Reach for at least two years (2003 and 2004). The drought of record statewide occurred in 2002. The hydrograph for the Yampa River was severely reduced in 2002 from flows during the sampling period. Median peak flow on the Yampa River was 9880 cfs and median minimum flow was 129 cfs (84 years) at the Maybell gage. In 2002, the peak flow was 3420 cfs and the minimum flow was only 2 cfs. The flows in the 15-Mile Reach in 2002 were also lower. The peak flow was only 2780 cfs and the minimum flow was 58 cfs compared to the median peak of 13500 cfs and the median minimum flow of 558 for the Palisade gage (11 years). Fish population data collected in 2003 could provide data on impacts from the 2002 flows. A result of this continued sampling would be validation of projections about impacts of habitat loss on fish density and biomass.

5. Complete and report on habitat availability for roundtail chub analysis.

6. Perform polygon analysis for the other fish native and nonnative in the 15-Mile Reach and the Yampa River. Include the new two additional years of fishery data for developing meso- habitat suitability. These species include roundtail chub, speckled dace, common carp, white sucker, channel catfish, smallmouth bass, largemouth bass and green sunfish.

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REFERENCES

Anderson, R. M. 2002. Riverine fish-flow investigations. Colorado Division of Wildlife. Federal Aid Project F-289-R5. Job Prog. Report. Fort Collins, CO 92pp.

Anderson, R. M. and G. Stewart. 2001. Riverine fish-flow investigations. Colorado Division of Wildlife. Federal Aid Project F-289-R4. Job Prog. Report. Fort Collins, CO 83pp.

Anderson, R. M. and G. Stewart. 2000. Riverine fish-flow investigations. Colorado Division of Wildlife. Federal Aid Project F-289-R3. Job Prog. Report. Fort Collins, CO 96pp.

Anderson, R. M. and G. Stewart. 1999. Riverine fish-flow investigations. Colorado Division of Wildlife. Federal Aid Project F-289. Job Prog. Report. Fort Collins, CO 44pp.

Anderson, R. M. 1998. Riverine fish-flow investigations. Colorado Division of Wildlife. Federal Aid Project F-288. Job Progress Report. Fort Collins, CO 44pp.

Anderson, R. M. 1997. An evaluation of fish community structure and habitat potential for Colorado squawfish and razorback sucker in the unoccupied reach (Palisade to Rifle) of the Colorado River, 1993-1995. Final Report. Project No. 18. Colorado Division of Wildlife. Federal Aid Project F-288. Job Progress Report. Fort Collins, CO 44pp.

Andrews, E.D., 1980. Effective and bankfull discharges of streams in the Yampa river basin, Colorado and Wyoming. Journal of Hydrology 46, pp. 311-30.

Bestgen, K. R. 1997. Interacting effects of physical and biological factors on recruitment of age-0 Colorado pikeminnow. Unpublished Ph.D. Dissertations, Colorado State University, Fort Collins, CO. 203 pp.

Bovee, K. 1996. Perspectives on two-dimensional river habitat models: the PHABSIM experience. *Proceedings - 2nd International Symposium on Habitat Hydraulics*. B150-B152.

Bovee, K. D. 1982. A guide to stream habitat analysis using the instream flow incremental methodology. Instream flow information paper 12. FWS/OBS-82/86. United States Department of the Interior, Coop Instream Flow Service Group, Fort Collins Colorado.

Bundy, J. M. and K.R. Bestgen. 2001. Evaluation of the interagency standardized monitoring program sampling technique in backwater of the Colorado River in the Grand Valley, Colorado. Larval Fish Lab Contribution 119, CSU, Fort Collins, CO.

Bureau of Reclamation, 1999, draft. Late summer and fall operations report of the HUP managing entities and water managers. BOR, Grand Junction CO, 13 pp.

Byers, D. W., C. Sodergren, J. M. Bundy, and K. R. Bestgen 2001. Habitat use and movement of bluehead sucker, flannelmouth sucker and roundtail chub in the Colorado River. Larval Fish Laboratory, CSU. Fort Collins Co 32 pp.

Brunner, G. W. 1998. HEC-RAS River analysis system, user manual version 2.2. U.S. Army Corps of Engineers, Hydrologic Engineering Center. Davis CA pp 230.

Carlson, C.A., C.G. Prewitt, D. E. Snyder, E. J. Wick, E. L. Ames, and W.D. Fronk. 1979. Fishes and macroinvertebrates of the White and Yampa Rivers, Colorado. Colorado Bureau of Land Management Biological Series 1.

DeVries, R and S. G. Maurer. 1997. Dolores River Guide. Southwest Natural and Cultural Heritage Asso. Albuquerque, NM.

Elmbald 2003 (in review). The interagency standardized monitoring program in Colorado result from 1986 to 2000. Final Report, Colorado Division of Willdlife, Grand Junction, CO.

Espegren, G. D. 1998. Evaluation of the standards and methods used for quantifying instream flows in Colorado. Colo. Water Con. Board. Denver, CO. 18 pp.

Everhart, W. H. and W. D. Youngs. 1981. Principles of fishery science. Cornell University press.

Hawkins, J.A., E. J. Wick and D. E. Jennings. 1997. Icthyofauna of the Little Snake River, Colorado, 1994. Report to: U.S. National Park Service, Denver CO, and Colorado River Endangered Fish Recovery Prog. , Denver CO. 44pp.

Instream Flow Council. 2002. Instream Flows for Riverine Resource Stewardship. Publisher at www.instreamflowcouncil.org. USA.

King, I. 1997. The users guide to RMA2 WES Version 4.3. The U.S. Army Corps of Engineers – Waterways experiment laboratory. pp 240.

Kondolf, G. M., E. W. Larsen and J. G. Williams. 2000. Measuring and modeling the hydraulic environment for assessing instream flows. North American Journal of Fisheries Management 20:1016-1028.

Leclerc, M., Boudreault, A., Bechara, J.A., and Corfa, G. 1995. "Two-dimensional hydrodynamic modeling: a neglected tool in the instream flow incremental methodology", *Trans. Am. Fisheries Soc.*, **124**(5), 645-662.

McLean, S.R., S.R. Wolfe, and J.M. Nelson. (1999). Predicting boundry shear stress and sediment transport over bed forms. Journal of Hydraulic Engineering. July 1999:725-736.

McAda, C.W. 2002. Subadult and adult pikeminnow monitoring; summary of results, 1986 – 2000. Recovery Program Project Number 22, Final Report. U.S.F.W.S., Grand Junction, Co. 60pp.

McAda, C.W, W.R. Elmblad, K.S. Day, M. A. Trammel and T. E. Chart. 1997. Interagency Standardized Monitoring Program; Summary of Results, 1996. Annual report. Recovery Program for the Endangered Fishes of the Upper Colorado River Basin, U.S. Fish and Wildlife Service , Denver, Co.

Miller, W.H., D.L. Archer, H.M. Tyus and R. M. McNatt. 1982. Yampa River fishes study. Final Report for Memorandum of Understanding 14-16-0006-81-931(IA), U.S. National Park Service. U.S. Fish and Wildlife Service, Salt Lake City, UT.

Modde, T., W. J. Miller, R M. Anderson, and D. Irving. 1995. Determination of habitat availability and habitat use, and flow needs of endangered fishes in the Yampa River between August and September. Colorado River Recovery Program Report for Project #CAP-9. Denver Colorado. 128 pp.

Modde, T. and G. Smith. 1999. Flow recommendations for endangereed fishes in the Yampa River. Final Rport submitted to the Recovery Implementation Program for the Recovery of Endangered Fishes in the Upper Colorado River Basin. U.S. Fish and Wildlife Service, Denver, CO. 44 pp.

Nehring, R. B. 1979. Evaluation of instream flow methods and determination of water quantity needs for stream in the state of Colorado. Colo. Div. Wild. Job Compl. Report. U. S. Fish and Wildl. Service Contract No. 14-16-0006-78-909. 144pp.

Nelson, J.M. (1996). Predictive techniques for river channel evolution and maintenance. Air and Soil Pollution. 90:321-333.

Nelson, J.M., R.L. Shreve, R. McLean, and T.G. Drake. (1995). Role of near-bed turbulence structure in bed load transport and bed form mechanics. Water Resources Research. 31(8):2071-2086.

Osmundson, D., and L. R. Kaeding. 1991. Recommendations for flows in the 15-Mile Reach during October-June for maintenance and enhancement of endangered fish population in the upper Colorado. Final Report. U. S. Fish and Wildlife Service Grand Junction, CO. 82 pp.

Osmundson, D., B., P. Nelson, K, Fenton, and D. W. Ryden. 1995. Relationships between flow and rare fish habitat in the '15-mile reach' of the upper Colorado River. U. S. Fish and Wildlife Service Final Report. Grand Junction, CO.

Osmundson, D., 1999. Longitudinal variation in fish community structure and water temperature in the Upper Colorado River: Implications for Colorado Pikeminnow habitat suitability. Report A, Project No. 48. U. S. Fish and Wildlife Service Final Report. Grand Junction, CO.

Osmundson, D., 2000. Importance of the 15-Mile Reach to Colorado River populations of endangered Colorado pikeminnow and razorback sucker. Final Report. U. S. Fish and Wildlife Service Position Paper. Grand Junction, CO.

Osmundson, D., 2001. Flow regimes for restoration and maintenance of sufficient habitat to recover endangered razorback sucker and Colorado pikeminnow in the Upper Colorado River. Project No. 47. U. S. Fish and Wildlife Service. Grand Junction, CO.

Osmundson, D., 2002. Population dynamics of Colorado pikeminnow in the Upper Colorado River. Project no. 22-A, U. S. Fish and Wildlife Service Final Report. Grand Junction, CO.

Parasiewicz, P. 2001. MesoHABSIM: A concept for application of instream flow models in river restoration planning. Fisheries. Vol. 26. 9:6-13.

Pitlick, J., M. M. Van Steeter, B. Barkett, R. Cress and M. A. Franseen. 1999. Geomorphology and Hydrology of the Colorado and Gunnison Rivers and implications for habitats used by endangered fishes. Final Report, U.S. Fish and Wildlife Service, Grand Junction.

Pitlick, J., and R. Cress. 2000. Longitudinal trends in channel characteristics of the Colorado River and implications for food-web dynamics. Final Report. University of Colorado, Boulder.

Prewitt, C. G. 1977. Catostomid fishes of the White and Yampa Rivers Colorado. M. S. Thesis, Colorado State Univ., Fort Collins, CO. 122 pp.

Rose, K. L., and D. R. Hahn. 1989. A summary of historic habitat modeling on the Yampa River using the physical habitat simulation system. U.S. Fish and Wildlife Service, Grand Junction, Colo. 18 pp.

Stewart, G. 2000. Two-dimensional hydraulic modeling for making instream-flow recommendations. M.S. Thesis. Colorado State University. Fort Collins CO.

