RIVERINE FISH FLOW INVESTIGATIONS

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The results of the research investigations contained in this report represent work of the authors and may or may not have been implemented as Division of Wildlife policy by the Director or Wildlife Commission.

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INTRODUCTION

Habitat loss is one of the single greatest causes of declines in populations of native fishes in North America (Williams et al. 1989). The need to preserve minimum stream flows was recognized by the state of Colorado by the passage of Senate Bill 97 in 1973. Espegren (1998) states that most instream flow water right filings in Colorado have been for protecting minimum flow for cold water (headwater) habitats. The most common methodologies used in Colorado is the R2Cross method (Nehring 1979) and Instream Flow Incremental Methodology (IFIM) (Bovee 1982). IFIM estimates the amount of usable habitat for fish as a function of discharge by combining habitat suitability curves with the hydraulic model. The habitat component of the model has received much criticism because of assumptions implicit with using suitability curves and assumptions of positive relationships between habitat availability and fish abundance. Validation of these assumptions have been obstacles for successfully using IFIM to model minimum flow impacts on large warm water rivers of the west slope (Rose and Hahn 1989).

Currently there is no standardized approach to establish minimum flow needs on warm water river sections, and the use of sophisticated models appear to be required in high profile situations (Espegren 1998). Warm water fish assemblages appear to require a more intensive approach to instream flow modeling compared to cold water fish communities. Warm water river reaches tend to be lower gradient and have higher channel complexity and sediment loads. Warm water fish populations tend to have higher species diversity. Also habitat suitability curves derived from microhabitat observations do not adequately describe habitat use for many warm water species. A broader community-level perspective, as opposed to an indicator species approach, may be required to protect all habitats of a functioning warm water stream ecosystem.

Instream flow techniques require integration of two processes that combine detailed knowledge of habitat requirements (by species and life stage), and the availability of necessary habitats. Both the collection and analysis of these data bases have been very labor intensive. Recent advances in surveying technique (e.g. G.P.S.) and computer capabilities (G.I.S.) allow for collection and processing of much larger databases. Also, two-dimensional (2-D) flow models may have potential for application in instream flow studies (Leclerc *et al.*, 1995; Bovee, 1996). In theory, 2-D models offer a significant improvement over one-dimensional (1-D) modeling by increasing spatial resolution, allowing for highly accurate quantification of physical habitat availability. A spatially explicit flow model may eliminate the need for microhabitat suitability curves used by IFIM, and also improve biological resolution of the method. Presently, however 2d modeling is not widely used for fishery applications and is still an unknown commodity as far as it practicality for instream flow assessment.

The original intent of this study was to develop and validate a methodology for determining instream flow recommendations for warm water fish communities in Colorado (Anderson 1999). This is to be accomplished by determining relationships between habitat availability and flow using a 2-D flow model to simulate meso-habitat diversity and abundance over a range of low flows on several sections of three different rivers. Also fish population and species' life history data will be collected within each of the study sites to provide habitat use and preference data to determine relationships between base flows and habitat availability for native fish species of warm water riverine fish communities.

A new study goal was added in 1999 to submit instream flow recommendations for the Yampa River and Colorado River in the 15-Mile Reach to the Colorado Water Conservation Board (CWCB), with biological justifications for a water right filings in those rivers, by August 2002. The CWCB withdrew water rights filings made in 1995 for these rivers. The

1995 filings were based on recommendations made by the U. S. Fish and Wildlife Service (USFWS) in regard to recovery of endangered fish species [Modde and Smith (1995) and Osmundson et al. (1995)]. In a more recent study Modde et al. (1999) used an infection point method to assess minimum stream flow needs for Colorado pikeminnow (*Ptychocheilus lucius*) on the Yampa River. Even though the intent of these studies was the same, to determine stream flow requirements for endangered fish, the methods in each study were different. The CWCB expressed a desire to have a more standardized approach for instream flow filings and it is hope that recommendations using this approach will be acceptable to agencies involved with endangered species recovery.

Study Objectives:

1). Model fish habitat availability on warm water sections of three rivers (Yampa, Colorado and Dolores) using the established methods (1d models) and evaluate the practically of using 2d flow models to quantify fish habitat.

2). Determine community structure, density and biomass for fish assemblages for river reaches listed above.

3). Test for relationships between habitat availability and fish abundance.

4). Develop and validate methodologies that use 1-D and 2-D flow models for the Division of Wildlife to use for minimum instream flow recommendations for the warm water sections of the Yampa and Colorado rivers.

STUDY AREA

Yampa River

The study site located at River Mile (RM) 63 is referred to as the Sevens, since most of this site is on the Sevens Ranch (Figure 1). Between RM 59 and 85, most of the river bottom is on private property and is used for grazing or hay fields. In 1999 the river channel was mapped from RM 63.1 to RM 62.5 for a total of 1.0-km. A 2.7-km reach was electro-fished in 1999, from RM 63.9 to 62.2. In 1998 the surveyed site was less (0.8 km), but a larger section of the river (6.1-km) was electro-fished last year, from RM 66.0 to 62.2.

The Duffy site is centered near River Mile 109.5, in the lower part of Little Yampa Canyon (Figure 1). Little Yampa Canyon extends from about RM 105 to RM 121. Here one side of the river is usually on a canyon wall and the BLM is the primary landowner. In some sections large boulders provide instream cover in pool and run habitats. A 2.2-km section of river channel was mapped in 1999, from RM 110.25 to 108.9. The electrofishing station shifted upstream about 0.5 mile in 1999 compared to last year, and was from RM 110.5 to RM 105.5 (8.0 km). It was from RM 109.9 to RM 104.8 (8.1 km) in 1998. This upstream shift was due to the fact that the size of channel surveyed was enlarged both up and downstream.

Flows at Sevens (RM 63) were based on the Maybell gage located at RM 85.8. The Maybell gage has been in continuous operation since May 1, 1916. During the irrigation season, flows recorded at Sevens may be somewhat higher, due to return flows from lands irrigated by the Maybell Canal diverted at RM 89. Flows at Duffy (RM 109) were determined by combining records from the Craig gage (RM 140) with the gage at the confluence of the Williams Fork (RM 127).

Peak flow for 1998 was 10,040 cfs and it was 9,980 cfs for 1999, which rank 44th and 39th, respectively for the Maybell gage 84-year period of record. The median peak flow for the 84 -year period is 10,000 cfs. Prior to 1999 there were four consecutive years with peaks above the median, indicating the hydrograph in recent years has been in a wetter than normal cycle and the last two years are medial (Figure 2). In contrast to the peak flows, base flows

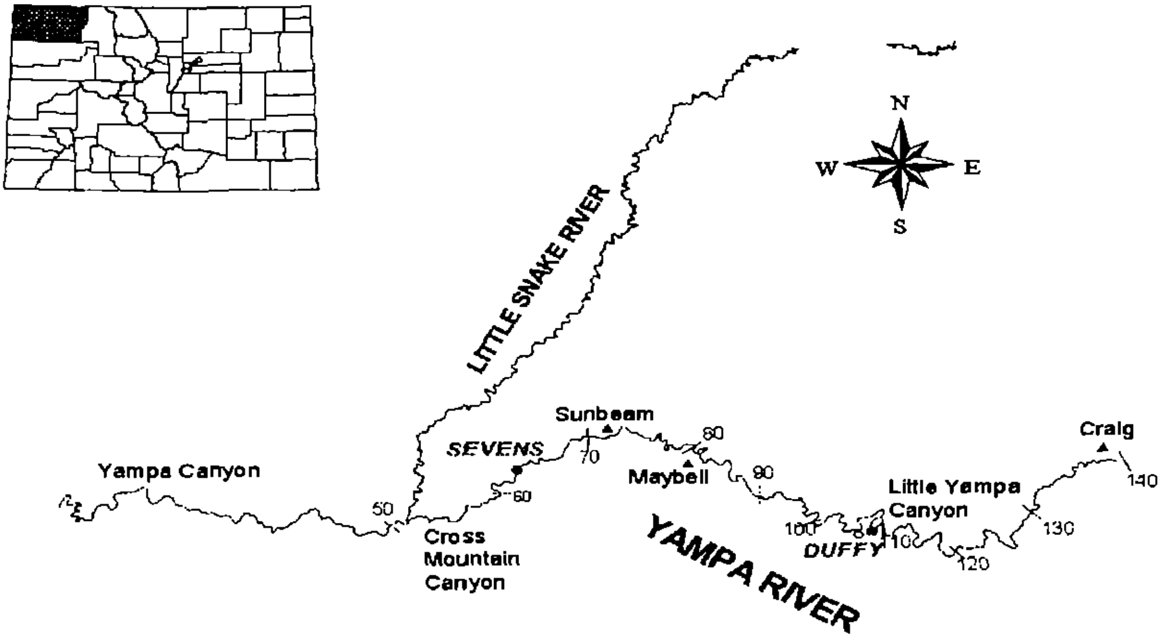

Figure 1. Location of the two study sites on the Yampa River, the Sevens at River Mile 63 and Duffy at River Mile 109.5.

have not been consistently above the median (which is 128 cfs) for the last five years (Figure 3). The minimum flow in 1999 was 168 cfs and 115 cfs in 1998. The 10-day minimum flow for both 1998 (179 cfs) and 1999 (212 cfs) however has been above the median (153 cfs) indicating that base flow conditions during the last two years have also been medial (Figure 3).

Gage records for Maybell (RM 86) were compared to gage records from above the Maybell diversion canal (RM 89) by combining flow from the Yampa River at Craig (RM 134) and the Williams Fork at its confluence with the Yampa (RM 130). Gage recording began for Craig and William Fork in October 1984, so the comparison represents the last 15

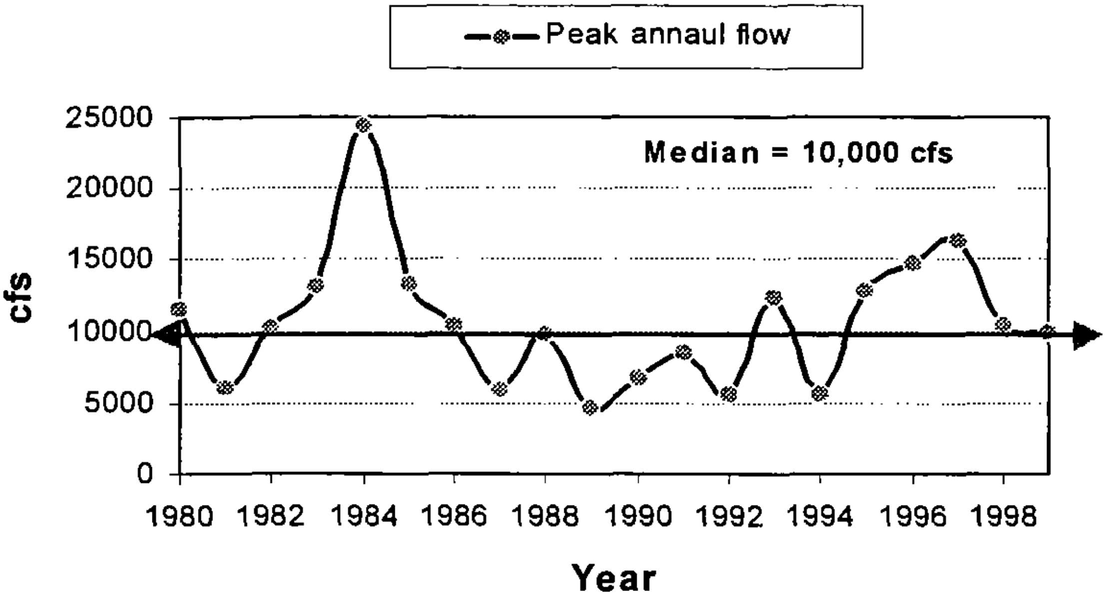

Figure 2. Peak annual flow recorded at the Maybell gage, Yampa River for the last 20- year period. Median flow for the 84-year period of Record is 10,000 cfs.

years 1985 to 1999. During the spring runoff season (March through June) flows representing both areas were very similar (Figure A1.1) and flow at the Maybell gage averaged 2% higher than the two combined upstream gages. During the summer months (July to October) flows at Maybell averaged 6.2% less than the two upstream gages (Figure A1.2). Mean flows were again higher at Maybell during the winter (November, December, January and February) by an average of 7.4%.

Tables A1.1 and A1.2 show the difference in mean monthly and minimum flows for the Maybell gage and for upstream of the Maybell canal in August and September. Anderson (1997) identified an average inflection point occurred at 93 cfs in the relationship between channel width and flow in 30 riffle cross sections in this part of the Yampa River. He believed this inflection point represents a reference flow in regard to severe degradation of fishery habitats. In four of the 15 years, 1985 to 1999, minimum flows were below 93 cfs in August. During September minimum flows were below 93 cfs in 6 years at the Maybell gage and five years upstream of the Maybell canal. In September the minimum flow at Maybell averaged 38 cfs less than the combined flow of Craig and William Fork gages.

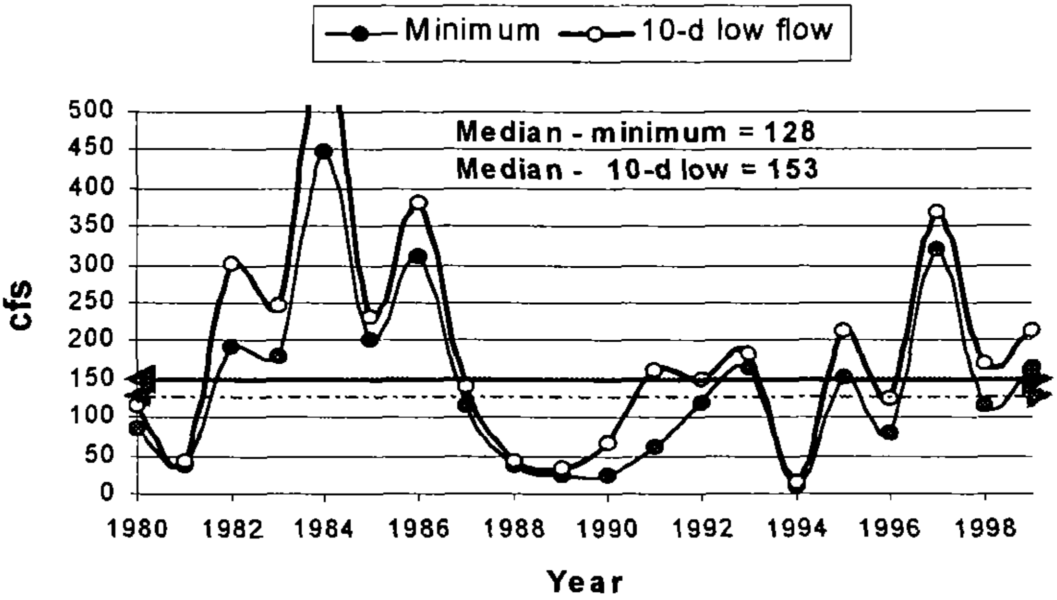

Figure 3. Minimum flow and the 10-day low flow for the last 20 years recorded at the Maybell gage, Yampa River, with a dashed line to indicate the 84-year median for the minimum (128 cfs) and a solid line for the 10-day low flow (153 cfs).