Sublette, J. E., M. D. Hatch and M. Sublette. 1990. The Fishes of New Mexico. University of Nextci Press, Albuquerque NM.

Thompson, D.M., J.M. Nelson, and E.E. Wohl. (1998). Interactions between pool geometry and hydraulics. Water Resources Research. 34(12):3673-3681.

Topping, D.J., D.M. Rubin, J.M. Nelson, P.J. Kinzel III, I.C. Corson. (2000). Colorado River sediment transport. 2. Systematic bed-elevation and grain-size effects of sand supply limitation. Water Resources Research. 36(2):543-570.

Valdez, R. A., W. J. Masslich and A.Wasowicz. 1992. Dolores River native fish habitat suitability study (UDWR Contract No. 90-2559). BIO/WEST Inc. Logan Utah. 118 pp.

Valdez, R. A., L. Jonas, and J. Munk. 1999. Nonnative fish control in backwater habitats in the Colorado River. Interim progress report, Project 87b. Colorado Division of Wildlife, Fort Collins. 11p.

Wick, E. J., T.A. Lytle, and C.M. Haynes. 1981. Colorado squawfish and humpback chub population and habitat monitoring, 1979-1980. Progress Report SE-3-3. Endangered Wildlife Investigations. Colorado Division of Wildlife, Denver, Colorado.

Wick, E. J., J. A. Hawkins and C. A. Carlson. 1986. Colorado squawfish population and habitat monitoring. 1985. Final Report, SE 3-8. Endangered Wildlife Investigations, Colorado Division of Wildlife, Denver, Colorado.

Williams, J. E., Johnson, J. E., Hendrickson, D. A., Contreras-Balderas, S., Williams, J. D., Navarro-Mendoz, M., McAllister, D. E., & Deacon., J. E. 1989. Fishes of North America endangered, threatened, or of special concern: 1989, Fisheries (Bethesda) 14(6): 2-20.

Woodling, J. 1985. Colorado's little fish: A guide to the minnows and other lesser know fishes in the state of Colorado. Colorado Division of Wildlife, Denver, CO.

Wydowski and Hamil 1991. Evolution of a cooperative recovery program for endangered fishes in the upper Colorado River basin. Pages 123-135 in W.L. Minckley and J.E. Deacon, editors Battle against extinction: native fish management in the American West. University of Arizona Press, Tucson.

APPENDIX

Tables and Figures

A-Table 1. Density estimates in **fish per kilometer** and biomass estimates in **kilograms per kilometer** for each study site.

	no./km	No./km	no./km	no./km	kg/km	kg/km	kg/km	kg/km
YAMPA RIVER	SEVENS	SEVENS	SEVENS	SEVENS	SEVENS	SEVENS	SEVENS	SEVENS
Species	1998	1999	2000	2001	1998	1999	2000	2001
Total Fish	1147	1115	778	**653**	1136.7	1004.5	633.1	491.9
Flannelmouth Sucker	395	376	296	**263**	413.4	411.6	361.4	227.7
Bluehead Sucker	274	238	309	**120**	110.5	93.5	26.0	30.1
Roundtail Chub	73	41	54	**29**	43.8	26.6	13.6	14.9
White S. + Crosses	200	190	106	**138**	157.6	159.3	63.5	55.9
Channel Catfish	111	109	22	**46**	161.5	122.7	41.3	58.1
Carp	77	69	45	**33**	215.3	168.6	118.5	95.2
Smallmouth Bass	20	29	6	**37**	10.0	10.0	4.3	5.2
Northern Pike	62	22	3	**3**	24.5	12.3	4.4	4.9
	no./km	no./km	no./km	no./km	kg/km	kg/km	kg/km	kg/km
LONG REACH	DUFFY	DUFFY	DUFFY	DUFFY	DUFFY	DUFFY	DUFFY	DUFFY
Species	1998	1999	2000	2001	1998	1999	2000	2001
Total Fish	387	403	316	430	509.6	453.8	340.5	291.9
Flannelmouth Sucker	25	15	11	5	34.2	19.3	15.6	6.1
Bluehead Sucker	24	23	16	19	14.0	9.5	10.1	12.1
Roundtail Chub	12	25	5	10	12.0	26.6	5.1	9.6
Colo. Pikeminnow	8	5	4	3	18.8	9.4	6.1	4.7
White S. + Crosses	241	242	203	185	265.8	266.6	231.5	176.0
Channel Catfish	19	29	15	23	34.5	39.1	23.7	27.5
Carp	22	8	4	2	101.6	39.7	21.8	10.6
Smallmouth Bass	40	58	58	215	17.2	26.8	22.4	43.7
Northern Pike	17	16	3	6	11.3	16.8	4.2	1.5
	no./km	no./km	no./km	no./km	kg/km	kg/km	kg/km	kg/km
MAPPED REACH	DUFFY	DUFFY	DUFFY	DUFFY	DUFFY	DUFFY	DUFFY	DUFFY
Species	1998	1999	2000	2001	1998	1999	2000	2001
Total Fish	435	343	467	716				
Flannelmouth Sucker	13	5	9	9				
Bluehead Sucker	21	10	12	3		2.6	4.1	2.1
Roundtail Chub	16	7	7	3		3.1	1.2	0.5
Colo. Pikeminnow	11	5	6	3				
White S. + Crosses	272	230	289	248				
Channel Catfish	6	20	66	25				
Carp	6	1	0	1				
Smallmouth Bass	119	51	112	399				
Northern Pike	33	13	3	15				
	no./km	no./km	no./km	no./km	kg/km	kg/km	kg/km	kg/km
YAMPA RIVER			Lily Park	Lily Park			Lily Park	Lily Park
Species			2000	2001			2000	2001
Total Fish			**6279**	**3168**			2368.6	1760.3
Flannelmouth Sucker			**2238**	**1667**			1315.7	801.3
Bluehead Sucker			**552**	**346**			194.5	114.0
Roundtail Chub			**2**	**2**			3.0	0.1
Colo. Pikeminnow			**5**	**2**			0.0	0.0
White S. + Crosses			**14**	**2**			1.1	0.6

Channel Catfish			**3668**	**1395**			555.4	526.3
Carp			**186**	**171**			193.4	203.8
Smallmouth Bass			**121**	**501**			69.9	87.0
Northern Pike			**19**	**14**			35.5	27.2
	no./km	no./km	no./km	no./km	kg/km	kg/km	kg/km	kg/km
COLORADO RIVER		CORN L.	CORN L.	CORN L.		CORN L.	CORN L.	CORN L.
Species		1999	2000	2001		1999	2000	2001
Total Fish		3962	3417	4007		2760.8	2854.1	2605.3
Flannelmouth Sucker		1550	998.75	1661.75		1261.2	1268.9	1280.6
Bluehead Sucker		1573	1182.25	1272		806.4	504.4	596.1
Roundtail Chub		192	357	170.5		57.2	68.0	41.2
Colo. Pikeminnow		5	0	0		9.3	18.8	5.7
White S. + Crosses		139	124	552		56.2	43.2	120.3
Channel Catfish		195	301.25	440.5		180.9	228.4	354.2
Carp		309	525.25	198.5		389.6	722.4	207.0
	no./km	no./km	no./km	no./km	kg/km	kg/km	kg/km	kg/km
COLORADO RIVER		CLIFTON	CLIFTON	CLIFTON		CLIFTON	CLIFTON	CLIFTON
Species			2000	2001		1999	2000	2001
Total Density estimate			3766	4547			3207	3341
Flannelmouth Sucker			1822	1563			1280.1	1075.2
Bluehead Sucker			1138	1164			452.2	496.0
Roundtail Chub			437	357			99.7	93.8
Colo. Pikeminnow			2	2				
White S. + Crosses			333	199			115.9	64.4
Channel Catfish			641	530			707.8	447.4
Carp			570	845			551.6	1164.6
	no./km	no./km	no./km	no./km	kg/km	kg/km	kg/km	kg/km
DOLORES RIVER			BIG GYP	BIG GYP			BIG GYP	BIG GYP
Species			2000	2001			2000	2001
Total Density estimate			196.6	231.7			259.0	48.7
Flannelmouth Sucker			35.8	105.9			88.7	1.5
Bluehead Sucker			3.0	12.7			7.0	0.3
Roundtail Chub			81.0	65.1			14.9	4.5
Channel Catfish			68.6	62.2			100.0	22.6
Carp			24.4	6.0			48.3	19.8
Green Sunfish			5.2	1.5				
Black Bullhead			13.7	3.7				

A-Table 2. Density estimates in **fish per hectare** and biomass estimates in **kilograms per hectare** for each study sites.

	no/ha	no/ha	no/ha	No/ha	kg/ha	kg/ha	kg/ha	kg/ha
YAMPA RIVER	SEVENS	SEVENS	SEVENS	SEVENS	SEVENS	SEVENS	SEVENS	SEVENS
Species	1998	1999	2000	2001	1998	1999	2000	2001
Total Fish	185.2	180.0	125.6	105.4	183.5	**162.1**	**102.2**	**79.4**
Flannelmouth Sucker	63.8	60.7	47.8	42.5	66.7	**66.4**	**58.3**	**36.7**
Bluehead Sucker	44.3	38.4	49.8	19.4	17.8	**15.1**	**4.2**	**4.9**
Roundtail Chub	11.8	6.6	8.6	4.7	7.1	**4.3**	**2.2**	**2.4**
White S. + Crosses	32.3	30.7	17.1	22.3	25.4	**25.7**	**10.2**	**9.0**
Channel Catfish	17.9	17.5	3.6	7.4	26.1	**19.8**	**6.7**	**9.4**
Carp	12.5	11.1	7.2	5.3	34.8	**27.2**	**19.1**	**15.4**
Smallmouth Bass	3.2	4.7	1.0	5.9	1.6	**1.6**	**0.7**	**0.8**
Northern Pike	10.0	3.5	0.5	0.4				
	no/ha	no/ha	no/ha	no/ha	kg/ha	kg/ha	kg/ha	kg/ha
LONG REACH	DUFFY	DUFFY	DUFFY	DUFFY	DUFFY	DUFFY	DUFFY	DUFFY
Species	1998	1999	2000	2001	1998	1999	2000	2001
Total Fish	55.3	57.7	45.3	61.4	72.9	64.9	48.7	41.7
Flannelmouth Sucker	3.6	2.1	1.6	0.7	4.9	2.8	2.2	0.9
Bluehead Sucker	3.5	3.3	2.3	2.7	2.0	1.4	1.4	1.7
Roundtail Chub	1.7	3.6	0.7	1.4	1.7	3.8	0.7	1.4
Colo. Pikeminnow	1.2	0.7	0.5	0.4	2.7	1.3	0.9	0.7
White S. + Crosses	34.5	34.7	29.1	26.4	38.0	38.1	33.1	25.2
Channel Catfish	2.6	4.1	2.1	3.3	4.9	5.6	3.4	3.9
Carp	3.1	1.2	0.5	0.3	14.5	5.7	3.1	1.5
Smallmouth Bass	5.7	8.3	8.3	30.7	2.5	3.8	3.2	6.3
Northern Pike	2.4	2.3	0.5	0.8	1.6	2.4	0.6	0.2
	no/ha	no/ha	no/ha	no/ha	kg/ha	kg/ha	kg/ha	kg/ha
MAPPED REACH	DUFFY	DUFFY	DUFFY	DUFFY				
Species	1998	1999	2000	2001				
Total Fish	85.9	67.8	92.3	141.4				
Flannelmouth Sucker	2.6	1.1	1.8	1.7				
Bluehead Sucker	4.1	1.9	2.3	0.7				
Roundtail Chub	3.1	1.3	1.4	0.7				
Colo. Pikeminnow	2.2	0.9	1.2	0.7				
White S. + Crosses	53.7	45.4	57.0	49.1				
Channel Catfish	1.2	4.0	13.1	5.0				
Carp	1.2	0.2	0.0	0.2				
Smallmouth Bass	23.5	10.0	22.1	78.9				
Northern Pike	6.4	2.7	0.5	2.9				
	no/ha	no/ha	no/ha	no/ha	kg/ha	kg/ha	kg/ha	kg/ha
YAMPA RIVER			Lily Park	Lily Park			Lily Park	Lily Park
Species			2000	2001			2000	2001
Total Fish			1047.6	528.5			395.2	293.7
Flannelmouth Sucker			373.3	278.1			219.5	133.7
Bluehead Sucker			92.1	57.7			32.5	19.0
Roundtail Chub			0.3	0.3			0.5	0.0
Colo. Pikeminnow			0.9	0.3			0.0	0.0

White S. + Crosses			2.3	0.3			0.2	0.1
Channel Catfish			611.9	232.7			92.7	87.8
Carp			31.0	28.5			32.3	34.0
Smallmouth Bass			20.2	83.5			11.7	14.5
Northern Pike			3.2	2.3			5.9	4.5
	no/ha	no/ha	no/ha	no/ha	kg/ha	kg/ha	kg/ha	kg/ha
COLORADO RIVER		CORN L.	CORN L.	CORN L.		CORN L.	CORN L.	CORN L.
Species		1999.0	2000.0	2001.0		1999	2000	2001
Total Fish		765.1	659.9	773.8		533.2	551.2	503.1
Flannelmouth Sucker		299.4	192.9	320.9		243.6	245.1	247.3
Bluehead Sucker		303.8	228.3	245.7		155.7	97.4	115.1
Roundtail Chub		37.0	68.9	32.9		11.1	13.1	8.0
Colo. Pikeminnow		1.0	0.0	0.0		1.8	3.6	1.1
White S. + Crosses		26.7	23.9	106.6		10.9	8.3	23.2
Channel Catfish		37.7	58.2	85.1		34.9	44.1	68.4
Carp		59.6	101.4	38.3		75.2	139.5	40.0
			no/ha	no/ha			kg/ha	kg/ha
COLORADO RIVER								
Species			2000	2001			2000	2001
Total Density estimate			600	724			511	532
Flannelmouth Sucker			290	249			204	171
Bluehead Sucker			181	185			72	79
Roundtail Chub			70	57			16	15
Colo. Pikeminnow			0	0				
White S. + Crosses			53	32			18	10
Channel Catfish			102	84			113	71
Carp			91	135			88	185
			no/ha	no/ha			kg/ha	kg/ha
DOLORES RIVER			BIG GYP	BIG GYP			BIG GYP	BIG GYP
Species			2000	2001			2000	2001
Total Density estimate			116.3	137.1			153.2	28.8
Flannelmouth Sucker			21.2	62.6			52.5	0.9
Bluehead Sucker			1.8	7.5			4.2	0.2
Roundtail Chub			47.9	38.5			8.8	2.6
Channel Catfish			40.6	36.8			59.1	13.4
Carp			14.4	3.5			28.6	11.7
Green Sunfish			3.1	0.9				
Black Bullhead			8.1	2.2				

A-Table 3. Corn Lake (Colorado River) polygon area, polygon mean depth, polygon mean velocity and mean bluehead and flannelmouth sucker density and biomass.

		Bluehead		Flannelmouth			
Polygon	AREA	Density	Biomass	Density	Biomass	Depth	Velocity
Lable	hectare	fish/ha	kg/ha	fish/ha	kg/ha	meters	m/s
CORN LAKE - 800							
lu-800	2.01	113	72	290	299	1.02	0.41
2r-800	0.87	211	114	23	24	0.56	0.85
3u-800	3.21	102	34	158	80	1.24	0.34
4r-800	1.95	370	187	357	303	0.61	0.66
5b-800	0.05	0	0	0	0	0.57	0.15
6r/u-800	2.26	362	158	315	278	0.61	0.83
7b-800	0.27	0	0	0	0	0.60	0.01
9r/u-800	1.24	193	89	383	61	0.90	0.61
10r/u-800	1.91	546	329	545	491	0.67	0.74
12r/u-800	0.86	458	206	782	552	0.80	0.74
13b-800	0.07	0	0	0	0	0.69	0.05
14r/u-800	2.17	316	74	453	369	0.79	0.71
15b-800	0.14	80	26	121	21	0.53	0.03
16u-800	1.56	230	119	329	218	0.38	0.64
CORN LAKE – 1000							
lu-1000	2.02	156	64	414	224	1.09	0.48
2r-1000	0.89	635	258	109	148	0.63	0.94
3u-1000	3.21	148	54	158	98	1.31	0.40
4r-1000	2.01	286	132	406	298	0.67	0.73
5b-1000	0.05	4	1	0	0	0.64	0.14
6r/u-1000	2.32	369	184	423	344	0.67	0.91
7b-1000	0.29	8	27	18	2	0.65	0.01
9r/u-1000	1.26	329	54	266	318	0.96	0.69
10r/u-1000	1.99	363	158	439	345	0.72	0.81
12r/u-1000	0.90	211	89	755	623	0.85	0.84
13b-1000	0.08	0	0	0	0	0.90	0.08
14r/u-1000	2.27	221	101	306	241	0.81	0.79
15b-1000	0.15	0	0	45	8	0.54	0.03
16u-1000	1.65	233	101	226	187	0.41	0.70
CORN LAKE – 1800							
1u-1800	2.15	314	151	403	305	1.25	0.69
2r-1800	1.01	449	231	107	188	0.76	1.17
3u-1800	3.29	57	28	223	147	1.49	0.61
4r-1800	2.41	375	175	293	218	0.78	0.89
5-1800	0.07	0	0	16	13	0.73	0.15
6r/u-1800	2.64	508	265	229	185	0.81	1.14
7b-1800	0.34	0	0	111	6	0.84	0.02
9r/u-1800	1.30	257	158	352	365	1.07	0.91
10r/u-1800	2.29	324	203	282	268	0.84	1.02
12r/u-1800	1.45	800	345	300	185	0.95	1.08
13b-1800	0.11	64	12	75	88	0.91	0.16
14r/u-1800	2.65	178	89	406	315	0.91	1.00
15b-1800	0.76	100	52	40	7	0.49	1.14

16u-1800	1.89	83	64	147	176	0.52	0.88

A-Table 4 Clifton (Colorado River) polygon area, polygon mean depth, polygon mean velocity and mean bluehead and flannelmouth sucker density and biomass.

		Bluehead		Flannelmouth		Mean	Mean
polygon	AREA	Density	Biomass	Density	Biomass	Depth	Velocity
lable	hectare	fish/ha	kg/ha	fish/ha	kg/ha	meters	m/s
CLIFTON 800							
3u-800	1.00	133	77	413	502	0.77	0.39
4u-800	0.18	840	200	nd	nd	0.54	0.73
5sc-800	0.15	55	22	127	64	0.14	0.19
6sc-800	0.24	49	20	51	26	0.12	0.27
8r-800	1.10	479	136	343	155	0.51	0.78
12u-800	1.67	154	74	358	251	0.50	0.51
15f-800	1.48	106	30	120	51	0.42	0.79
18u-800	1.27	317	154	516	378	0.76	0.39
21r-800	1.22	105	40	33	22	0.43	0.81
24u-800	1.35	234	106	267	193	0.93	0.37
27f-800	1.71	275	120	273	206	0.75	0.82
30u-800	3.70	47	18	123	86	1.14	0.24
33u-800	1.24	375	149	585	333	0.51	0.63
37u-800	0.77	512	270	535	415	0.42	0.55
38u-800	0.88	185	77	271	163	0.43	0.72
42u-800	2.12	249	122	520	287	0.65	0.56
45u-800	2.07	359	169	337	249	0.73	0.46
CLIFTON 1000							
3u-1000	1.02	60	34	404	370	0.84	0.44
5sl-1000	0.17	117	47	188	94	0.22	0.30
6sc-1000	0.32	199	80	188	94	0.18	0.38
8r-1000	1.15	629	201	359	221	0.57	0.80
12u-1000	1.82	213	94	463	261	0.59	0.52
15f-1000	1.66	335	149	96	52	0.48	0.74
18u-1000	1.30	169	82	886	544	0.85	0.41
21r-1000	1.30	387	218	65	59	0.50	0.80
24u-1000	1.43	73	49	248	343	0.97	0.41
27f-1000	1.73	347	155	203	189	0.81	0.87
30u-1000	3.71	25	8	47	26	1.20	0.28
33u-1000	1.43	86	27	802	551	0.52	0.59
37u-1000	0.87	90	42	328	345	0.50	0.53
38u-1000	0.98	246	104	86	185	0.50	0.72
42u-1000	2.24	246	67	295	151	0.74	0.58
45u-1000	2.15	273	86	140	84	0.81	0.49
49b-1000	0.13	0	0	0	0	0.89	0.05
50b-1000	0.68	0	0	0	0	1.32	0.03

A-Table 5 Lily Park (Yampa River) polygon area, polygon mean depth, polygon mean velocity and mean bluehead and flannelmouth sucker density and biomass.