Colorado River – 15-Mile Reach

The 15-Mile Reach of the Colorado River is from Palisade, Colorado (RM 185) downstream to the confluence of the Gunnison River at about RM 170 (Figure 4). Two major upstream diversions dewater the river in the 15-Mile Reach during the irrigation season (April 1 to November 5). The Government Highline diversion is located in lower Debeque Canyon (RM 193.7) and the Highline canal has a capacity of 1,620 cfs. The Grand Valley diversion dam is at RM 185.4 and the Grand Valley canal has a capacity of 640 cfs. A USGS gauge is located about 0.4 km downstream from the intake for the Grand Valley canal (Figure 4). The study site is a 4-km section located from RM 177.4, which is at the boat launch at Corn Lake, downstream to RM 174.9.

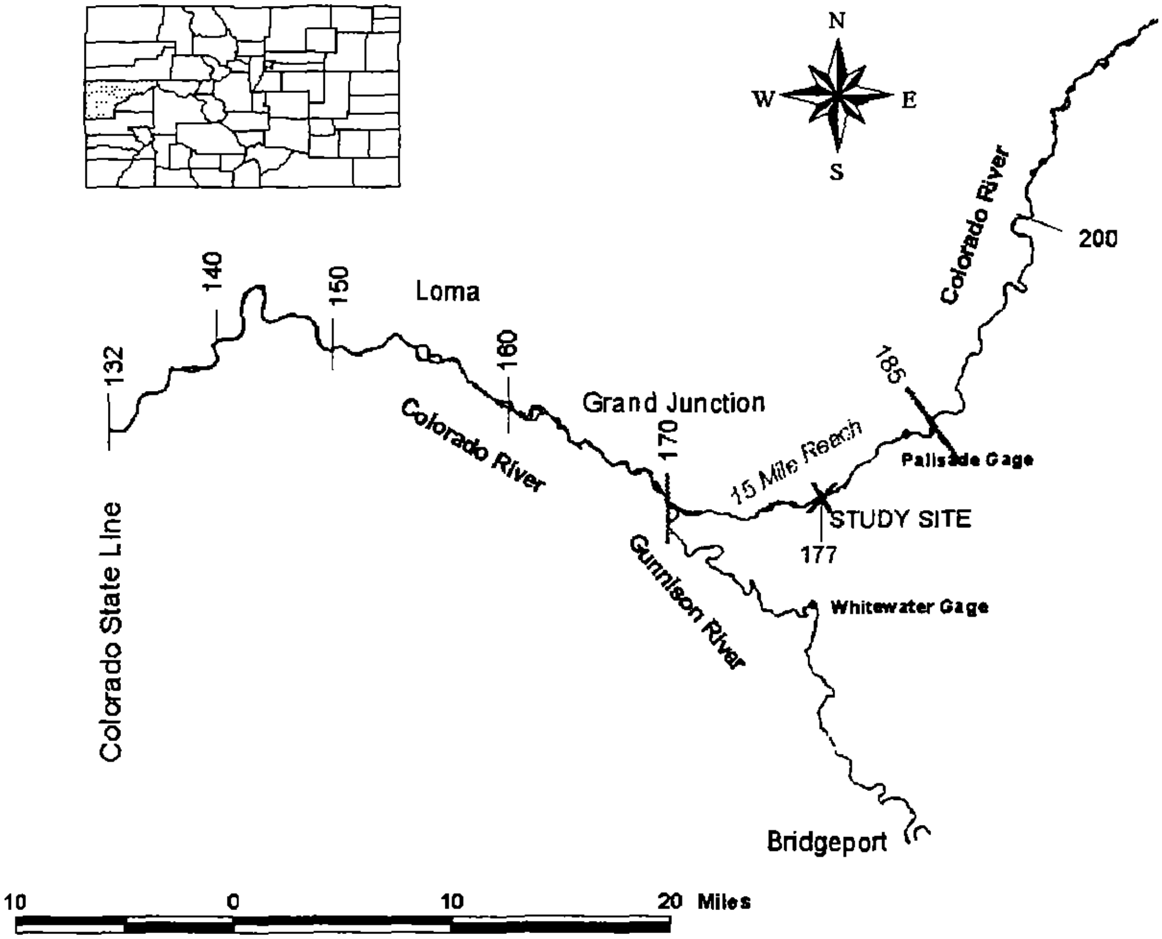

Figure 4. Location of study area in the 15-Mile Reach, Colorado River.

It appears that low flows are not a factor during the non-irrigation season in the 15-mile reach. Winter (November to March) flows recorded at the Cameo gage (RM 199.9) and in the 15-Mile Reach appear to be native or higher due to the senior water right at the Shoshone power Plant in Glenwood Canyon. Also there are some releases for power generation from Green Mountain (Per comm. Karen Flogequest USBR). Flows recorded at Palisade are usually higher than at Cameo between November and April due to Plateau Creek which joins the river at RM 193.3 (Appendix Figure 1.3).

Lower than native flows are typical during the irrigation season (April to October) in the 15-Mile Reach. Flows at the Palisade gage are typically 1,200 to 1,600 cfs less than Cameo, except in June when runoff flows from Plateau Creek compensate for diversions into the Highline canal (Figure A1.3). In Cameo flow generally increases from 2,000 to 4,000 cfs during the month of April in contrast to Palisade where flows can decrease in April before runoff begins (Figure A1.3).

Efforts are currently underway to manage late summer and fall flows in the 15-Mile Reach to benefit the recovery of endangered fish. The results of coordinated efforts involving the BOR, reservoir operators and irrigation companies resulted in increased flows in the 15 Mile Reach during the 1999 irrigation season (BOR, draft report).

The peak flow (12,700 cfs) for the Palisade gage in 1999 was on June 10 (Appendix Figure A1.2). The median peak flow for the nine-year Palisade gage history is 12,500 cfs indicating that peak flow was near normal in 1999. In 1999 flow during the ascending limb of the hydrograph were lower than typical (Figure 5). Flow was near the norm of 2,000 cfs during March, but dropped to 435 cfs on April 15, and did not return to 2,000 cfs until May 2. Flows at Palisade during summer were near to above the medial conditions, but flows from mid September through October were typical of a wet year (Figure 6).

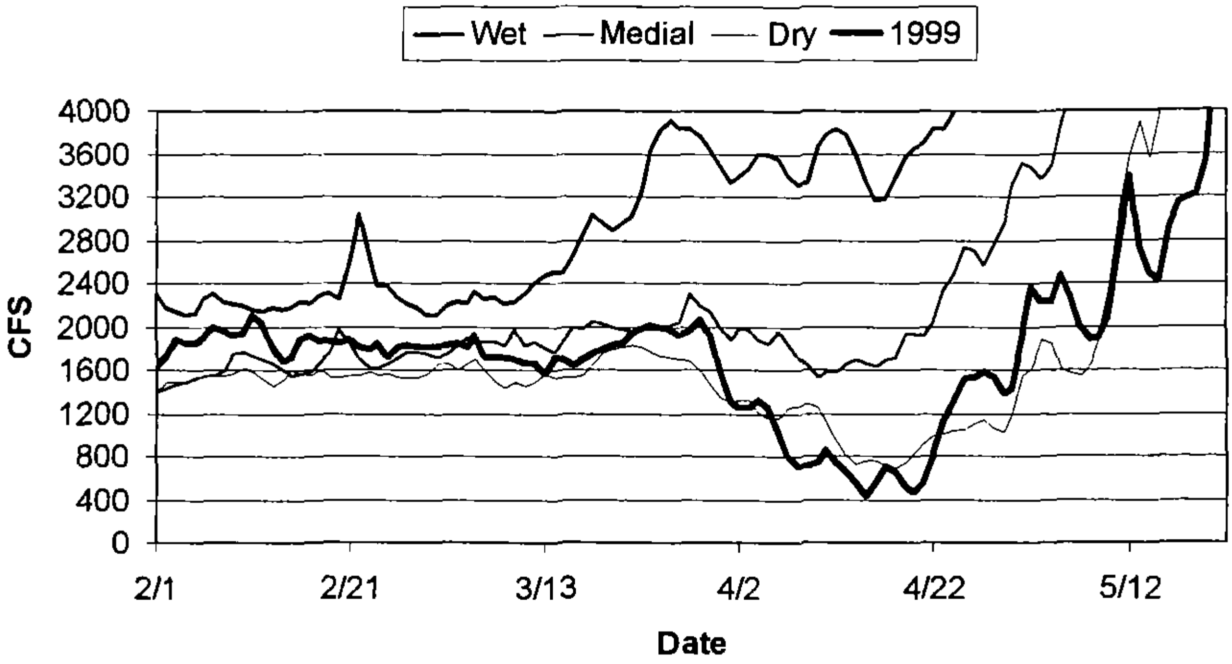

Figure 5: 1999 flows between February 1 and May 31, Palisade gage and mean flow for wet, medial and dry years for the gage period of record (9 years).

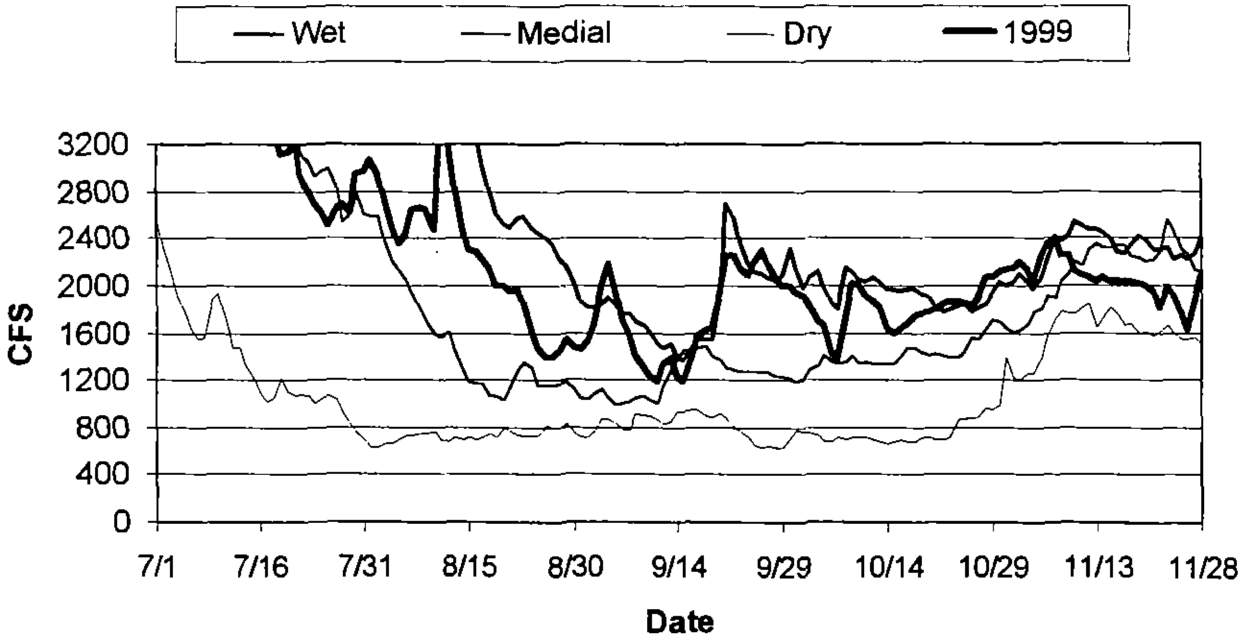

Figure 6: 1999 flows between July 1 and November 30, Palisade gage and mean flow for wet, medial and dry years for the gage period of record (9 years).

METHODS

FISH SAMPLES

Fish were electro-shocked and netted from an Achilles raft using a Smith-Root electrofisher powered by a 5000-watt generator with the anode mounted on a forward boom. The boat was maneuvered by either oars or by a battery powered 40 pound 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 150mm were marked and therefore used for mark and recapture population estimates. The Darroch multiple mark method (Everhart and Youngs 1981) was used to estimate abundance with ninety-five percent confidence intervals.

Sections of river both up and downstream of the mapped site were electrofished on the Yampa and Colorado Rivers. Fish were measured and released at specific locations in each study reach. The stops were typically above each riffle. This allowed for a qualitative assessment for species composition and relative abundance in each riffle-run sequence in the sample reach. 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 changed sequences between captures. Four total passes were made at the Sevens stations, on August 30, September 1, 14 and 16. Flow on those dates (Maybell gage) were 315 cfs, 280 cfs, 219 cfs and 201 cfs, respectively. The reach from the Duffy run above the launch to the lower end was electro-fished on August 25, September 2, 15 and 17. The flows on those dates were 302 cfs, 347 cfs, 293 cfs and 265. The upper section and the run directly upstream of the launch site were electro-fished on August 23, 24, September 1, and September 7 at flows of 340 cfs, 302 cfs, 318 cfs and 370 cfs.

In the 15-Mile reach study site fish were marked to designate the upper, middle and lower sections of the site. Also the mark on the 15-Mile Reach indicated on which side of the river the fish was caught. Eight electrofishing passes were made in this study site. The dates and the flow (cfs) of the fish sampling were 9/28 (2,060), 9/29 (2,000), 9/30 (1,990), 10/5 (1,660), 10/6 (1,420), 10/8(1,740) and 10/12 (1,860). To determine if marked fish could be recaptured upstream, a 4.8 km reach was sampled from RM 180.4 to RM 177.4 (upper terminus of study site) on October 13 and 14. A 4.5 km section of river was electro-fished immediately downstream of the study site (RM 174.9) to RM 172.1 on October 15 and 18.

HABITAT MAPPING

The use of two-dimensional flow models requires intensive channel mapping so that the modeled reach can be accurately represented. The collection of this data can be very time consuming and may represent a large proportion of the project cost. There are several ways topographic and flow data can be collected, and several different methods were used in this study.