		Bluehead		Flannelmouth		Mean	Mean
Polygon	Area	Density	Biomass	Density	Biomass	Depth	Velocity
Lable	hectare	fish/ha	kg/ha	fish/ha	kg/ha	meters	(m/s
LILY PARK - 150 CFS							
1-150	0.35	161	66	493	401	0.24	0.26
2-150	1.50	173	66	278	159	0.20	0.24
4-150	1.36	65	25	473	262	0.28	0.28
5-150	0.95	87	34	443	254	0.23	0.37
6-150	2.44	17	6	116	67	0.55	0.19
7-150	0.42	0	0	0	0	0.23	0.43
8-150	0.58	81	28	751	376	0.61	0.23
9-150	1.61	29	10	235	110	0.65	0.17
10-150	0.48	86	23	709	330	0.38	0.46
11-150	0.34	70	20	711	272	0.34	0.26
12-150	0.05	0	0	0	0	0.47	0.12
13-150	0.32	443	148	888	392	0.33	0.32
14-150	0.38	15	4	1022	538	0.72	0.26
15-150	1.02	0	0	0	0	1.17	0.17
16-150	0.28	360	116	764	394	0.44	0.31
17-150	0.66	18	5	112	51	1.08	0.14
18-150	1.14	21	7	84	44	0.93	0.17
19-150	0.56	11	4	95	50	0.70	0.31
LILY PARK - 300 CFS							
1-300	0.38	264	95	218	201	0.37	0.34
2-300	1.67	95	38	239	152	0.31	0.38
4-300	1.47	201	78	329	203	0.32	0.37
5-300	1.12	124	48	228	144	0.24	0.43
6-300	2.51	46	19	396	247	0.57	0.25
7-300	0.45	0	0	0	0	0.17	0.49
8-300	0.62	154	60	721	489	0.50	0.28
9-300	1.63	35	12	154	80	0.55	0.19
10-300	0.54	311	102	835	486	0.36	0.64
11-300	0.36	148	45	485	294	0.50	0.41
12-300	0.06	0	0	0	0	0.57	0.14
13-300	0.41	220	88	498	307	0.43	0.56
14-300	0.43	112	44	685	462	0.77	0.38
15-300	1.18	20	9	441	305	1.15	0.22
16-300	0.32	195	76	920	550	0.50	0.50
17-300	0.75	83	30	495	348	1.09	0.22
18-300	1.24	19	6	418	270	0.97	0.28
19-300	0.65	81	32	821	488	0.74	0.27

A-Table 6 Sevens (Yampa River) polygon area, polygon mean depth, polygon mean velocity and mean bluehead and flannelmouth sucker density and biomass.

		Bluehead		Flannelmouth		Mean	Mean
polygon	Area	Density	Biomass	Density	Biomass	Depth	Velocity
lable	hectare	fish/ha	kg/ha	fish/ha	kg/ha	meters	m/s
SEVESN 80							
1-80	0.50	155	31	199	173	0.32	0.14
2-80	0.52	286	94	38	83	0.21	0.21
3b-80	0.54	48	13	238	182	0.60	0.07
3a-80	1.38	9	2	39	23	0.53	0.07
4-80	0.96	18	7	23	25	0.41	0.10
5a-80	0.42	41	12	268	283	0.62	0.07
5b-80	0.68	0	0	4	4	0.41	0.09
6-80	0.44	39	14	138	137	0.54	0.08
7-80	1.20	22	7	30	33	0.28	0.14
9-80	1.07	0	0	16	14	0.62	0.05
10-80	1.64	32	6	71	61	0.42	0.12
11-80	0.18	0	0	0	0	0.24	0.02
12-80	0.46	0	0	0	0	0.48	0.09
13-80	0.02	0	0	0	0	0.26	0.00
13-80	1.15	0	0	29	46	0.42	0.09
14-80	1.53	0	0	69	50	0.76	0.04
SEVENS 200							
1-200	0.54	170	109	188	169	0.40	0.25
2-200	0.57	183	40	47	11	0.28	0.34
3b-200	0.59	191	72	471	318	0.66	0.15
3a-200	1.49	11	16	80	104	0.60	0.15
4-200	1.02	16	4	53	75	0.48	0.20
5a-200	0.43	255	53	202	97	0.70	0.16
5b-200	0.70	8	2	46	12	0.50	0.18
6-200	0.51	98	35	164	181	0.66	0.17
7-200	1.30	73	13	36	18	0.36	0.25
8-200	0.86	0	0	0	0	0.24	0.23
9-200	1.16	41	27	132	183	0.73	0.10
10-200	1.79	40	16	86	93	0.53	0.20
11-200	0.22	0	0	13	0	0.34	0.00
12-200	0.46	23	7	47	21	0.64	0.15
13a-200	0.02	0	0	0	0	0.26	0.00
13-200	1.21	17	7	51	44	0.56	0.17
14-200	1.57	22	0	78	45	0.89	0.10

A-Table 7. Duffy (Yampa River) polygon area, polygon mean depth, polygon mean velocity and mean bluehead and flannelmouth sucker density and biomass.

		Bluehead		Flannelmouth		Mean	Mean
polygon	Area	Density	Biomass	Density	Biomass	Depth	Velocity
lable	hectare	fish/ha	kg/ha	fish/ha	kg/ha	meters	m/s
DUFFY 80							
1	1.4	0		0		**0.37**	**0.11**
2	0.4	0		4		**0.23**	**0.36**
3	2.7	0		2		**0.84**	**0.05**
4	1.0	0		0		**0.40**	**0.08**
5	0.3	0		7		**0.41**	**0.18**
6	0.5	0		5		**0.30**	**0.21**
7	1.0	6		4		**0.46**	**0.14**
8	1.0	0		4		**0.26**	**0.25**
9	1.1	6		6		**0.28**	**0.15**
DUFFY 200							
1	1.6	0		0		**0.49**	**0.18**
2	0.6	0		0		**0.32**	**0.53**
3	2.9	4		0		**0.86**	**0.12**
4	1.1	0		0		**0.44**	**0.17**
5	0.4	59		0		**0.43**	**0.34**
6	0.5	0		0		**0.37**	**0.33**
7	1.2	26		1		**0.51**	**0.28**
8	1.2	40		1		**0.35**	**0.35**
9	1.3	16		1		**0.39**	**0.22**

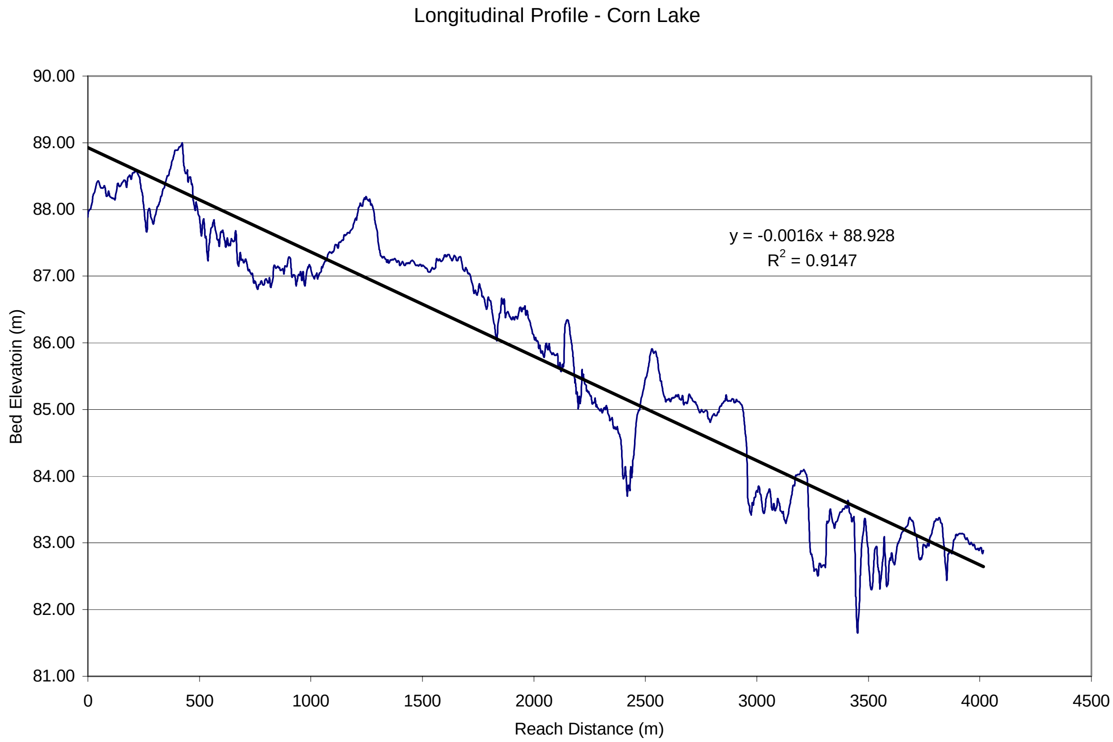


Figure 1. Longitudinal profile for Corn Lake site, Colorado River.

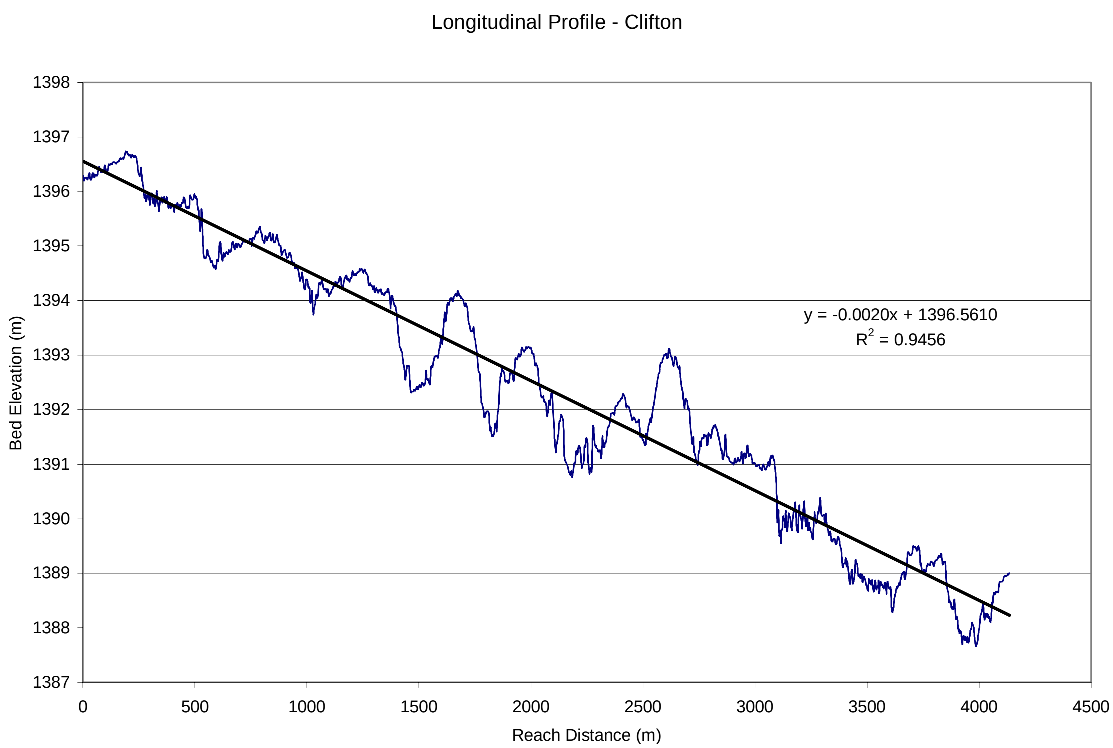


Figure 2. Longitudinal profile for Clifton site, Colorado River.