Total Station

In 1998, bathymetry was collected at two locations on the Yampa River using a Pentax PTSIII total station. A total station gives flexibility to the user and allows them to determine which survey points are necessary to represent the topography and to only gather data at those points. Total stations calculate positions using basic trigonometric relationships. The total station uses a laser beam to determine the distance to a survey prism and simultaneously measures the horizontal and vertical angles to the prism. Machine accuracy is represented by the precision to which angles can be measured and distances can be measured. Because distance can be measured repeatedly and can be averaged, accuracy is generally contingent upon angle measurement and can be expressed as a function of the measurement distance. With a horizontal and vertical accuracy of 3 arc seconds, the relative horizontal and vertical error is 1.45E-5 of the measurement distance. Because an effort was made to not shoot points at a distance of more than 1000ft from the total station, the amount of error introduced by the machine was limited to less than +/- 4mm.

Global Positioning Systems and Sonar

In 1999, a second technique was used to gather bathymetric surveys of the channel. Global Positioning Systems (GPS) and sonar technology were used together to allow the mapping of the channel from a moving boat, thereby gathering a large amount of data in a short amount of time. In recent years there have been advances in GPS technology but the basic concept of GPS remains the same. GPS satellites with known orbits broadcast pseudo random code which is synchronized to universal time. A GPS receiver receives the signal and calculates a distance to the satellites based on the amount of time required for the signal to reach the receiver. Using trigonometry, it is possible to locate a single point in space if you know the distance to four other known points.

The GPS satellites have atomic clocks on board which allow them to all broadcast pseudo random code in complete synchronicity. Because the receiver does not have an atomic clock on board from which to determine universal time, it looks for a single time correction that will allow the receiver to resolve the four time signals to into a single point. Once the receiver has determined universal time, it can then determine the time offset and distance to the satellites.

When calculating a GPS position, vertical distance is the hardest to accurately calculate due to the relative position of the satellites, errors introduced by the atmosphere, and method by which the receiver calculates universal time. Because the errors in bathymetry mapped by GPS and sonar represent the sum of the errors in the sonar and GPS data, it is very important to use a very high quality GPS system. The GPS system used in this study was a Javad Oddessy L1/L2 RTK GPS with Glonass and Multi-path reduction options turned on. This system has a published vertical accuracy of 15mm +/- 1.5 ppm. As a quick test of the accuracy of the system in the field, a single point was surveyed repeatedly at a rate of about once per minute. The point was located approximately 1km from the base station and the standard deviation of the elevations was 0.002 meters which suggests that the positions gained from the GPS were good to +/- 5mm.

The sonar unit used was an ODOM Hyrographic Systems, Hydrotrac - Single Frequency, Portable Survey Sounder. This unit used a 200kHZ frequency with a published accuracy of 1cm +/- 1% of depth and an output resolution of 1cm. No detailed study was made to verify the accuracy of the sonar unit due to time constraints and the difficulty of making such determinations in a river system. However, the Hydrotrac outputs depth in realtime to a screen which is visible to the user and by watching the realtime output of data when the boat was still or in a section of river with plainbed features, it was possible to visually verify that the readings did not generally vary by more than 1cm.

One of the greatest hindrances to using sonar to map the channel bottom is that there is a minimum depth requirement. In order for the sonar to get a reading off the bottom of the channel, the transducer must have at least half a meter of water underneath it. The transducer was located approximately 15cm underwater as to give room to roll and minimize air entrainment under the transducer head making it difficult to gather bathymetric data in areas shallower than 75cm.

Acoustic Doppler and Marsh McBernie Velocity Meters

For model calibration it is important to have observed 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 requires another set of instruments. Two different technologies were used for measuring velocities in this project.

In 1998, a Marsh McBernie Flo-Mate Portable Flowmeter was used in conjunction with the total station to determine point velocities. The Marsh McBernie has a published accuracy of 1.5cm/s +/- 2% of reading and is based on the electrical principle known as Faraday's Law, where the flow rate of the fluid can be determined by passing a conductive fluid through a magnetic field. A wading rod used to hold the meter head which is placed at a depth chosen to represent average velocity (usually .6 of total depth) Locations were recorded by shooting the point with the total station and then recording the average of three 10-second readings.

In larger rivers with high velocities and deep areas, 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 purchased to gather calibration data on the 15-mile reach of the Colorado River. The ADP measures the velocity of water using a physical principle called the Doppler shift. This states that if a source of sound is moving relative to the receiver, the frequency of the sound at the receiver is shifted from the transmit frequency. By determining the Doppler shift using three beams, it is 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, it is possible to compute absolute velocity and direction. The ADP measures velocities in 15cm vertical increments down to the river bottom. These velocities are averaged over a specified time interval.

1998 Duffy Tunnel and Sevens Surveys

During July and August of 1998, we used the Pentax PTSIII total station to obtain XYZ coordinates for two reaches on the Yampa River (Figure 1). The first reach was located approximately 15 miles upstream of Juniper Hotsprings near the Duffy Tunnel diversion. This site is approximately 1.3 km long and 3777 data points were collected. The second site was located adjacent to Cross Mountain Ranch approximately five miles upstream of Cross Mountain Canyon. This site was approximately 1.2 km long and was represented by 1900 data points.

To make sure that the data collected at each of the sites could be used in future research, a conscious effort was made to tie the surveys into permanent benchmarks. Due to the remote nature of the Yampa study sites, it was determined that the use of existing benchmarks would impractical. In order to place the surveys into a real world reference system, a Trimble GeoExplorer II was used to GPS in at least two benchmarks for each site. The BLM in Craig maintains a base station that was used to differentially correct the GPS data though post-processing. By letting the GPS average the position for each point for 10minutes and post-processing, it was possible to determine the positions with a horizontal accuracy of approximately 10cm. These positions were then converted into the State Plane 1983 coordinate system with a NAD83 datum using the Colorado North zone. The State Plane coordinate system was chosen because it was the coordinate system of choice for the CDOW and is based on the English unit system, which the PTSIII allows. At each site, one ground control point was selected to be the reference position and other GCP's were used for determining azimuth and as a rough check on total station coordinates.

Data points were gathered during the low flow periods by walking, wading, or floating the channel with a collapsible rod and prism and shooting the position with the total station. Points were captured at breaks in slope not on transects. Where channel topography varied, a greater density of points were captured compared to areas with relatively planar surfaces. A relative measure of channel substrate was recorded for each XYZ data point. Substrate was determined visually on dry land and on shallow riffles, by feel where water shallow enough to wade yet too deep to visually estimate, and by tapping with the rod where the water was too deep to wade. Channel substrate, feature, and habitat type were communicated by radio to the total station operator where it was recorded with the total station coordinates using a HP48GX, with TDS48 software. An effort was made not to shoot any points at a distance of over 1,000ft as to reduce the amount of measurement error.

Depth and velocity were recorded at a number of cross-sections within each reach to determine discharge and for use in calibrating the two-dimensional model. Velocities were determined at 0.6 depth, which was determined to represent average velocity, using a Marsh-McBirney current meter. A stage (staff gage) marker was installed at each site and measurements of channel geometry, velocity, and stage were taken at random intervals through the summer so a stage-discharge relationship could be determined.

1999 15-Mile Reach Survey

During a seven day period beginning June 27th and ending July 7th, 38,880 usable bathymetric survey points were collected on a 4 kilometer stretch of the 15-Mile reach of the Colorado River between river miles 174.8 and 177.4 (no data was collected on the 3rd-6th of July).

The 15-Mile reach of the Colorado River runs through Grand Junction, CO, so it was possible to tie the river survey into the Mesa County Survey System. The Mesa County Dept. of Public Works Engineering Division/Survey Section maintains a web page where it is possible to lookup survey information. The latitude and longitude of the brass marker at the intersection of 31 and C Road was determined through the use of this website. Using the brass marker reference point, it was possible to use the Javad RTK GPS to pinpoint the location of a rebar pin on the "Government Property" near the river. This point was subsequently used as the reference point for the entire 15-Mile reach survey.

The bathymetric survey data was collected using the Javad RTK GPS and ODOM Hydrographic 3000HZ narrow beam sonar. The GPS system output a NMEA GGA string at a rate of 1HZ while the sonar output text strings indicating depth at a rate of 10HZ. Data from these instruments was sent to a laptop and recorded using the COMLOG software from ODOM Hydrographic. Because the 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.

On October 22nd, additional topographic points were collected at the waterline with the GPS, Psion data collector, and Field Face software. These additional points were used for calibrating the Manning roughness values.

1999 Duffy Tunnel and Sevens Surveys

Over a three-day period beginning July 9th and ending July 12th 1999, bathymetric data was collected along a 2.25 km section of the Yampa River near Duffy Tunnel and a 1.3km section near Sevens. In order to compare the 1998 and 1999 data sets, the 1999 survey used the coordinates for the primary base pins of the 1998 surveys. Bathymetric data was collected on each reach of river using the same method as used on the 15-Mile reach (Sec. 2.1.2). However, because flows were relatively low it was not possible to survey the margins of the channel using GPS and sonar. As such, from the 27th through the 29th of July, the GPS was used with a Psion data collector running Field Face software to survey in the waterline at the Duffy Tunnel site. Waterline data was collected at the Sevens site in late August, but that data was lost making it very difficult to model the site.

Data Reduction and Preparation

Each of the survey methodologies used required that data be collected over several days, and in each survey methodology a large number of data were collected. Because of this, quality control was a very important part of the survey process. Data from individual surveys had to be joined together and an effort had to be made to determine when a sufficient amount of data had been collected. The use of GPS and sonar to collect data on the fly added additional data issue since it was generally not possible to perform any quality control as the data was being collected.

Using the total station, it was possible to only collect data where it would help define the channel topography. As topographic data were collected over the summer, they were input into the ArcView software package. Using ArcView it was possible to create a Triangular Irregular Network (TIN) surface model of the channel. By mapping the topographic points on the TIN it was possible to determine where additional survey points were needed in order to accurately represent channel topography.

The use of GPS, sonar, and the COMLOG program resulted in a large amount of data to be reduced during post-processing. As part of this data reduction, an Excel macro was written to determine which points would be used as part of the final survey. First, the macro examined the GPS signals and eliminated all the ones not considered to be RTK, based on the GPS data quality indicator in the GGA string. Therefore because data was being collected from the sonar at such a high rate, and sonar readings were sometimes affected by floating material like fish or woody debris, spikes in the sonar data were eliminated based on the running average of the three sonar pings prior to and after a given sonar ping. If the elevation recorded in a given reading was different than the moving average of the 6 readings surrounding the given reading by more than 15cm, that ping was marked as "bad". 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.

HYDRAULIC SIMULATION

Hydraulic simulation and 2-D flow modeling was contracted with the Earth Resources Department of Colorado State University (CSU). Greg Stewart, a graduate student at CSU, collected, input the data for hydraulic modeling and performed the analysis. Many attempts were made to run the 2-D model during the first year of this contract but two-dimensional modeling results could not be presented in the 1999 annual report. Several difficulties in making production model runs were encountered again this year. These difficulties are identified and discouraged the use of this particular model by persons without extensive training and familiarity with RMA2 and supportive software.

Pre-model modeling using HEC-RAS

The two-dimensional model RMA2 cannot handle the drying of any point along any inflow or outflow boundary. Because the purpose of this project was to model a range of flows including very small discharges, it became necessary to create artificial rectangular channels at both ends of the modeled reaches. These artificial channels allow the model to have stable boundary conditions that never go dry while still allowing for the modeling of flows that would otherwise dry out elements at the inflow and outflow boundaries of the mesh. HEC-RAS was used to develop stage discharge relationships for the artificial rectangular channels. HEC-RAS output was also calibrated against known water surface elevations to estimate a Mannings n for the channel, to determine the wetted perimeter at the highest modeled discharge for use in creating the mesh, and for evaluating wetted perimeter (1-D) vs. wetted area (2-D) as stated in the objectives.

HEC-RAS is a 1-D hydraulic flow model created by the Hydrologic Engineering Center of the U.S. Army Corps of Engineers (Brunner, 1998), and is based on solution of the one-dimensional energy equation (1).

$$Y_2 + Z_2 + \frac{a_2 V_2^{\,2}}{2g} = Y_1 + Z_1 + \frac{a_1 V_1^{\,2}}{2g} + h_e \qquad (1)$$

where Y_1, Y_2 = depth of water at cross sections
Z_1, Z_2 = elevation at cross sections
V_1, V_2 = average velocities (total discharge/total flow area)
α_1, α_2 = velocity weighting coefficients
g = gravitational acceleration
h_e = energy head loss

$$h_e = L\overline{S}_f + C\left|\frac{\alpha_2 V_2^{\,2}}{2g} - \frac{\alpha_1 V_1^{\,2}}{2g}\right| \qquad (2)$$

where L = discharge weighted reach length
S_f = representative friction slope between two cross sections
C = expansion or contraction loss coeffiecient

Water surface profiles are computed from one cross section to the next by solving the energy equation with an iterative procedure called the standard step method. The steady flow component is capable of modeling subcritical, supercritical, and mixed flow regime water surface profiles (Bruner, 1998). HEC-RAS has a graphical user interface (GUI) and requires station and elevation coordinates for each cross section. Energy loss due to friction is accounted for with cross-section average values for Manning n. Contraction and expansion of the channel is accounted for with the inclusion of the distance between right, left and thalweg points at adjacent cross sections. Simulation output can be expressed in tabular or graphical format and generally consists of depth, average cross-sectional velocity, and permutations of depth and velocity.

Because cross-sections were not specifically surveyed in the field, and to make sure that wetted perimeter and wetted area measurements were based on the same channel surface, HEC-RAS cross-sections were based on a Triangulated Irregular Network (TIN) representing the channel bed. The TIN's used as a basis for these measurements included points that were interpolated from the original survey to make sure that the TIN portrayed channel characteristics as realistically as possible.

HEC-RAS output includes water surface elevation and average velocity for each cross-section in the model. By applying the HEC-RAS calculated water surface elevations to the ends of the cross-sections, a TIN can be created that represents the water surface elevation. By subtracting the bathymetry TIN from the water surface elevation TIN, a line can be drawn which delimitates the aerial wetted perimeter. This line can then be used to bound the 2-D mesh if water surface elevations are not available for the highest discharge to be modeled.

There is one user-defined parameter in the HEC-RAS model that can affect the water surface elevations and that is the Manning n. Manning's n is an empirically derived number that represents the roughness of the bed in the Manning equation. As Manning n increases the velocity slows and the water surface elevation increases. By calibrating the watersurface elevation in HEC-RAS to the water surface elevations surveyed in on October 22nd, it was possible to approximate the average Manning n for the channel.

Two-Dimensional Modeling using SMS and RMA2

SMS is the Surface-Water Modeling System, a commonly used graphical user interface (GUI) to a number of computational fluid dynamic models including RMA2, FESWMS, and HIVEL2D. SMS is a pre- and post-processor for RMA2 which allows for the creation of the finite element mesh and associated boundary conditions with a GUI. SMS was developed at Brigham Young Universities Environmental Modeling Research Laboratory and is distributed by contract through Environmental Modeling Systems, Inc. (EMS-I).

RMA2 is a two-dimensional depth averaged finite element hydrodynamic model created for the Corps of Engineers in 1973. RMA2 computes water surface elevations and horizontal velocity components for subcritical, free-surface flow in two-dimensional flow fields using a finite element solution of the Reynolds form of the Navier Stokes equations for turbulent flows. The forms of the depth-integrated equations of fluid mass and momentum conservation in two directions are shown below.

$$h\frac{\partial u}{\partial t} + hu\frac{\partial u}{\partial x} + hv\frac{\partial u}{\partial y} - \frac{h}{\rho}\left(E_{xx}\frac{\partial^2 u}{\partial x^2} + E_{xy}\frac{\partial^2 u}{\partial y^2}\right) + gh\left(\frac{\partial a}{\partial x} + \frac{\partial h}{\partial x}\right) + \frac{gun^2}{\left(1.486h^{\frac{1}{6}}\right)^2} + \left(u^2 + v^2\right)^{\frac{1}{2}} = 0 \tag{3}$$

$$h\frac{\partial v}{\partial t} + hu\frac{\partial v}{\partial x} + hv\frac{\partial v}{\partial y} - \frac{h}{\rho}\left(E_{yx}\frac{\partial^2 v}{\partial x^2} + E_{yy}\frac{\partial^2 v}{\partial y^2}\right) + gh\left(\frac{\partial a}{\partial y} + \frac{\partial h}{\partial y}\right) + \frac{gvn^2}{\left(1.486h^{\frac{1}{6}}\right)^2} + \left(u^2 + v^2\right)^{\frac{1}{2}} = 0 \tag{5}$$

$$\frac{\partial h}{\partial t} + h\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right) + u\frac{\partial h}{\partial x} + v\frac{\partial h}{\partial y} = 0$$

where h = depth
u,v = velocities in cartesian directions

x,y,t = cartesian coordinates and time
ρ = density of fluid
E = eddy viscosity coefficient
for xx = normal direction on x axis surface
for yy = normal direction on y axis surface
for xy and yx = shear direction on each surface
g = acceleration due to gravity
a = elevation at bottom
n = Mannings roughness coefficient

Equations 3, 4, and 5 are solved by the finite element method using the Galerkin Method of weighted residuals. Elements may be two dimensional quadrilaterals or triangles and each may have curved sides. Integration in space is performed by Gaussian integration and derivatives in time are replaced by a non-linear finite difference approximation. Solutions are fully implicit and the set of simultaneous equations is solved by Newton-Raphson non-linear iteration. RMA2 permits wetting and drying within the grid either through elemental elimination or gradual wetting and drying through the consideration of marsh porosity (King 1997)

Modeling low flow conditions over a long reach of river has proven problematic for many reasons including the need for a highly refined finite element mesh and a large amount of computing power. The elemental elimination method for wetting and drying removes elements as soon as the water surface elevation drops below the elevation of any one node on the element. Once an element “dries”, flow must get around the newly formed land boundary until the projected depth exceeds a specified value for all nodes of the element. If the elements are large, the change in velocities in the remaining areas can be large enough to cause the solution to diverge and the model to crash. Additionally, if an element becomes disconnected from the main body of flow, RMA2 is likely to diverge when the pond is reattached to the wetted network.

RMA2 begins with the assumption of a universally flat water surface elevation. Using revision cards and hotstart files, a simulation can be stepped down to reflect real world conditions. As the simulation is stepped down, the previous solution is used to provide initial guesses to the next solution. If the simulation is stepped down too quickly, the solution is likely to diverge and the model will crash. The time needed for a given step is dependent on a number of factors including the size of the mesh, the speed of the computer, and the relative change in flow characteristics in each step. With a PIII500 processor and 256MB of Ram, each iteration in a model with 20,000 elements can take up to 3 minutes to process assuming nothing else is running on the computer. A total of 1,000 successful iterations may be required to step the model down to a real world condition. During this process, it may become obvious that the mesh has to be refined in someway. If the mesh is altered in any significant way, hotstart files cannot be used and the stepdown process must be started again using a flat water surface elevation.

HABITAT AVAILABILITY

On September 15, 1999, at a flow of 287 cfs, aerial photographs were flown at a scale of 1"=600'. The aerial photography included the survey site and the representative reach section described for the fish sampling. Aerial photos were qualitatively used to compare habitat availability in the surveyed study sites to longer sections of the river. The images of the sites were rectified using ground control points and the Imagine software package. These images were then registered in the Surface Modeling Software (SMS) and were used for reference in creating the finite element mesh. Aerial photography for the 15-Mile Reach were purchased from Mesa County. The county rectified the photo with highly precise UTM coordinates. The 15-Mile Reach photographs were taken on September 30 and October 1, 1997 at a flow of 3000 cfs.

To quantify fish habitat availability, maps were made of the river at a given flow that delineated the surface area for sixteen habitat types based on depth and velocity criteria. Pools had a velocity of zero to 0.15 m/sec and had five differing depths from very shallow (< 0.2m) to deep (>2m). The velocity of runs ranged from 0.15 to 0.6 m/sec and depths were the same as give for pools. Riffles had velocity ranging from 0.6 to 1.5 m/sec and rapids had velocities over 1.5 m/sec. The fish sampling effort will attempt to determine which habitat type is more or less suitable for each species and size of fish collected during the base flow period. This will indicate which habitats are useable and which are not. Fish composition for each study will be compared to its habitat composition. As more sites are sampled correlations will be examined to determine if similar river section with similar habitat composition have similar species composition. As more empirical fish data is collected it may be necessary to adjust the number and criteria of habitat types used in the analysis. Habitat diversity and composition will be calculated in each study site at an optimal base flow. The flow model will be used to determine how habitat diversity and composition are affected as flows drop.

RESULTS

SPECIES COMPOSITION

YAMPA RIVER FISH SAMPLES

Species composition of fish over 15 cm captured by electrofishing were similar at the Sevens station between years even though the 1999 electrofishing site was about half the distance it was in 1998 (Table 1). Flannelmouth sucker was the most common fish caught in both years at 46% of the total in 1998 and 47% in 1999 (Table 1). The next most common fish was bluehead sucker (about 20% in both years) followed by white sucker (about 10% in both years). The next most common fish in 1998 were roundtail chub, catfish, the white-flannelmouth cross and carp but in 1999 it was catfish, carp, the white-flannelmouth cross and roundtail chub (Table 1). Non-native fish predators (pike, catfish, and bass) were 9% of the catch in 1998 and 11% in 1999. Native fish comprised 72% of the total in 1998 and 68 % in 1999. Colorado pikeminnow were only 0.1% of the catch in 1998 and 0.2% in 1999.

Table 1: Species composition for fish >15 cm at the Sevens station in 1998 and 1999. Column 4 is for the study area that has habitat availability data.

	1.TOTAL Columns 2,3,4&5	2. UPPER SECTION (1998 only)	3. ABOVE STUDY AREA	4. SURVEY STUDY AREA	5. BELOW STUDY AREA	6. Total Areas 3,4&5
Species	1998 ELECTFOFISHING					
Flannelmouth Sucker	44.7%	41.6%	48.1%	45.6%	47.2%	47.0%
Bluehead Sucker	20.9%	20.9%	20.7%	12.7%	35.1%	21.0%
Roundtail Chub	6.0%	6.4%	6.3%	7.2%	2.0%	5.7%
Colo. Pikeminnow	0.1%	0.0%	0.3%	0.2%	0.0%	0.2%
White sucker	11.2%	13.0%	7.3%	15.1%	5.5%	9.8%
White X Flannelmouth	5.4%	8.9%	2.8%	4.0%	1.2%	2.9%
White X Bluehead	0.4%	0.5%	0.2%	0.4%	0.6%	0.3%
Channel Catfish	5.9%	5.1%	7.8%	5.6%	5.2%	6.4%
Carp	2.9%	1.6%	4.5%	4.8%	1.4%	3.9%
Smallmouth Bass	0.9%	0.8%	0.5%	1.6%	0.9%	1.0%
Northern Pike	1.3%	1.0%	1.3%	2.1%	0.6%	1.5%
White Crappie	0.3%	0.1%	0.2%	0.7%	0.3%	0.4%
Sample size	2614	1098	603	568	345	1516
Recaptures	389	129	97	109	54	260
Species	1999 ELECTROFISHING					
Flannelmouth Sucker			42.9%	48.0%	49.4%	46.0%
Bluehead Sucker			22.3%	7.9%	31.8%	18.1%
Roundtail Chub			3.8%	4.6%	1.8%	3.8%
Colo. Pikeminnow			0.0%	0.5%	0.0%	0.2%
White sucker			9.4%	11.0%	8.8%	10.0%
White X Flannelmouth			2.7%	7.0%	2.9%	4.4%
White X Bluehead			0.0%	0.5%	0.0%	0.2%
Channel Catfish			9.4%	7.4%	1.2%	7.2%
Carp			6.5%	4.6%	1.2%	4.8%
Smallmouth Bass			1.3%	2.9%	2.4%	2.1%
Northern Pike			1.8%	2.4%	0.6%	1.8%
White Crappie			0.0%	3.4%	0.0%	1.4%
Sample size			448	417	170	1035
Recaptures			52	49	12	113

The species composition in the study area was not very similar to the longer reach, an indication that the habitat in the study area may not be representative of the river in general. In the study area bluehead composition was 12.7% in 1998 and 7.9% in 1999, but was 23.2% and 24.9% for 1998 and 1999, respectively for the non- study area. (Table 1). The study area also had a higher percent of white sucker and roundtail chub than outside the study area. Native fish comprised 66% of the total in 1998 and 61% in 1999 in the study area compared to 73% for the non-study sites in both years.

Percentages of fish over 15 cm captured at the Duffy site (RM 105 to 110) were also similar between years (Table 2). Total electrofishing distance was about the same in both years, but was shifted upstream 0.75 km. White sucker was the most common fish caught in both years followed closely by the white-flannelmouth cross (Table 2). White sucker, the white-flannelmouth and white-bluehead crosses together comprised 69% of the total catch in 1998 and 73% of the total catch in 1999. The next most common fish was smallmouth bass at 8% in 1998 and 6% in 1999 (Table 2). Flannelmouth sucker, bluehead sucker, catfish, pike and carp ranged between 6% and 2% for both years. Nonnative fish predators (pike, catfish, and bass) were 13% of the catch in 1998 and 15% in 1999. Native fish comprised 14% of the total in both 1998 in 1999. Colorado pikeminnow were 1.5% of the catch in 1998 and 0.6% in 1999.

The species composition in the study area was fairly similar to the longer fish sampling reach, but as was the case with the Sevens station, fewer native fish were caught inside than outside the study site. Native fish comprised 11% of the total catch in 1998 and 10% in 1999 in the study area compared to 16% in 1998 and 16% in 1999 for the non-study sites. This was mainly due to a reduced percentage of flannelmounth sucker in the river section that was surveyed for habitat availability.

Species composition was found to shift when all fish (including < 15 cm) are used. Small fish are more typically associated with shoreline habitats and comprise a small percent of the main channel population. Also the effort to sample small fish from the electrofishing boat varied between years. At the Sevens station in 1998 a 30 m section in the lower part of the study area was walked electrofished and several hundred speckled dace, sand shiner and a few redside shiner were taken from along the bank under an overhanging tree. Inclusion of these fish resulted in a shift in species composition with dace becoming the third most common fish (Appendix Table A.1). That shoreline electrofishing special effort was not made at Sevens in 1999.

At the Duffy station, the smallmouth bass YOY count was 774 in 1998 and 698 in 1999. YOY smallmouth bass were dispersed and ubiquitous in the main channel and were easy to capture or count from the boat without any special effort. When fish less than 15 cm are included, smallmouth bass had the highest percent composition in 1998 at 27% and white sucker were second at 22% (Appendix Table A.2). In 1999 at Duffy YOY white suckers increased and white sucker was still the most common species but dropped to 27% of the total and smallmouth bass increased to 23% overall (Appendix Table A.2).

Fish collected by seining include: speckled dace *Rhinichthys osculus*, mottled sculpin *Cottus bairdi*, sand shiners *Notropis stramineus*, fathead minnows *Pimephales promelas*, brook stickleback *Culaea inconstans*, redside shiner *Richardsonius balteatus* and green sunfish *Lepomis cyanellus*) (Appendix Table A2.3).

COLORADO RIVER

Percentages of fish over 15 cm captured by electrofishing in the 15-mile reach varied in the three sections sampled. Flannelmouth sucker were the most common fish caught at all three main channel sites and their percent composition was 41% in the study area, 55% in the

Table 2: Species composition for fish >15 cm at the Duffy station in 1998 and 1999. Column 3 is for the study area with habitat composition data.