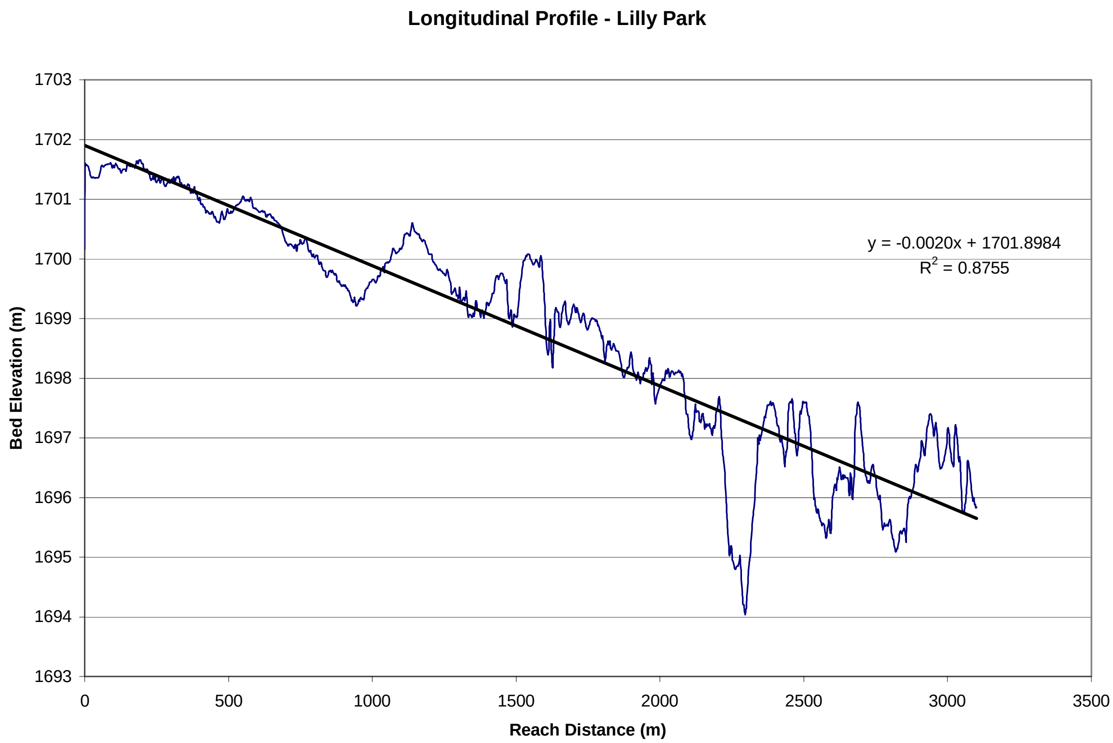


Figure 3. Longitudinal profile for Lily Park site, Yampa River.

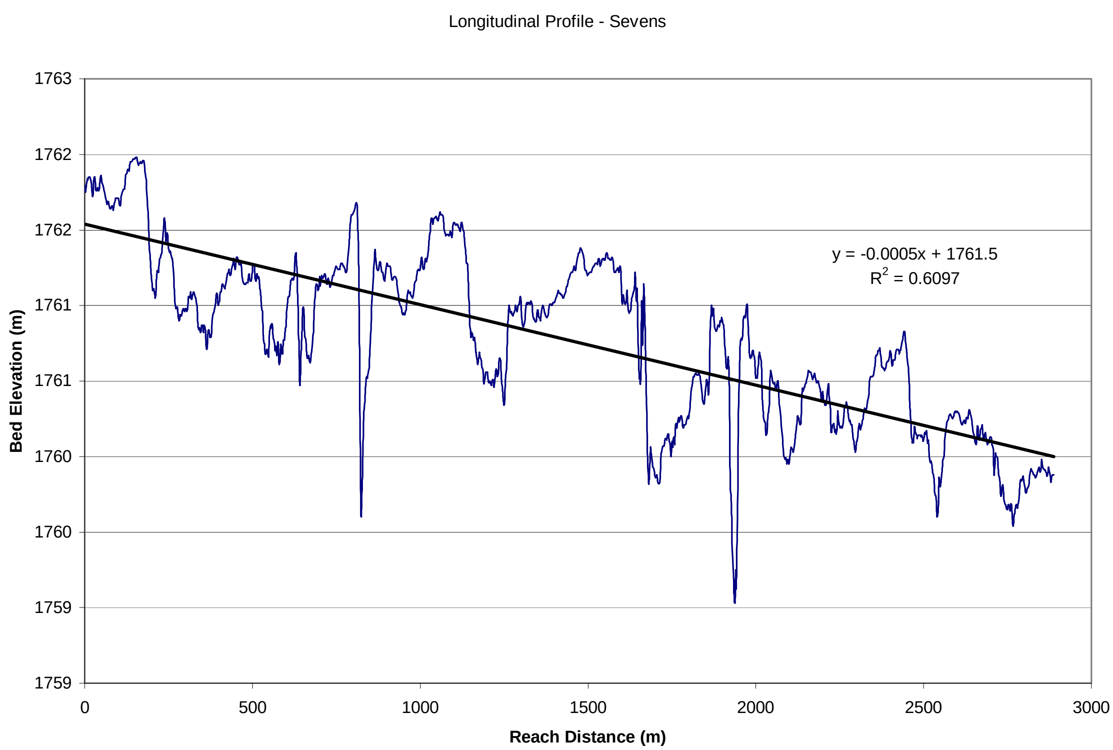


Figure 4. Longitudinal profile for Sevens site, Yampa River.

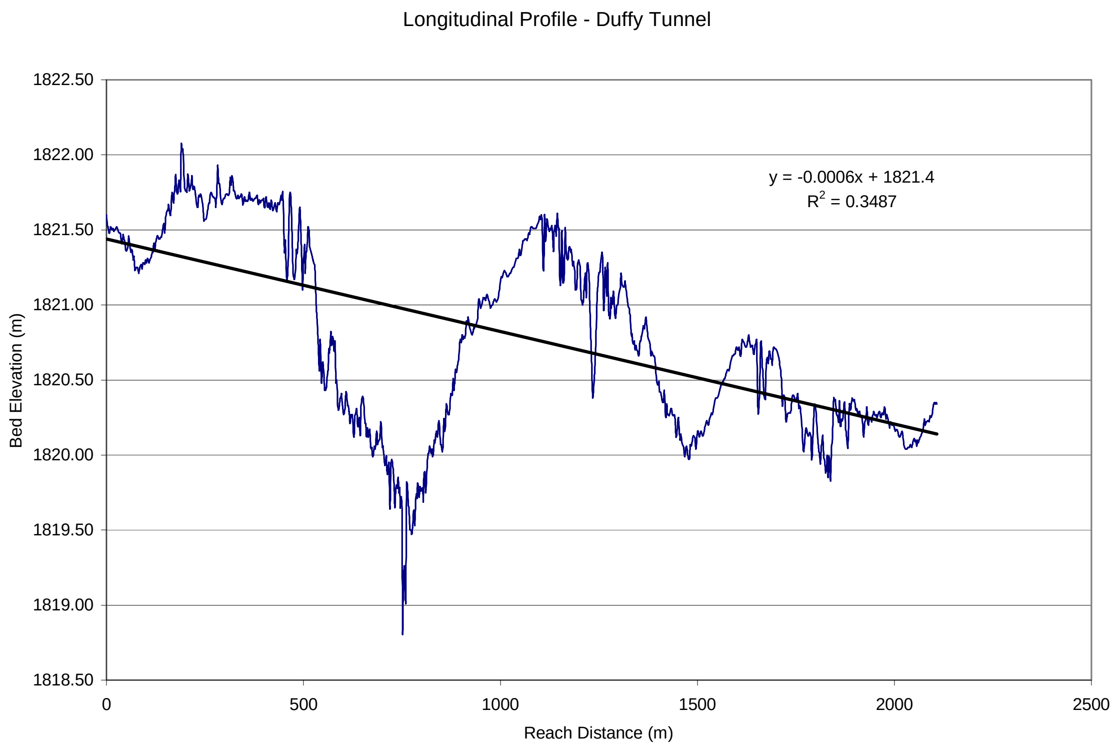


Figure 5. Longitudinal profile for Duffy site, Yampa River.

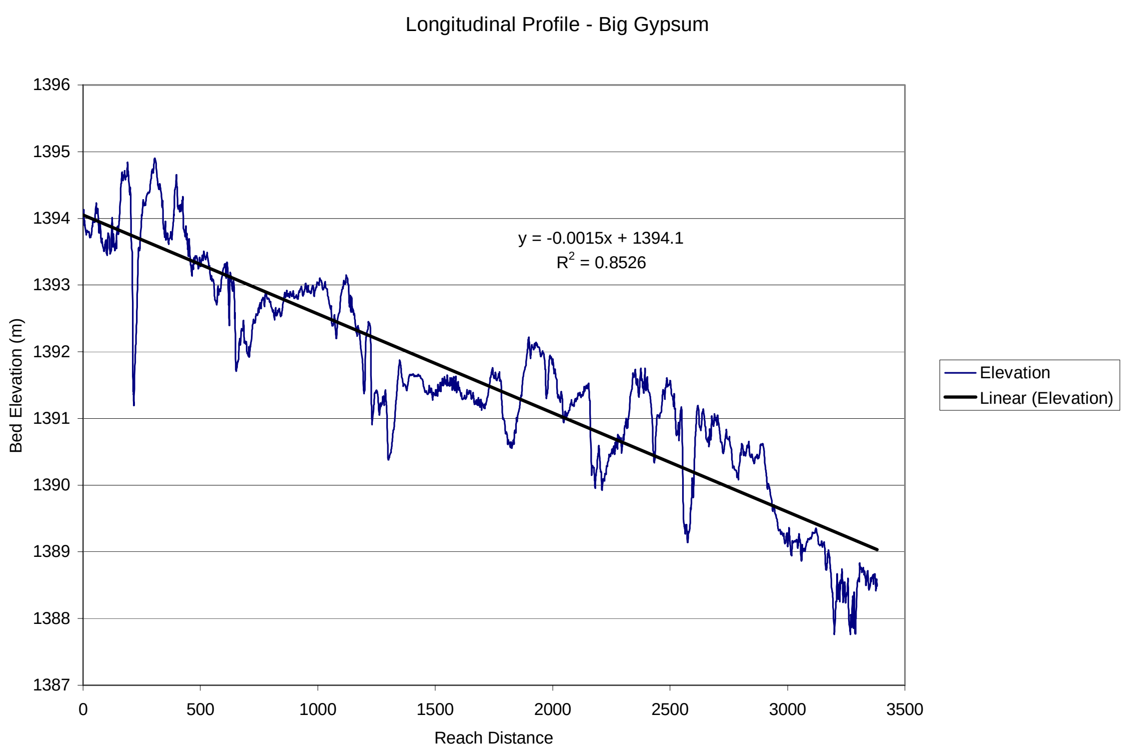


Figure 6. Longitudinal profile for Big Gypsum site, Dolores River.