	1.TOTAL Columns 2,3,4&5	2. ABOVE STUDY AREA	3. SURVEY STUDY AREA	4. STUDY TO BEND	5. BEND TO TAKE OUT
Species	1998 ELECTROFISHING				
Flannelmouth Sucker	5.3%		2.7%	7.5%	6.1%
Bluehead Sucker	4.4%		4.4%	4.1%	4.6%
Roundtail Chub	3.3%		2.1%	6.6%	2.7%
Colo. Pikeminnow	1.5%		1.7%	0.0%	2.0%
White sucker	34.9%		49.1%	34.6%	25.7%
White X Flannelmouth	28.1%		22.6%	27.4%	31.9%
White X Bluehead	6.0%		4.0%	12.9%	4.6%
Channel Catfish	3.0%		0.9%	0.9%	5.1%
Carp	2.7%		0.9%	0.0%	4.8%
Smallmouth Bass	8.2%		7.4%	4.1%	10.3%
Northern Pike	2.8%		4.0%	1.9%	2.3%
White Crappie	0.1%		0.2%		
White S. + Crosses	68.9%		75.7%	74.8%	62.2%
Sample size	1654		527	318	809
Recaptures	270		87	71	112
Species	1999 ELECTROFISHING				
Flannelmouth Sucker	5.1%	5.6%	2.4%	2.7%	7.6%
Bluehead Sucker	5.6%	3.3%	4.3%	4.8%	8.2%
Roundtail Chub	2.9%	3.5%	2.4%	3.3%	2.7%
Colo. Pikeminnow	0.6%	0.0%	1.0%	0.3%	0.9%
White sucker	33.4%	33.7%	40.9%	37.5%	26.3%
White X Flannelmouth	32.8%	41.6%	30.1%	28.5%	30.9%
White X Bluehead	5.9%	2.5%	5.7%	13.5%	4.8%
Channel Catfish	4.0%	1.0%	4.1%	3.0%	6.1%
Carp	1.1%	0.2%	0.2%	0.6%	2.6%
Smallmouth Bass	6.3%	7.5%	6.3%	3.9%	6.5%
Northern Pike	2.3%	0.8%	2.8%	1.8%	3.1%
White Crappie	0.1%	0.2%	0.0%	0.0%	0.1%
White S. + Crosses	72.0%	77.8%	76.6%	79.6%	62.1%
Sample size	2092	483	509	333	767
Recaptures	440	130	107	61	142

section below the study area, and 32% above the study area (Table 3). The weighted mean for all sites combined was 43% (Table 3). The next most common fish was bluehead sucker. The study area had the highest percent of bluehead sucker, almost as common as flannelmouth, with a percentage of 38%. Below the study area the percentage of bluehead sucker was 15% and above it was 25%, and the mean of all three was 26%. The study area had the lowest percent of roundtail chub (3%). The percentages of roundtail chub below and above the study area were 6 and 7%, respectively. Channel catfish were the only non-native predators in the main channel. Its' composition was 5% in the study area, 6% below and 13% above. Native fish comprised 82% of the total in the study area, 75% below and 63% above and 72% for the mean of the three sites. Colorado pikeminnow were only 0.2% of the catch (Table 3).

Table 3: Species composition for fish >15 cm at the 15-MILE Reach, Colorado River station in October 1999. Column 2, has both percent composition for >15 cm and for (total fish) sampled in five backwaters.

	1.STUDY AREA Main Channel	2. STUDY AREA Backwater	3. BELOW STUDY AREA	4. ABOVE STUDY AREA	5. Combined Weighted Mean
Species	4.0 km	n = 5	4.5 km	4.8	1,3 &4
Flannelmouth Sucker	40.6%	21.7% (9.6%)	54.9%	31.5%	42.7%
Bluehead Sucker	38.1%	0.3% (1.1%)	14.7%	24.6%	26.1%
Roundtail Chub	3.1%	4.0% (16.8%)	5.6%	6.6%	5.0%
Colo. Pikeminnow	0.1%	0	0.2%	0.5%	0.2%
White sucker	2.2%	16.5% (8.9%)	1.6%	3.5%	2.4%
White X Flannelmouth	0.7%	(0.3%)	0.8%	0.5%	0.7%
White X Bluehead	1.3%	0	1.4%	1.1%	1.3%
Channel Catfish	4.6%	0	6.1%	13.0%	7.7%
Carp	8.5%	39.4% (14.6%)	13.5%	17.6%	12.9%
Smallmouth Bass	0.0%		0.4%		0.2%
Largemouth bass	0.1%	5.9% (5.9%)	0.1%	0.2%	0.1%
Green Sunfish	-	0.9% (5.3%)	0.0%	0.2%	0.0%
Brown trout	0.4%	(0.1%)	0.5%	0.5%	0.5%
Rainbow trout	0.03%			0.2%	0.1%
Black Bullhead	0.3%	11.2% (4.1%)	0.1%	0.3%	0.2%
NNC*	-	(32.5%)*			
Razorback Sucker	-	(0.7%)			
Blue gill	-	(0.1%)			
Sample size	3144 (3209)	322 (1071)	946 (961)	654(705)	
Recaptures					

*NNC is non-native cyprinids, the red shiner, sand shiner and fathead minnow. Since we did not attempt to make a total capture of NNC, their percentage in backwaters is higher.

In the main channel the vast majority of fish caught were over 15 cm, however in backwaters the majority of fish were less than 15 cm. Non-native cyprinids as a group were the most common fish sampled in backwater and most of them were deliberately not netted. The next most common species in backwaters were roundtail chub (17%), carp (15%), flannelmouth sucker (10%) and white sucker (9%). Largemouth bass were about 6% and green sunfish were 5% of the total in the backwaters sampled. For fish over 15 cm the most common species were carp, flannelmouth sucker and white sucker (Table 3).

LENGTH FREQUENCY and MEAN LENGTH

Length frequency histograms given in Appendix C Figures 1, 2 and 3 are for total fish captured in 1998 and 1999. The length frequency histograms for bluehead sucker were very similar between years on the Yampa River. On the Yampa river the Duffy station in 1999 had 39% bluehead sucker at 40 cm or larger, in contrast to only 2% at the Sevens. The Colorado River had 21% of bluehead sucker at and over 40 cm. Duffy also had the highest mean length in 1999 of bluehead sucker at 382 mm, Sevens had the smallest mean length of 336 mm and it was 366 mm in the Colorado River (Table 4). Mean lengths between all sites were statistically different at $P<0.001$ in 1999 for bluehead sucker.

The length frequency histograms were also different for flannelmouth sucker between the three sites. Duffy in 1999 had the highest percent (44%) of fish over 50 cm, and Sevens the lowest at 16%, and it was 28% in the 15-Mile Reach in 1999 (Figure A). The Colorado River had the highest percent (28%) of fish under 40 cm and fish under 40 cm were only 6% for both sites on the Yampa (Appendix C Figures 4, 5 and 6). Mean length of flannelmouth sucker in 1999 in the Colorado River was 422 mm and it was 465 and 486 mm for Sevens and Duffy, respectively (Table 4). The higher mean length on the Yampa River reach was a function of a lack of smaller fish there, instead of a lack of larger fish on the Colorado River. Mean lengths between all sites were statistically different at P<0.001 in 1999.

Duffy in 1999 also had the highest percent of larger roundtail chub with 90% of the sample 40 cm or larger, a result of very few chub under 40 cm. At Sevens 67% of the chub were 40 cm or larger, but on the Colorado River only 4% were in over 40 cm (Appendix C Figure 7, 8 and 9). Mean length of roundtail chub on the Colorado River was 321 mm and 449 mm and 400 mm for Duffy and Sevens, respectively (Table 4.), and mean lengths between all sites were statistically different at P<0.001 in 1999. The smaller mean length on the Colorado River for Chub is due to a much better representation of smaller sized fish.

Table 4. Mean length for fish >15 cm collected in the Yampa and Colorado Rivers.

	MEAN LENGTH IN MM				
	Sevens	**Sevens**	**Duffy**	**Duffy**	**15-Mile**
Species/year	**1998**	**1999**	**1998**	**1999**	**1999**
BH	342	336	357	382	366
CC	497	448	529	476	433
CP	572	533	670	679	440
CPM	628	610	608	575	573
FM	488	465	459	486	422
NP	383	411	433	518	
RTC	380	400	442	449	321
SMB	295	276	278	292	
WB	329	375	413	421	374
WF	460	442	475	473	393
WS	359	352	411	406	287

Duffy also had significantly higher mean lengths for most other species including catfish, carp, white sucker and white-flannelmouth and white-bluehead hybrids, pike and bass (Table 6). On the Colorado River small white sucker were found primarily in backwater habitats whereas white sucker over 25 cm were primarily in the main channel (Appendix C Figure 10 and 11). The smallest channel catfish caught on the Yampa River was 30 cm and

23% were over 55 cm at Duffy (Figures A2. 5a, 52, 53, and 54). In contrast catfish under 30 cm were common on the Colorado River (Figure A2.55) and only 5% were over 55 cm. Length frequency histograms for other species are included in Appendix C.

White sucker and smallmouth bass were the only species in the Yampa River with a large percent of YOY or yearling sized fish in the main channel. YOY bass were abundant at Duffy but rare at the Sevens in both years (Figures A2.59, 60, 61, and 62). By September 1999 the mean length of YOY smallmouth bass at Duffy was 65 mm which was higher than what was identified for fish from 1998 (60 mm) (Table 5). In Table 5, the fish from August 12 and 17, 1999 were collected by seining and the fish from later dates by boat electrofishing.

Table 5: Mean length with sample size of YOY smallmouth bass for each sample date at Duffy in 1998 and 1999.

	1998 sample						
				3-Sep	15-Sep 16-Sep	22-Sep 24-Sep	30-Sep
MM				60	64	70	70
Sample size				47	60	228	31
	1999 sample						
	12-Aug	17-Aug	24-Aug 25-Aug	31-Aug 2-Sep	15-Sep 17-Sep		
MM	38	47	53	65	66		
Sample size	33	15	91	23	35		

DENSITY ESTIMATION

Fish density estimates were similar between years on the Yampa River at both sites. The 1998 total fish density for the long Sevens reach was estimated to be 950/km ± 78 (95% C.I.) not significantly different than the 1999 estimate of 1137/km ± 182. This was in spite of the fact the sampling station was reduced in size by about half in 1999. The total fish estimate for the long Duffy station (Representative Reach) in 1998 was 411/km ± 40 which was not significantly different from the 1999 estimate of 409/km ± 29. The fish sampling site was about the same total length in both years, but shifted upstream by about 0.75 km.

Fish density was significantly higher on the Colorado River station than for the Yampa sites. Total fish density was estimated at 3,962 per km at the 15-Mile Reach station (Table 6). Total fish density on the Colorado River (3.92 per 100 m^2) was 2.3 times higher than at Sevens (1.72 fish/100 m^2) and 6.4 times higher than Duffy (0.62 fish/100 m^2). Native sucker density was very low at the Yampa Duffy site, where the estimate was only 25 bluehead and 20 flannelmouth per kilometer, especially when compared to the Colorado River where both native sucker estimates were over 1,500 per km (Table 6). The density of native sucker per 100 m^2 at the15-Mile Reach was over three times higher than at Sevens and over 46 times higher that at Duffy (Table 6).

Channel catfish was the only nonnative predator collected in the 15-Mile reach and its density (1.95 fish/100 m^2) was comparable to that on Yampa River at the Sevens (2.01 fish/100 m^2) and at Duffy (1.55 fish/100 m^2) (Table 6). Smallmouth bass and northern pike density was 2.2 times greater at Duffy than at the Sevens.

Table 6: Population estimates with 95% C.I. and density estimates (No./1000m) for the 15-Mile-Reach, Sevens and Duffy stations, fall 1999.

SEVENS	15 Mile Reach. CO. R.		Sevens, Yampa		Duffy, Yampa	
	No./km±95%C.I.	No./1000m²	No./km±95%C.I.	No./1000m²	No./km±95%C.I.I	No./1000m²
Total	3962±11%	39.62	1137±16%	17.07	409±7%	6.14
Bluehead	1573±20%	15.73	238±43%	3.57	25±33%	0.38
Flannelmouth	1550±17%	15.50	376±19%	5.65	20±30%	0.30
Roundtail Chub	192±83%	1.92	41±84%	0.62	27±71%	0.41
Colo. Pikeminnow	5±NR	0.05	3±NR	0.05	8±NR	0.12
Carp	309±36%	3.09	89±196%	1.34	8±96%	0.12
Channel Catfish	195±54%	1.95	134±192%	2.01	110±108%	1.65
Small Mouth Bass	-	-	29±123%	0.44	83±60%	1.25
Northern pike	-	-	22±120%	0.33	31±104%	0.47
White Sucker	62±65%	0.62	110±51%	1.65	113±11%	1.70
White-Bluehead	50±103%	0.50	1±NR	0.02	22±51%	0.33
White-Flannel.	27±196%	0.27	85±104%	1.28	110±11%	1.65
Brown trout	18±196%	0.18			-	-

On the Colorado River the same reach that was electrofished was also surveyed for habitat composition. However on the Yampa River the surveyed reach was shorter. Because the surveyed reaches were shorter in distance the number of fish in sample was smaller and the result was a fewer number of recaptures. Therefore confidence intervals are higher for the surveyed reaches, in spite of similar recapture rates. The surveyed sites in 1999 supersede the 1998 sites because channel surveying was enlarged.

Total fish density at the Duffy site in the surveyed reach was somewhat higher than in the longer reach, probably because the surveyed reach had a higher proportion of deep run habitat than the longer representative reach. Density estimates for bluehead sucker, flannelmouth sucker, roundtail chub and Colorado pikeminnow were very similar between the surveyed and the long station. For the Sevens station the density of flannelmouth and roundtail chub were very similar for the surveyed and longer reach. However bluehead sucker density in the surveyed site was less than half that found outside the surveyed area.

Table 7: Density estimates with 95% C.I. and Surveyed Sites (shorter sections) at Sevens and Duffy, for September 1998 and 1999.

	Sevens 1998	Sevens 1999	Duffy 1998	Duffy 1999
	No./km	No./km	No./km	No./km
Total fish	893 ±19%	1138 ±24%	559 ±17%	543 ±9%
Bluehead Sucker	125±104%	112 ±99%	21 ±174%	24 ±52%
Flannelmouth S	250±20%	371 ±26%	15 ±49%	28 ±58%
Roundtail Chub	84±80%	36 ±88%	10 ±150%	22 ±59%
Colo. Pikeminnow	3±NR	9±NR	17 ±NR	5 ±NR
Carp	59±120%	61 ±196%	9 ±NR	2 ±NR
Channel Catfish	78±49%	144 ±NR	9±NR	26 ±NR
Smallmouth Bass	22±159%	23 ±107%	74 ±131%	70 ±91%
Northern Pike	19±NR	47 ± NR	40 ±123%	18 ±NR
White Sucker	±	214 ±132	206 ±22%	178 ±14%
White-Bluehead	±	9±NR	38 ±113%	22 ±44%
White-Flannelmouth	±	135 ±186%	121 ±27%	148 ±12%

SEINING

Fish collected by seining is presented by both total seine hauls (included fish from isolated pools) and with isolated pools removed. It was assumed that isolated pools would not reconnect with the river in the fall or winter and that fish collected there would parish. Sand shiners comprised 57% of the fish caught in 32 seine hauls at the Sevens station on August 18, 1999 (Table & and Appendix Table A3.3). Very few sand shiner were found in isolated pools and when those habitats are excluded the percent of sand shiner is 66% of the total (Table 8). At Sevens about 6% of the fish seined were native species and most of those were speckled dace.