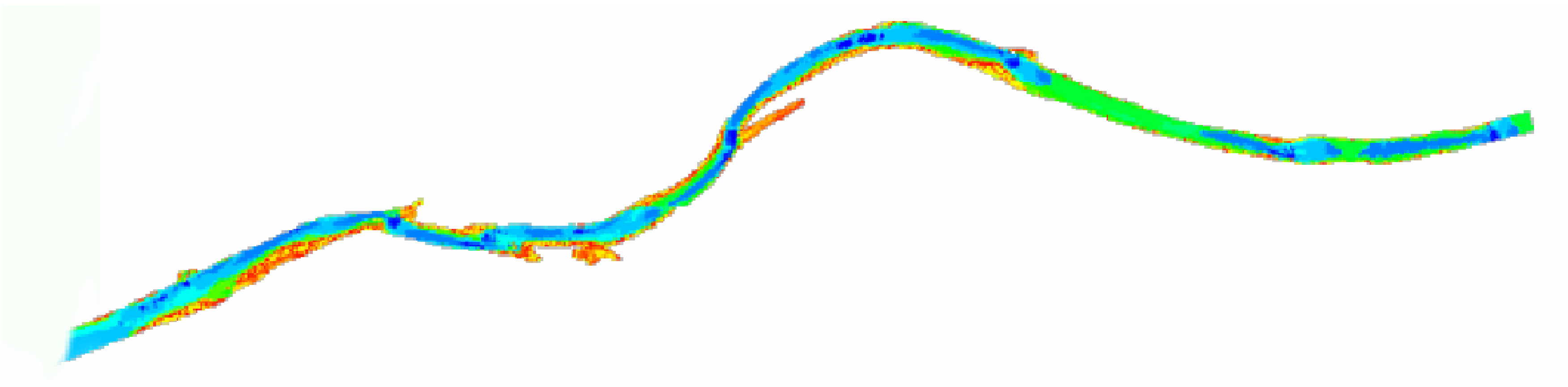


Figure A7. Corn Lake study site with meso-habitat distribution at 1000 cfs, Colorado River.

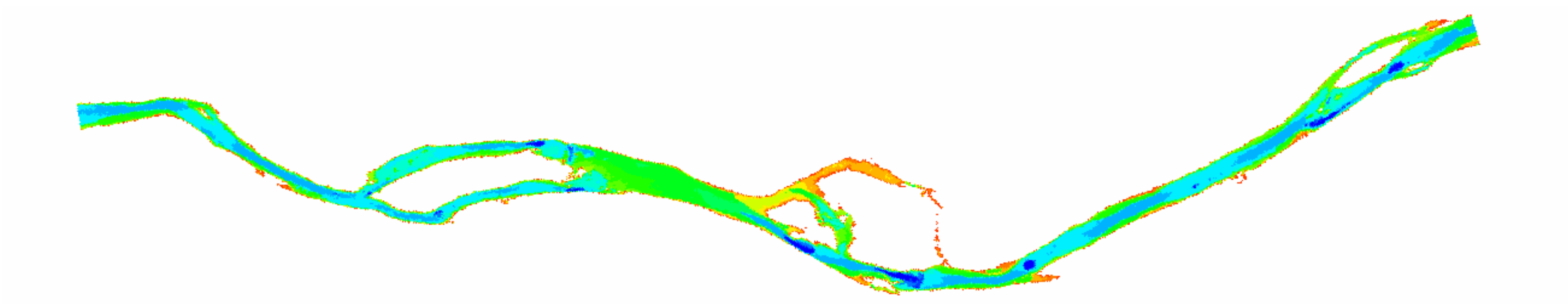


Figure A8. Clifton study site with meso-habitat distribution at 1000 cfs, Colorado River.

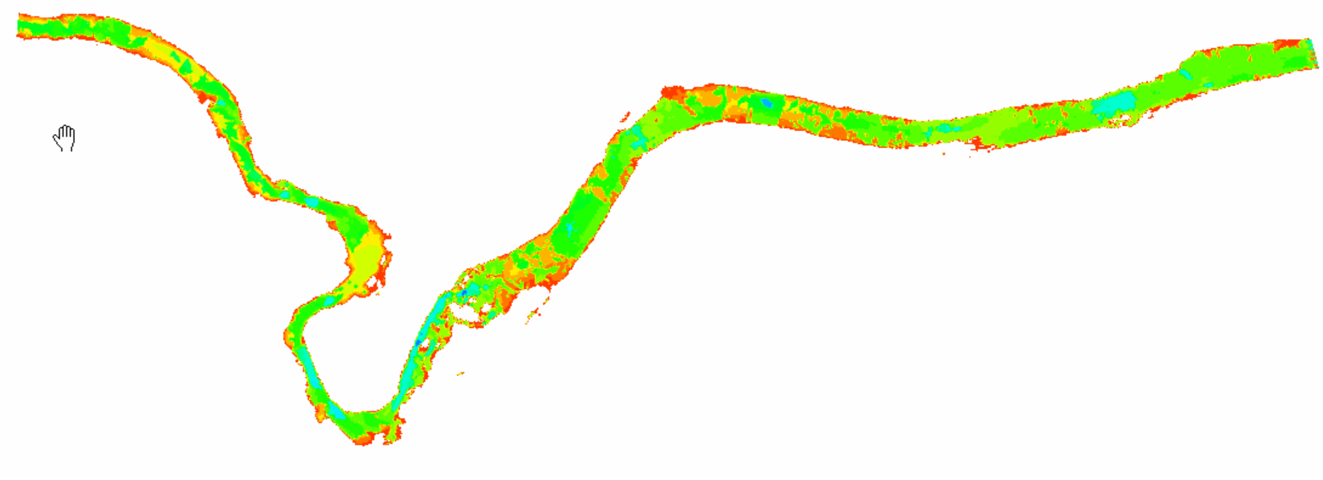


Figure A9. Lily Park study site with meso-habitat distribution at 200 cfs, Yampa River.

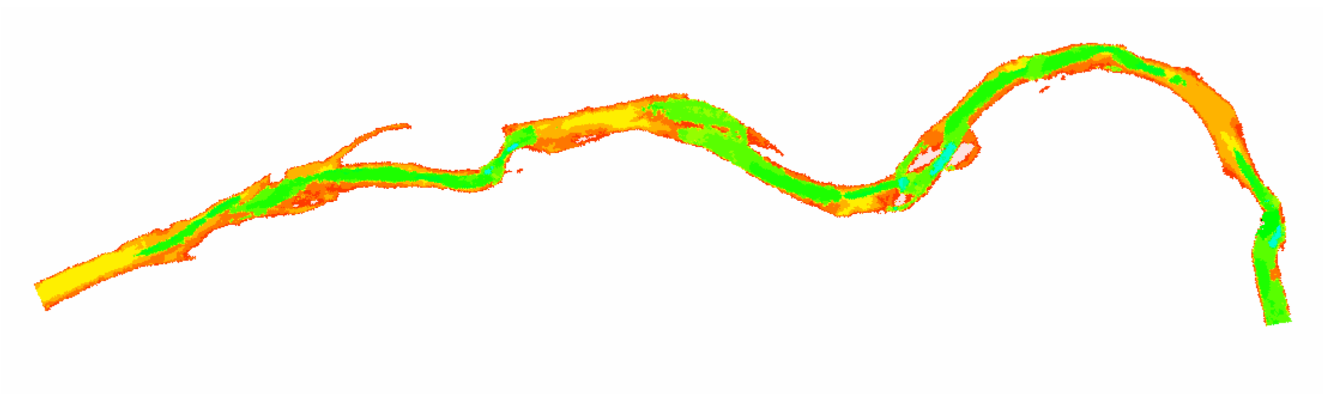
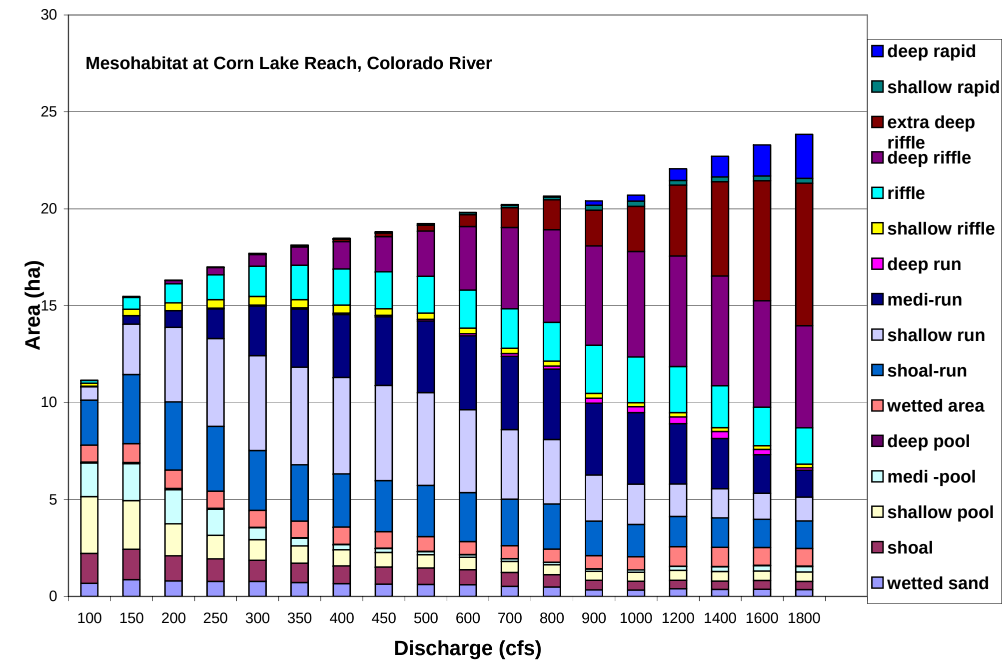
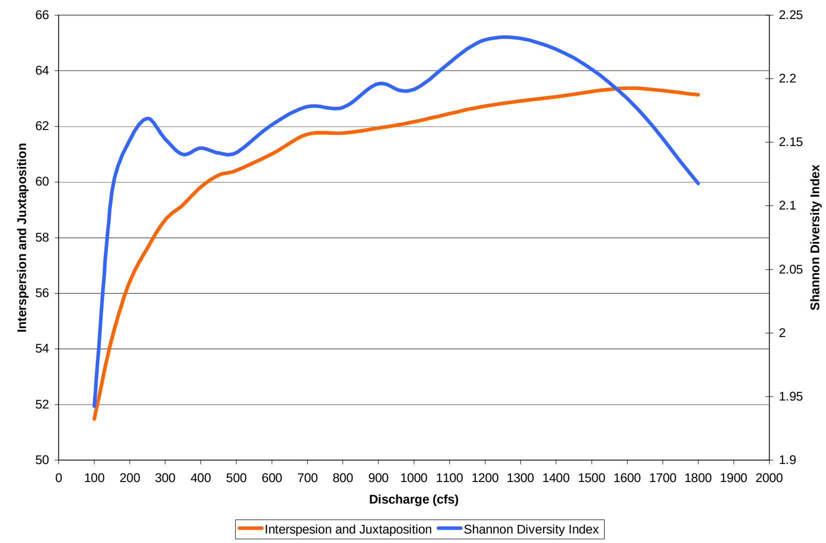
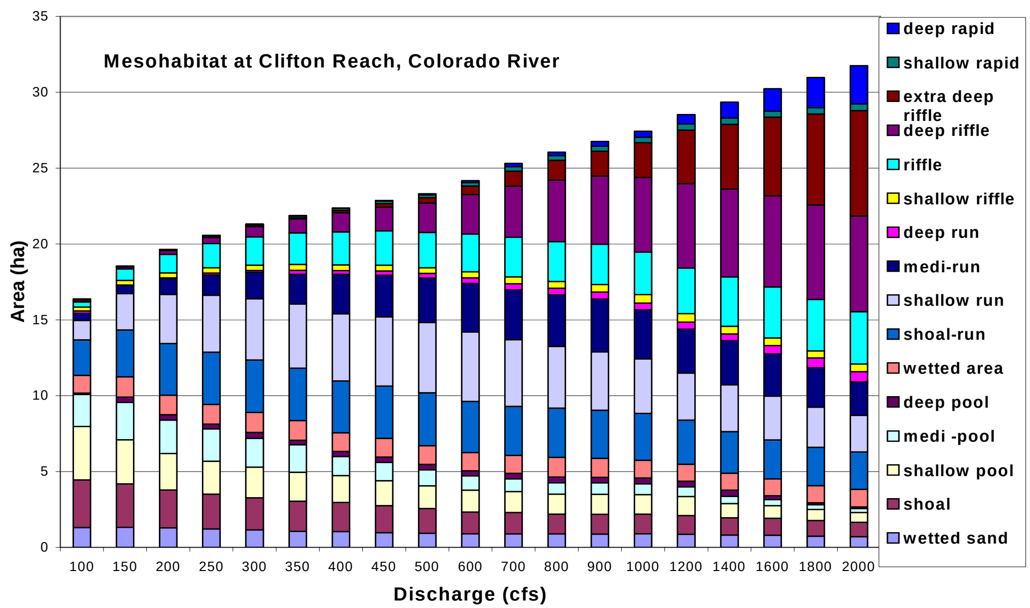
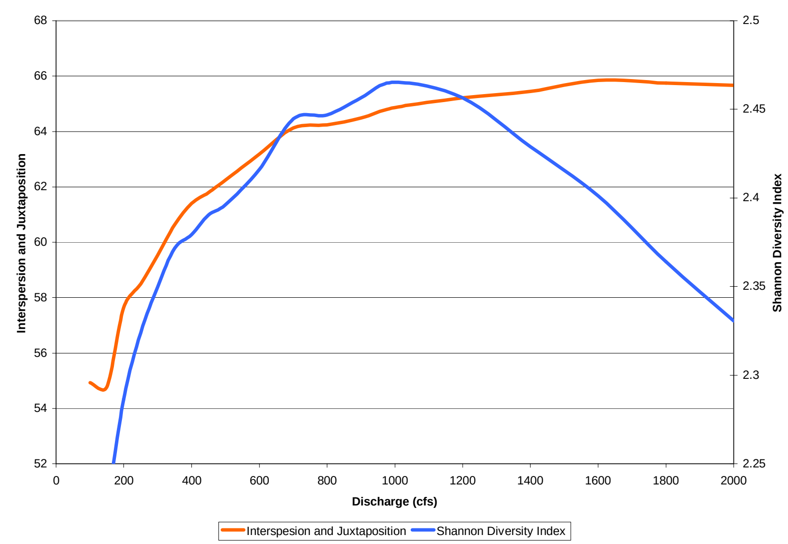


Figure A10. Sevens study site with meso-habitat distribution at 200 cfs, Yampa River.

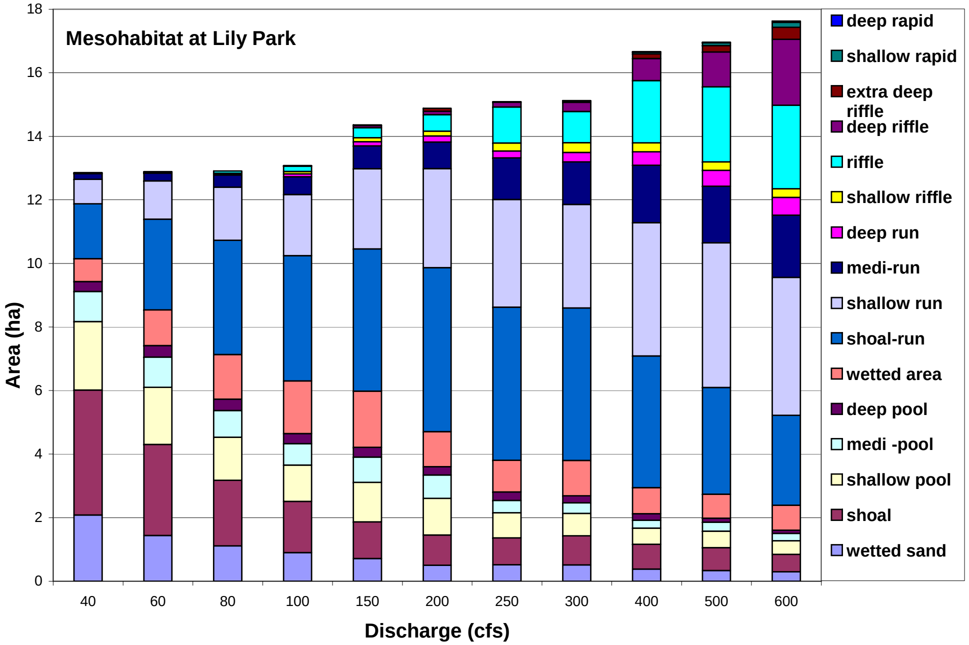


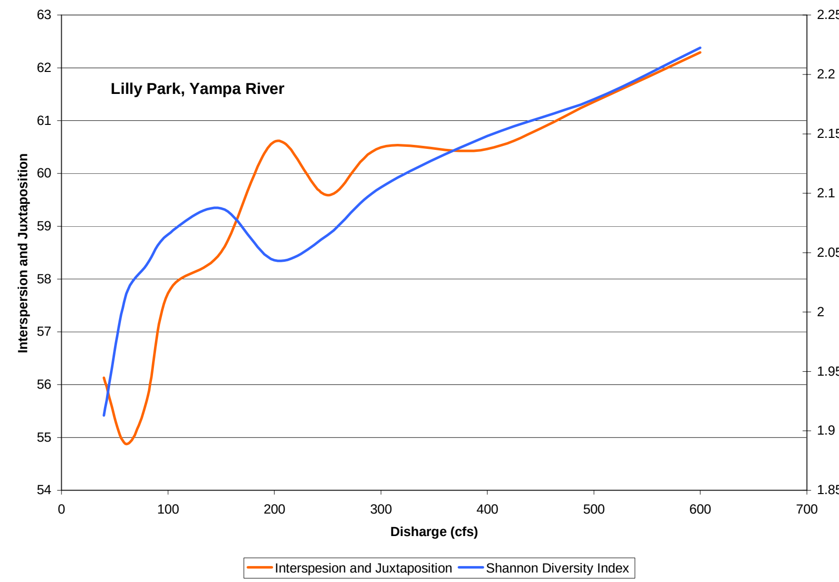


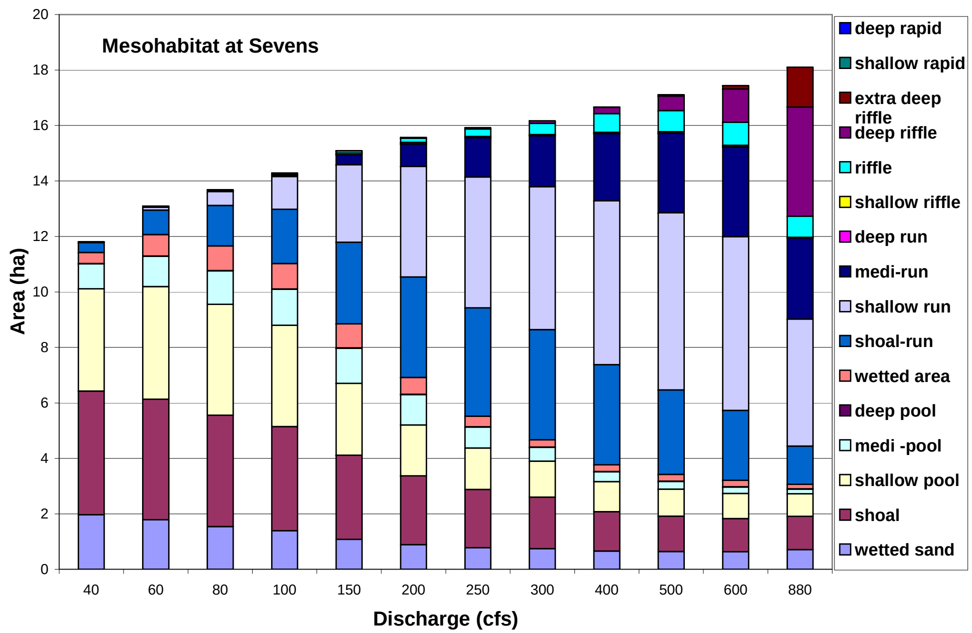


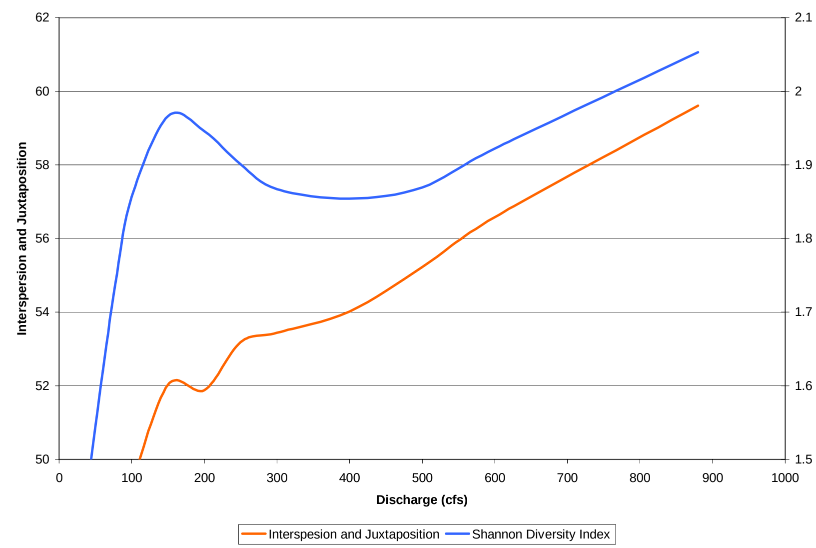


Figures A11 a, b, c, d. Meso-habitat and Shannon Diversity and Interspers
Clifton, Colorado River