At Duffy the percent of native fish collected by seining was 59% for the total and 43% with isolated pools excluded. Speckled dace were much more common at Duffy (24%) than at Sevens (4%). In an isolated pool 526 roundtail chub YOY were counted from one seine haul (Table A3.3). Even without that sample, roundtail chub YOY were much more common at Duffy (18%) that at the Sevens (1.4%). Even though YOY chub were commonly collected in the August seining, no YOY chub were collected during electrofishing in September. Smallmouth bass comprised only 3.5% of the fish in seining, but were abundant in the electrofishing samples. Bass YOY were typically in deeper water with boulders providing cover and this habitat was more difficult to effectively seine.

Table 8. Number and percent of fish collected by seining in the Yampa River, 1999.

	All Seine Hauls				Seine Hauls without Isolated Pools			
	SEVENS	DUFFY	SEVENS	DUFFY	SEVENS	DUFFY	SEVENS	DUFFY
	Number	Number	%	%	Number	Number	%	%
No. of seine hauls	32	72			28	57		
Total	2165	2272	-	-	1866	1353		
Native Species			6.5%	59%			5.9%	43%
Sand Shiner	1241	315	57%	14%	1239	315	66%	23%
White Sucker	588	497	27%	22%	491	366	26%	27%
Fathead minnow	77	10	3.6%	0.4%	13	2	0.7%	0.1%
Smallmouth Bass	9	57	0.4%	2.5%	9	48	0.5%	3.5%
Carp	93	35	4.3%	1.5%	1	23	0.1%	1.7%
Northern Pike	1	14	0.0%	0.6%	1	14	0.1%	1.0%
Brook Stickleback	16	9	0.7%	0.4%	0	4	0.0%	0.3%
Redside Shiner	1	1	0.0%	0.0%	1	1	0.1%	0.1%
Plains Killifish	1	0	0.0%	0.0%	0	0	0.0%	0.0%
Roundtail Chub	34	773	1.6%	34%	26	243	1.4%	18%
Flannelmouth S.	23	23	1.1%	1.0%	12	22	0.6%	1.6%
Speckled Dace	83	538	3.8%	24%	73	315	3.9%	23%
Unk (small suckers)	239				113			

In order not to conflict with a seining study in progress funded by the recovery program, no fish were seined in backwaters by this study in the 15-mile reach. All backwaters in the 15-Mile reach were seined during the spring (Valdez 1999).

HABITAT COMPOSTION

Preliminary analysis of habitat composition were based on habitat typing made subjectively during field surveying, and on partially completed hydraulic modeling that quantified surface area of habitat type possessing combinations of depth and velocity attributes. The quantification of habitat types is still in process but some preliminary results are available and suggest that final results will validate the assumption that fish respond to physical habitat availability.

The results given in last years' report indicated riffles and runs were more common at Duffy than at Sevens. At the time of this writing no 2-D results are available for the Sevens stations.

The two-dimensional modeling results in this report are from uncalibrated model runs of the 15-Mile reach at 2000cfs and calibrated runs of the Duffy Tunnel reach at 600cfs. Calibration provides a confidence level for the model output. While uncalibrated model runs should not be used to draw definitive connections between habitat availability and fish habitat utilization, the nature of the data strongly indicates the types of habitat and the relationships that should be found in further analysis. This data is preliminary and will be undergoing substantial revision between June and August 2000.

Meso-habitat units were broken out into ranges of depth and velocity for preliminary analysis (Table 9). The analysis of the 15-Mile reach data suggests that most of the reach has velocities between 0.6 and 1.5 m/s with depths above 0.5m at a discharge of 2000cfs. The Duffy Tunnel reach has much lower velocities with almost 74% of the velocities falling between 0.15 and 0.6 m/s at a discharge of 600 cfs. The 15-Mile reach data presented here is based on a flow of 2000 cfs but further analysis will examine discharges in this area down to 100 cfs. The Duffy Tunnel data presented here is based on a discharge of 600 cfs and further analysis will examine discharges down to 50 cfs. The discharges shown here are representative of typical summer discharges on the reaches of interest and represent the highest discharges that will be modeled for those reaches. Based on 9 years of data from the Palisade gage just upstream for the 15 mile reach, the median daily flow on the Duffy Tunnel reach was less than 2000 cfs for 210 days of the year. On the Yampa River, 81 years of data suggest that the median daily flow is less than 600 cfs for 241 days of the year at the Maybell gage.

Duffy Tunnel model runs have been roughly calibrated to observed models with an $r^2=0.912$ for depth and $r^2=0.872$ for velocity (Figure 7) and indicate model projections were very accurate. Calibration correlations are not yet available for 15-Mile reach data, but the habitat data offered should give reasonable insights into the types of physical habitat available. This is especially true when considering only 16 habitat types were used which means the range of depths and velocities used to define meso-habitat types is broad. Calibration correlations will be much more critical if 30 or more types are used to describe habitat composition.

On the 15-mile reach, the study site was broken into five sub-reaches, which had differing compositions of habitat-types and fish. It was determine that is was possible to compare meso-habitat units to fish composition using correlation analysis. Sections with higher percentages of riffle habitats also have higher composition of bluehead sucker and sections with higher proportions of run habitats had high composition of flannelmouth sucker (Figure 8). This preliminary analysis suggests that community structure can be correlated against physical habitat availability, at least at the meso-habitat scale. Further analysis with calibrated models should provide further insight into habitat dynamics.

Table 9: Habitat composition, based on depth and velocity criteria, for the 15-Mile Reach and the Duffy Tunnel study sites.

Habitat Types	Depth	Velocity	15 Mile Reach	Duffy Tunnel
	(m)	(m/s)	(2000 cfs)	(600 cfs)
wetted sand	0.01 - 0.2	< .15	1.4%	11.4%
shoal	0.2 - 0.5	< .15	0.9%	2.3%
shallow pool	0.5 - 1.0	< .15	1.2%	2.5%
medi –pool	1.0 - 2.0	< .15	1.0%	0.6%
deep pool	> 2.0	< .15	0.1%	0.0%
wetted run	.01 - 0.2	.15 - .6	2.7%	2.4%
shoal-run	0.2 - 0.5	.15 - .6	5.8%	13.0%
shallow run	0.5 to 1.0	.15 - .6	5.1%	48.9%
medi-run	1.0 to 2.0	.15 - .6	4.2%	8.4%
deep run	> 2.0	.15 - .6	0.5%	1.1%
shallow riffle	< 0.2	0.6 - 1.5	0.5%	0.2%
Riffle	0.2 to 0.5	0.6 - 1.5	6.1%	3.4%
deep riffle	0.5 to 1.0	0.6 - 1.5	27.8%	5.6%
extra deep riffle	> 1.0	0.6 - 1.5	36.3%	0.3%
shallow rapid	< 0.5	> 1.5	0.9%	0.0%
deep rapid	> 0.5	> 1.5	5.5%	0.0%

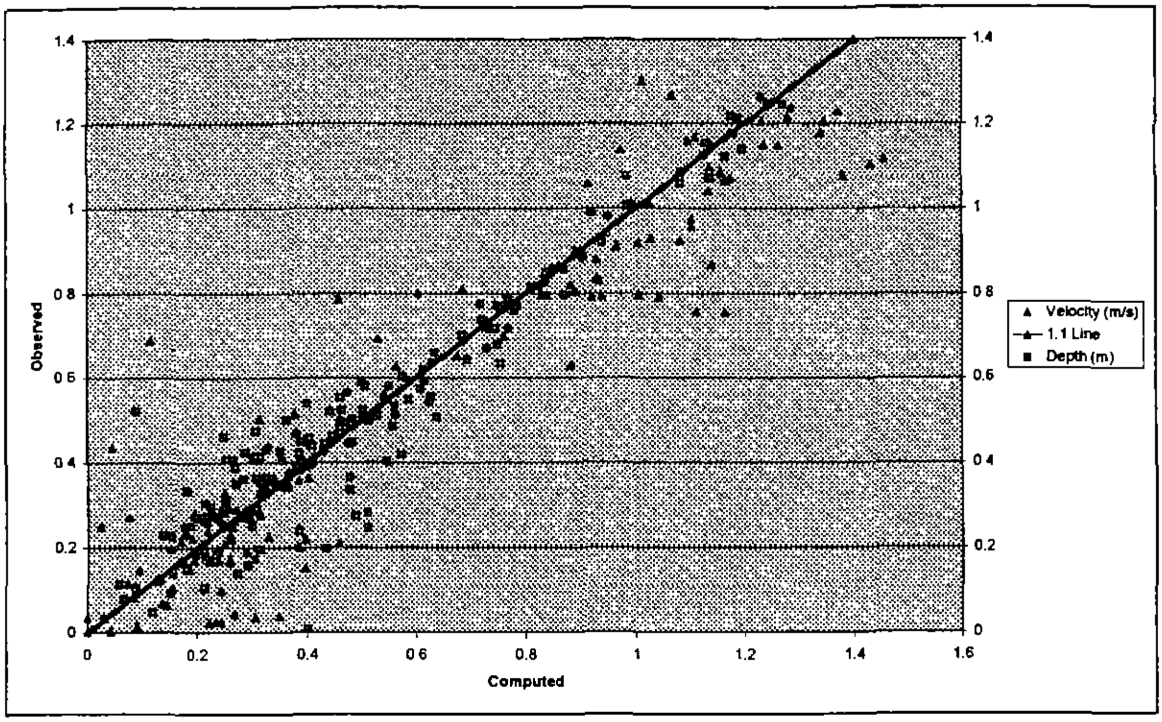

Figure 7: Calibration correlations for Duffy that are based on computed versus observed velocities and depths.

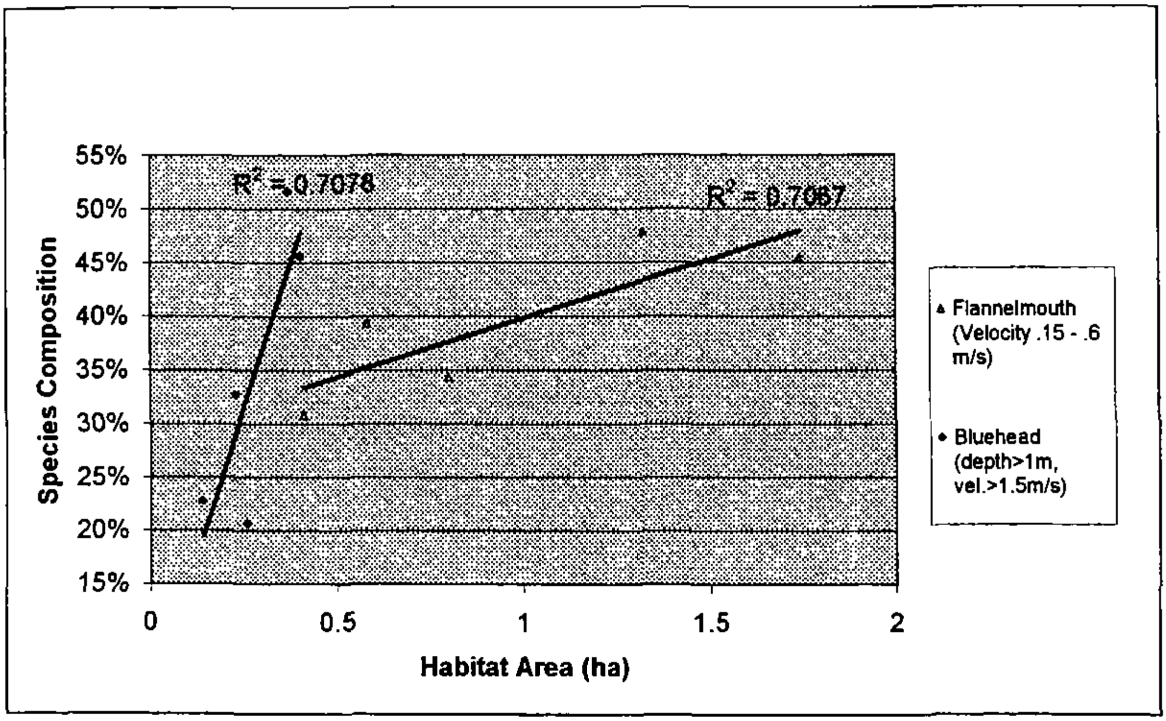

Figure 8: Correlations between percent habitat and fish composition from 5 subsections of the 15-Mile reach study site.

DISCUSSION

Species composition, density and size structure for fish over 15 cm were very similar between years on the Yampa River. This indicates stable and consistent population parameters at both Sevens and Duffy between 1998 and 1999. Significant differences in species composition, density, and size were found between Duffy and Sevens in both years, 1998 and 1999. The differences identified between the two Yampa sites could be related to biological interactions, differences in macro habitat availability (temperature, water quality) or differences in meso-habitat availability (gradient, substrate particle size, riffle/run ratios).

A lack of fish under 30 cm, higher mean lengths for virtually all species, and a much lower density estimate of only 410 fish/km at the Duffy site could suggest increased predatory pressures there compared to the Sevens site. Duffy had the higher density of large predator fish, northern pike, smallmouth bass and Colorado pikeminnow. Unfortunately it is not possible to compare habitat availability between the Sevens and Duffy sites at this time. Channel catfish catch abundance was similar between both Yampa stations and the 15- Mile Reach.

There were large differences found in habitat composition between Duffy and the 15-Mile reach. At Duffy the dominant habitat type was shallow runs at 49% and that habitat was observed to be mostly unproductive in regards to adult fish. Shallow runs were only 5% of the habitat in the 15-mile reach. Another habitat type that is unproductive for adult fish is the wetted-sand pool or low velocity areas with depths less than 0.2 m. This habitat was 11% at Duffy at a flow of 600 cfs.

The dominant habitat type in the 15-mile reach was riffles over 0.5m in depth. Areas of deep fast current comprised 64% of the surface area in the 15-mile reach study site. It is believed that the high amount of deep and fast habitat accounts for the high percentage (38%)

of bluehead sucker in this reach, but correlations between habitat and fish are not available. Bluehead sucker composition below the study site was 15% and 25% above the study site and it was also a casual observation that there was less deep riffle habitat in those reaches.

Even though flows that have been modeled so far are not considered low or problematic flows, the habitat composition presented in the results can be used to indicate the general nature of these sites. This is because habitat composition is primarily a function of channel morphology and gradient. Riffles are areas of higher gradient, so as flow drops, depths, velocity and wetted area of the riffle habitat decrease. At the flow of 2,000 cfs on the 15-mile reach and 600 cfs for Duffy, the channel perimeter is nearly wetted so habitat at these flows should be near maximum diversity. As flow drops, the riffle habitats decrease at the highest rate and the area and percent of riffle both decline. At reduced flow, surface area of pools decrease at a lower rate so the area of pools will decrease but the percentage of pools will increase. It is expected that habitat diversity will simplify as flows drop.