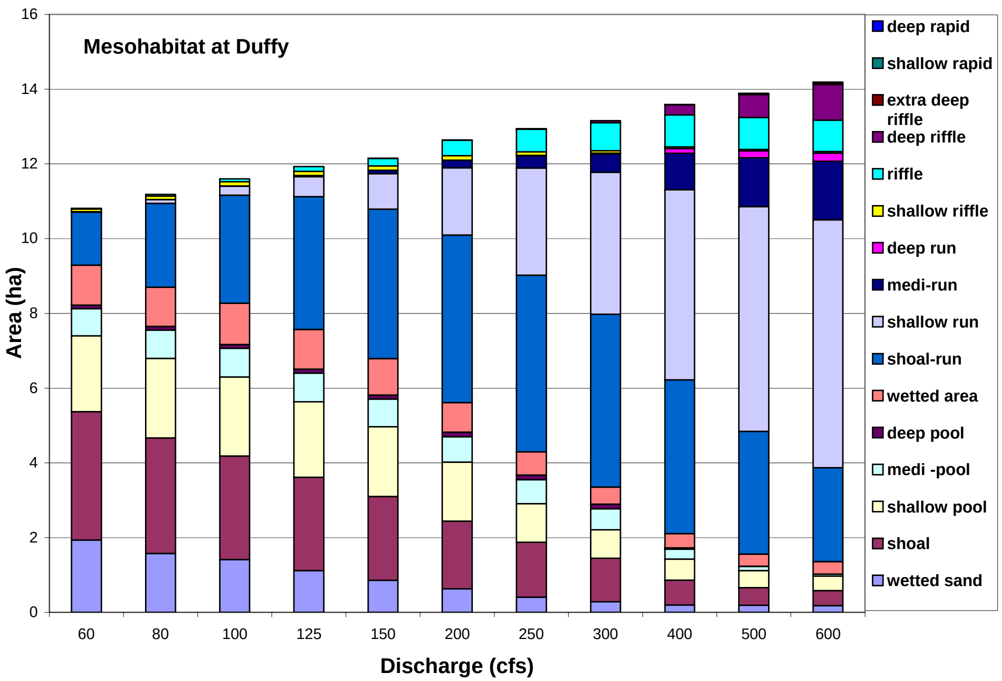


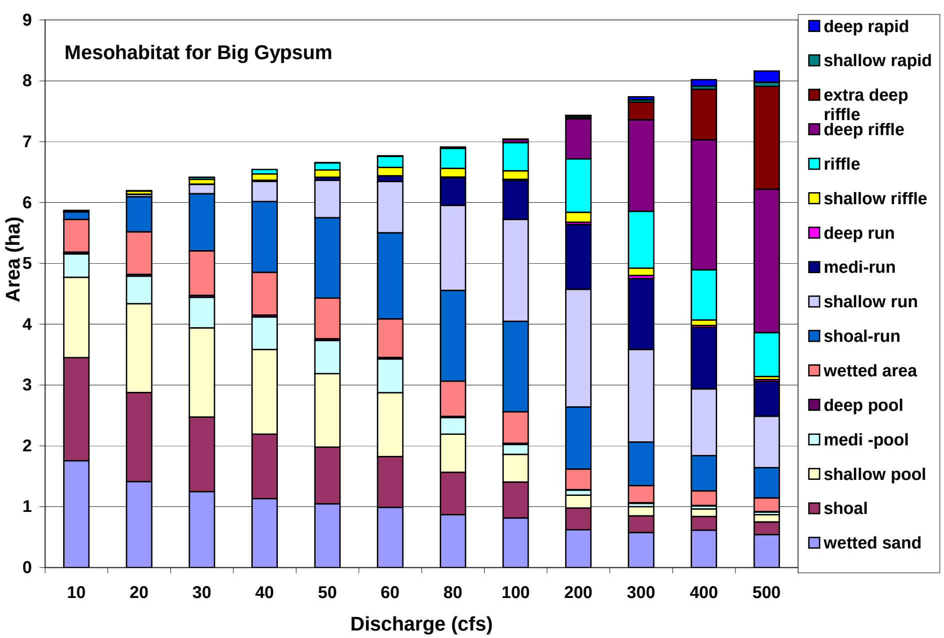


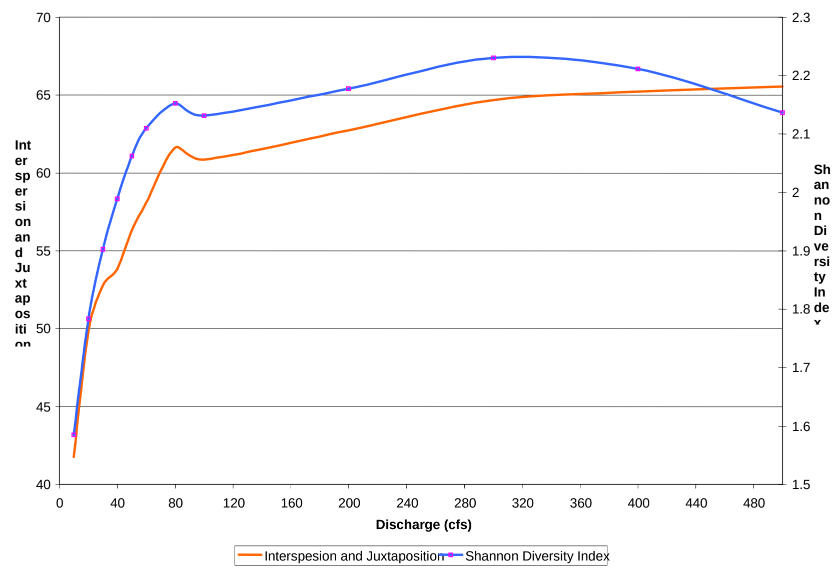




Figures A12 a, b, c, d. Meso-habitat and Shannon Diversity and Interspersion for modeled flows at Lily Park (above) and Sevens, Yampa River







Figures A13 a, b, c, d. Meso-habitat and Shannon Diversity and Interspersion for modeled flows at Duffy(above), Yampa River and Big Gypsum, Dolores River

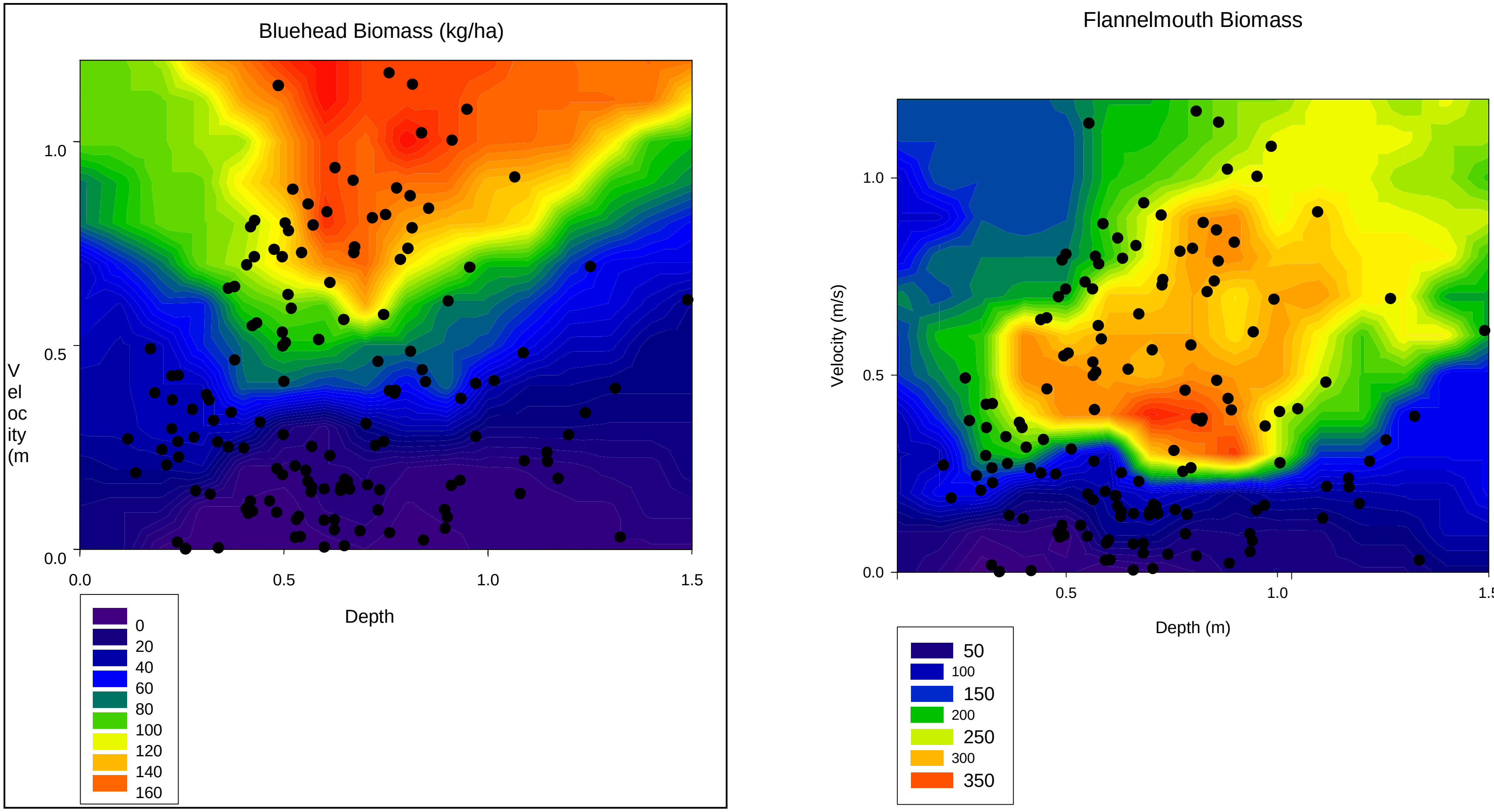


Figure A14. Sigma plot for Bluehehad (left) and Flannelmouth (right) sucker, showing biomass at polygon mean depth (x axis) and velocity (y axis).