The two study sites have opposing extremes in terms of habitat composition. The 15-Mile reach is primarily high-gradient deep habitats and the Duffy is primarily low-gradient shallow habitats. In order to make better comparisons between fish and habitat the plan in 2000 is to map habitat and sample fish in the Lily Park area of the Yampa and also above the study site on the 15-Mile reach. Lily Park area has been shown to have a high composition of native fish (Anderson 1999) and also has a long stretch of high gradient habitat and this allows the opportunity to determine if similar habitats produce similar fish between the two rivers. Also the Lily Park section has a low gradient area near the mouth of the Little Snake River. The new site in the 15-mile reach will probably be in an area with a lower composition of riffle habitats. Both the above and below sections sampled for fish in the 15-Mile reach had a lower percent of bluehead sucker in the sample. These additional sites should fill the gaps and improve relating the fishery to habitat features.

The draw back of additional stations is the lack of sufficient personnel to continue with habitat mapping and flow modeling after July 2000. At the onset of the project it was anticipated that once the "bugs" were identified and worked out, the modeling process could become more or less by the book. If so, production runs at all flows of interest would be practical and a computer literate temporary employee could be hired for that assignment. However, it is now clear that there is a very steep learning curve and a lot of experience in using this model is required for efficient application. Attempts to initiate a new graduate project with the Fishery and the Earth Science departments at CSU were not successful this year. Without a part-, or full-time computer modeler working on the project it will not be possible to compile the habitat database and perform statistical testing in the same year the data is collected. Efforts will be made to contract the modeling with a private consultant or out of state. The instream flow recommendations are due to the CWCB by August 2002. It was anticipated that more sites would be added in 2001 field season to strengthen fish-habitat relationships. However without a modeling contract this principal investigator will have to spend considerable time on modeling and reporting.

SUMMARY AND CONCLUSIONS

- Large differences were found in species composition between the two Yampa sites and the 15-Mile reach. The 15-Mile reach had the highest percent of native fish followed by the Sevens and Duffy had a very low percent of native fish.

- Fish sampling has produced density estimates in the study area and indicate the carrying capacity of the river sections. This sampling effort does not indicate how fish shift in habitat use as flow change. However it is believed that density estimates are a higher priority for justifying instream flow recommendations.

- Fish density and biomass on the 15-Mile reach was much greater than in the Yampa River.

- Preliminary modeling results show large differences in habitat composition between the Duffy site and the 15-Mile Reach. But statistical tests have not been completed.

- Significant differences in density and biomass between the three study sites could be related to differences in habitat composition.

- The 2-D modeling contract was vital for establishing data sampling protocols. The RTK GPS and echo sounder system proved very effective for surveying large sections of river. The project is now adequately equipped to survey river sections.

- The 2-D flow modeling clearly produces excellent habitat mapping results and is absolutely necessary for this project to develop instream flow recommendations for the Yampa and Colorado Rivers. The 2-D modeling is still problematic mainly because of the large amount of time required to calibrate and run the model for a set of desired flows. It is not likely that modeling efficiency will improve without significant upgrades to the RMA2 software.

- Without a new contract for 2-D flow modeling, sampling sites and fish sampling will be reduced to give more time to the researcher for modeling and reporting.

- Additional information on the performance and practicality of the 2-D model will be included in the M.S. Thesis by Greg Stewart.

RECOMMENDATIONS and ADJUSTMENTS TO STUDY DESIGN

1. In the 2000 field season, efforts will be made to sample a section on the Dolores River, the Lily Park reach on the Yampa River and a new site on the Colorado River. Spring runoff is very low in 2000 and could hamper field surveying because of low flows.

2. At the time of this report there is no contract set up for 2-D modeling. Efforts to get a graduate project to replace Greg Stewart have been unsuccessful so far. Efforts will be made to contract with a private consultant or with Utah State University. The Water Research Laboratory in Logan has a graduate program that uses and tests 2-D and 3-D flow models. This department has a full time staff capable of adapting the model to specific projects.

ACKNOWLEDGEMENTS

The hydraulic modeling was contracted with Colorado State University, the Department of Earth Resources. The contract was administered and supervised by Dr. Ellen Wohl and Greg Stewart performed the work for a M.S. project. Greg supervised the habitat quantification portion in the field and performed the hydraulic modeling. I greatly appreciated the enthusiasm and energy Greg put into this study and the long hours he spent setting up the technical equipment and calibrating the SMS model. District Wildlife Managers, Brad Petch and Chuck Woodward were very helpful and provided valuable assistance and information concerning landowners and logistics. I am very grateful to Tom Deacons who allowed us access to the river on his property in the Duffy area. Also I thank the Cross Mountain Ranch and Phil George for allowing access to the Sevens Ranch for habitat surveying and the other property owners on the river that granted access for electrofishing. On the 15-Mile reach the main property owner was the BOR.

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APPENDIX I

Flow Data and Hydrographs

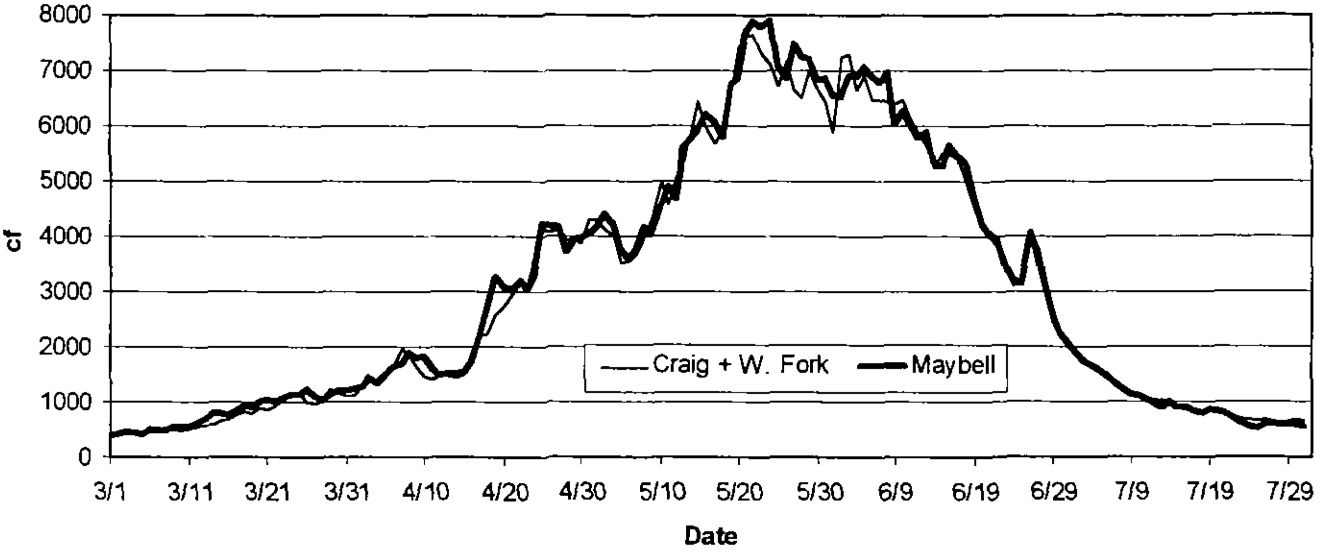

Figure A1.1: Spring and summer hydrographs for median daily flows for the combined Craig and Williams Fork gages and the Maybell gage, October 1984 to 1999.

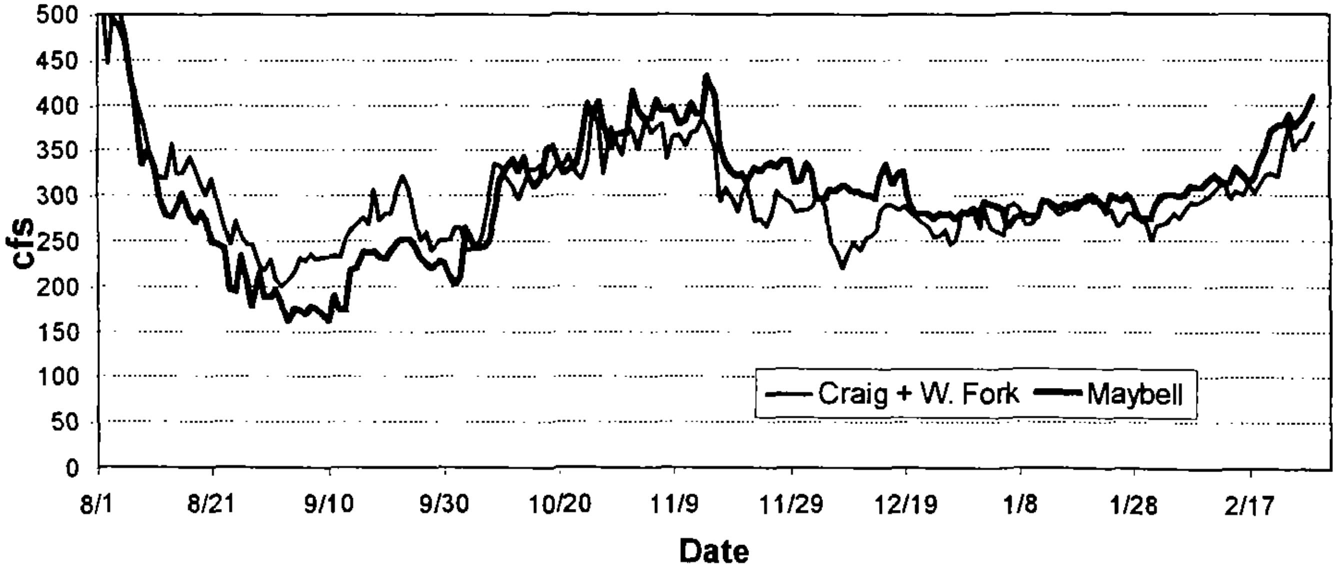

Figure A1.2: Fall and winter hydrographs for median flows for the combined Craig and Williams Fork gages and the Maybell gage, October 1984 to 1999.

Table A1.1. Comparison of river flows above and below the Maybell diversion for August.

AUGUST, MONTHLY FLOW VALUES								
Water Year	Craig + W. Fork Monthly ean (cfs)	Maybell Monthly ean (cfs)	Times Maybell < raig+W.F. DAYS	Amount Maybell < Craig+W.F. mean (cfs)	Times flow <93 cfs DAYS	Times flow <93 cfs DAYS	Craig + W. Fork Minimum cfs	Maybell Minimum cfs
1985	471	518	7	-19	0	0	235	201
1986	495	564	5	-17	0	0	337	310
1987	278	262	28	-30	0	0	132	124
1988	200	185	31	-24	3	3	26	65
1989	178	166	29	-25	3	3	61	31
1990	117	105	22	-37	12	18	57	27
1991	328*	300*	28	-44	0	0	175	166
1992	243	207	31	-42	0	0	172	129
1993	431	414	25	-46	0	0	268	214
1994	67	32	31	-35	31	26	35	13
1995	632	671	20	-47	0	0	325	303
1996	299	285	26	-41	0	0	158	130
1997	847	865	22	-42	0	0	488	453
1998	519	495	30	-56	0	0	292	237
1999	429	378	31	-67	0	0	245	166

Table A1.2. Comparison of river flows above and below the Maybell diversion for September.

SEPTEMBER, MONTHLY FLOW VALUES								
Water Year	Craig + W. Fork Monthly mean (cfs)	Maybell Monthly Mean (cfs)	Times Maybell < Craig+W.F. DAYS	Amount Maybell < Craig+W.F. mean (cfs)	Times Flow <93 cfs DAYS	Times Flow <93 cfs DAYS	Craig + W. Fork Minimum Cfs	Maybell Minimum cfs
1985	295	278	21	-19	0	0	222	201
1986	475	541	11	-14	0	0	352	340
1987	233	199*	30	-36	0	0	158	143
1988	158	152	13	-13	11	13	18.3	37
1989	128	88	30	-39	9	14	51	25
1990	176	111	30	-62	3	10	66	23
1991	203	195	18	-9	2	3	74	61
1992	294	239	26	-67	0	0	170	119
1993	280	224	30	-57	0	0	216	165
1994	70	31	30	-38	27	30	29	7.9
1995	307	250	27	-58	0	0	227	153
1996	233	186	30	-40	0	2	115	79
1997	1214	1366	18	-92	0	0	394	320
1998	277*	188	30	-91	0	0	177	115
1999	351	267	30	-84	0	0	265	170

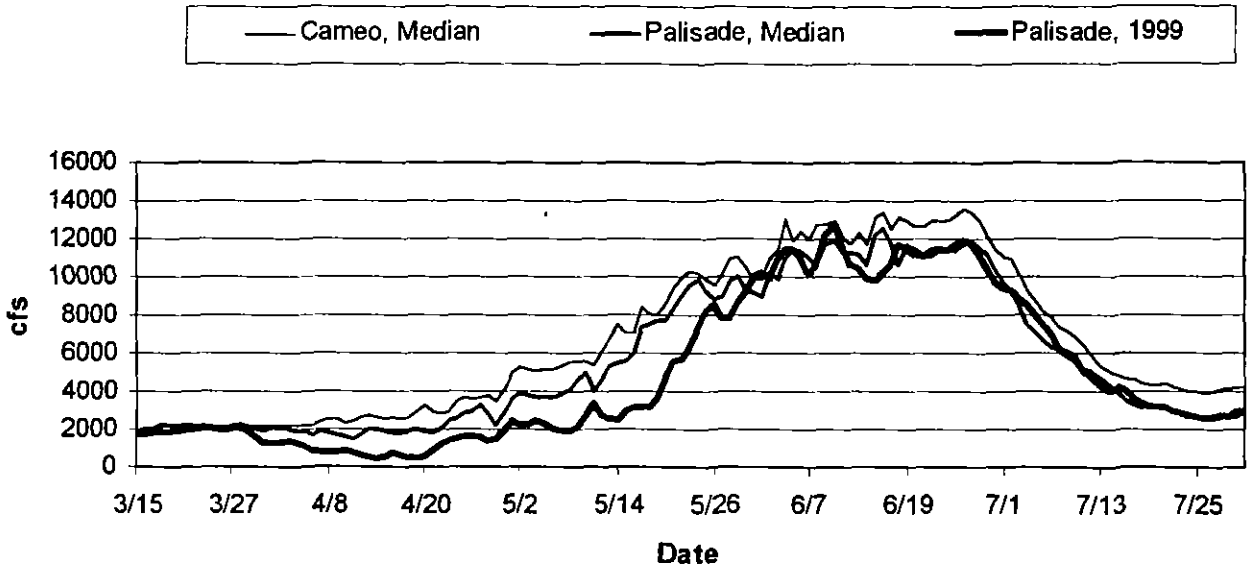

Figure A1.3: The mean differences in daily flows (10 years) between Cameo and Palisade gages, October 1, 1990 to December 1999 and 1999 daily mean flows. cameoweb page c&p90-95.

APPENDIX II

Fish Data

Table A2.1: Number of fish per species collected or observed during fall electrofishing at the Sevens station in 1998 and 1999.

1998 Electrofishing					
Species	>15 cm	<15 cm	YOY	TOTAL	
Flannelmouth Sucker	1169	1	14	1184	33.2%
Bluehead Sucker	547	2	0	549	15.4%
Roundtail Chub	156	4	66	226	6.3%
Colo. Pikeminnow	3	0	0	3	0.1%
White sucker	292	8	34	334	9.4%
White X Flannelmouth	142	0	0	142	4.0%
White X Bluehead	11	0	0	11	0.3%
Channel Catfish	153	1	0	154	4.3%
Carp	77	1	0	78	2.2%
Smallmouth Bass	24	2	9	35	1.0%
Northern Pike	33	0	0	33	0.9%
White Crappie	7	9	3	19	0.5%
Mottled Sculpin	0	16	52	68	1.9%
Speckled Dace	0	15	510	525	14.7%
Sand Shiner	0	27	151	178	5.0%
Redside Shiner	0	2	22	24	0.7%
Fathead minnow	0			2	0.1%
Sample size	2614	88	861	3565	
1999 Electrofishing					
Species	>15 cm	< 15 cm	YOY	TOTAL	
Flannelmouth Sucker	476	0	0	476	42.7%
Bluehead Sucker	187	0	0	187	16.8%
Roundtail Chub	39	0	0	39	3.5%
Colo. Pikeminnow	2	0	0	2	0.2%
White sucker	103	11	4	118	10.6%
White X Flannelmouth	46	0	0	46	4.1%
White X Bluehead	2	0	0	2	0.2%
Channel Catfish	75	0	0	75	6.7%
Carp	50	0	0	50	4.5%
Smallmouth Bass	22	13	11	46	4.1%
Northern Pike	19	0	0	19	1.7%
White Crappie	14	3	2	19	1.7%
Mottled Sculpin	0	0	0	0	0.0%
Speckled Dace	0	10	0	10	0.9%
Sand Shiner	0	27	0	27	2.4%
Total	1035	64	17	1116	

Table A2.2: Number of fish per species collected or observed during fall electrofishing at the Duffy station in 1998 and 1999.

1998 ELECTROFISHING					
Species	>15 cm	<15 cm	YOY	TOTAL	
Flannelmouth Sucker	87	0	1	88	2.7%
Bluehead Sucker	73	0	0	73	2.2%
Roundtail Chub	54	0	1	55	1.7%
Colo. Pikeminnow	25	0	0	25	0.8%
White sucker	577	17	128	722	22.0%
White X Flannelmouth	464	0	0	464	14.1%
White X Bluehead	99	0	1	100	3.0%
Channel Catfish	49	1	0	50	1.5%
Carp	44	1	3	48	1.5%
Smallmouth Bass	135	7	744	886	27.0%
Northern Pike	46	0	0	46	1.4%
White Crappie	1	4	4	9	0.3%
Mottled Sculpin		289	25	314	9.6%
Speckled Dace		167	27	194	5.9%
Sand Shiner		208	0	208	6.3%
Sample Size	1654	694	934	3282	
1999 ELECTROFISHING					
Species	>15 cm	< 15 cm	YOY	TOTAL	
Flannelmouth Sucker	106	0	2	108	2.8%
Bluehead Sucker	117	1	0	118	3.1%
Roundtail Chub	61	0	43	104	2.7%
Colo. Pikeminnow	13	0	0	13	0.3%
White sucker	698	90	234	1022	26.5%
White X Flannelmouth	686	0	0	686	17.8%
White X Bluehead	123	0	0	123	3.2%
Channel Catfish	83	0	0	83	2.2%
Carp	24	0	0	24	0.6%
Smallmouth Bass	131	44	698	873	22.6%
Northern Pike	48	0	0	48	1.2%
White Crappie	2	0	0	2	0.1%
Mottled Sculpin	0	465	2	467	12.1%
Speckled Dace	0	142	0	142	3.7%
Sand Shiner	0	42	0	42	1.1%
Sample Size	2092	784	979	3855	

Table A2.3. Sevens seining collections from 8/18/99. Fish collected in isolated pools are highlighted.

DATE 1999	seine #	BANK	RM	Habitat Type	Total Fish	% Native	SS	WS	FH	SMB	CP	NP	BS	RSS	KF	RC	FM	SD	UNK (small sucker)
18-Aug	1	left bank	63.1	SHLN, BAR	207	1.4%	204									3			
18-Aug	2	left bank	63.1	BA, SMALL	5	0.0%		5											
18-Aug	3	left bank	63.2	SHLN, COBBLE	3	0.0%	2	1											
18-Aug	4	left bank	63.1	BA, SMALL	12	0.0%	11			1									
18-Aug	5	left bank	63.1	SHLN	0														
18-Aug	6	left bank	63	SHLN	0														
18-Aug	7	left bank	63	SHLN	0														
18-Aug	8	left bank	63	BA, SHALLOW	21	0.0%	2	19											
18-Aug	9	left bank	63	BA, MOUTH	95	0.0%	91	4											
18-Aug	10	right bank	63	SHLN, BAR, ROCKY	59	0.0%	55	4											
18-Aug	11	right bank	63	SHLN, BAR, ROCKY	69	0.0%	64	4		1									
18-Aug	12	right bank	63	SHLN, MUD	129	8.5%	89	27	1					1		8	1	2	
18-Aug	13	right bank	63.1	SHLN, ROCKY	19	21.1%	13	2								2	1	1	
18-Aug	14	right bank	63.1	SHLN, MUD	2	100%												2	many
18-Aug	15	right bank	63.15	SHLN, ROCKY	14	0.0%	14												
18-Aug	16	right bank	63	ISOPOOL, LARGE	32	15.6%	1	17	6		3		2			3		2	
18-Aug	17	right bank	63	ISOPOOL, SMALL	8	37.5%			3				2					3	20
18-Aug	18	right bank	63	BA, LARGE, UPPER	153	5.9%	98	45			1					3		6	4
18-Aug	19	right bank	62.9	BA, LARGE, MIDDLE	143	1.4%	73	68								2			7
18-Aug	20	right bank	62.9	BA, LARGE, MIDDLE	76	9.2%	67	1	1									7	
18-Aug	21	right bank	62.8	SHLN, NEAR BA	117	17.9%	95		1									21	
18-Aug	22	right bank	62.8	SHLN	2	0.0%				1		1							
18-Aug	23	right bank	62.8	SHLN	1	0.0%				1									
18-Aug	24	right bank	62.8	BA, SMALL	156	5.8%	86	59	1	1						1	5	3	
18-Aug	25	right bank	62.8	SHLN, SAMD	26	7.7%	8	9	3	4								2	
18-Aug	26	left bank,	62.7	SHLN, SAND	103	2.9%	91	8	1							1		2	9
18-Aug	27	left bank,	62.7	BA, SMALL	42	40.5%	11	13	1							3		14	11
18-Aug	28	left bank,	62.7	ISOPOOL, LARGE	79	10.1%	1	40	12		7		11			3	1	4	64
18-Aug	29	left bank,	62.7	ISOPOOL, LARGE	180	7.2%		40	43		82		1		1	2	10	1	42

Table A2.3(continued). Sevens seining collections from 8/18/99. Fish collected in isolated pools are highlighted.

DATE	seine	BANK	RM	Habitat Type	Total	%													
18-Aug	30	left bank,	62.8	SHLN, SAND	44	11.4%	31	6	2								1	4	20
18-Aug	31	left bank,	62.8	BA,	366	4.4%	132	216	2							3	4	9	62
18-Aug	32	left bank,	62.9	SHLN, SAND	2	0.0%	2												
				TOTAL FISH	2165	6.5%	1241	588	77	9	93	1	16	1	1	34	23	83	239
				Percent			57%	27%	3.6%	0.4%	4.3%	0.0%	0.7%	0.0%	0.0%	1.6%	1.1%	3.8%	
				MEAN LENGTH	cm		40	33	44	32	69		42	71	72	34	44	41	24
				n for Mean length			149	42	15	9	11	0	6	1	1	11	3	2	12
				TOTAL -ISOPOOL	1866		1239	491	13	9	1	1	0	1	0	26	12	73	113
				% -ISOPOOL			66%	26%	0.7%	0.5%	0.1%	0.1%	0.0%	0.1%	0.0%	1.4%	0.6%	3.9%	

Table A2.4. Duffy seining collections from 8/12/99. Fish collected in isolated pools are highlighted.

DATE 1999	Seine #	Bank	RM	Habitat	Total Fish	% Native	SS	WS	FH	SMB	CP	NP	BS	RSS	RC	FM	SD
8/12	1	left	109.45	ISOPOOL	0												
8/12	2	left	109.45	ISOPOOL	0												
8/12	3	left	109.45	ISOPOOL	0												
8/12	4	left	109.45	ISOPOOL	1	0.0%				1							
8/12	5	left	109.46	SHLN, MUD	6	0.0%				5		1					
8/12	6	left	109.47	SHLN, ROCK	0												
8/12	7	left	109.48	SHLN, WEED	20	95.0%				1					4		15
8/12	8	left	109.48	SHLN, WEED	18	100%									6	1	11
8/12	9	left	109.5	SHLN, ROCK	6	66.7%				1		1					4
8/12	10	island	109.5	SHLN	61	24.6%	4	41		1					1	7	7
8/12	11	island	109.5	SHLN	10	10.0%	1	7		1						1	
8/12	12	island	109.5	SHLN	61	31.1%	39	2		1					5	2	12
8/12	13	island	109.5	SHLN	12	0.0%	11			1							
8/12	14	island	109.49	SHLN	43	20.9%	6	26		2					1		8
8/12	15	island	109.45	SHLN	186	5.9%	168	7								2	9
8/12	16	island	109.44	ISOPOOL	205	100%											205
8/12	16a	island	109.44	SHLN BA	77	76.6%		18							4		55
8/12	17	left	109.44	ISOPOOL	20	0.0%		15		5							
8/12	18	left	109.44	ISOPOOL	1	0.0%			1								
8/12	19	left	109.44	ISOPOOL	0												
8/12	20	left	109.42	ISOPOOL	25	44.0%		14							3		8
8/12	21	left	109.42	ISOPOOL	9	44.4%					5						4
8/12	22	left	109.41	ISOPOOL	5	0.0%		4		1							
8/12	23	left	109.41	ISOPOOL	15	46.7%		7			1				1	1	5
8/12	24	left	109.36	BACKWATER	222	41.9%		122		5		2			1	5	87

Table A2.4 (continued). Duffy seining collections from 8/12/99. Fish collected in isolated pools are highlighted.

8/12	25	left	109.35	SHLN, WEED	11	45.5%				5		1			5		
8/12	26	left	109.34	SHLN, WEED	11	45.5%				5		1			5		
8/12	27	left	109.33	SHLN, WEED	7	100%									1		6
8/12	28	left	109.32	SHLN, WEED	9	77.8%				1		1			3		4
8/12	29	left	109.31	SHLN, WEED	10	90.0%		1								3	6
8/12	30	island	109.3	SHLN, WEED	17	0.0%	13	1		2			1				
8/12	31	island	109.28	SHLN, WEED	59	28.8%	35	3	1	3							17
				TOTAL FISH	1127	46.6%	277	268	2	41	6	7	1	0	40	22	463
				Percent			25%	24%	0%	4%	1%	1%	0%	0%	4%	2%	41%
				MEAN LENGTH	CM		56	35	50	38	34	212	40		34	42	30
				n for Mean length	n		29	55	1	33	6	6	1		23	12	42
				Total -ISOPOOL	846		277	228	1	34	0	7	1	0	36	21	241
				% -ISOPOOL			33%	27%	0%	4%	0%	1%	0%	0%	4%	2%	28%

Table A2.5. Duffy seining collections from 8/17/99. Fish collected in isolated pools are highlighted.

DATE	Seine	Bank	RM	Habitat	Total	%											
6/21	#				Fish	Native	SS	WS	FH	SMB	CP	NP	BS	RSS	RC	FM	SD
8/17	1	left	109.6	SHLN	1	0.0%				1							
8/17	2	left	109.64	SHLN	1	0.0%				1							
8/17	3	left	109.68	SHLN	0												
8/17	4	left	109.68	SHLN	0												
8/17	5	left	109.69	SHLN, MUD	0												
8/17	6	left	109.7	SHLN, MUD	0												
8/17	7	left	109.72	SHLN, BOULDERS	0												
8/17	8	left	109.72	SHLN, BOULDERS	0												
8/17	9	left	109.75	SHLN	2	0.0%						2					
8/17	10	island	110	SHLN	0												
8/17	11	island	110	SHLN	7	100%									7		
8/17	12	island	110	BA, MUD	1	0.0%				1							
8/17	13	island	110	BA, LARG	62	29.0%		41		3					18		
8/17	14	island	110.02	INNER CHAN.	53	50.9%		26							3	1	23
8/17	15	island	110.05	SIDE CHAN.	8	25.0%		5				1			2		
8/17	16	island	110.1	SHLN, MUD	23	43.5%		13							10		
8/17	17	left	110.1	SHLN, ROCKS	0												
8/17	18	left	110.1	SHLN	15	53.3%	1	6							8		
8/17	19	left	110.1	SHLN	4	100%									3		1
8/17	20	left	110.2	ISOPOOL	31	0.0%		31									
8/17	21	left	110.16	shln	3	33.3%		1			1						1
8/17	22	left	110.17	shln	3	66.7%		1									2
8/17	23	left	110.18	shln	1	100%									1		
8/17	24	left	110.2	small mud BA	39	25.6%		3			22	4			10		
8/17	25	left	110.28	Isopool (>1m)	606	87.0%		60	7	1	6		5		526		1
8/17	26	left	110.3	shln	4	100%									4		
8/17	27	right	110.3	shln, in	1	0.0%				1							
8/17	28	right	110.25	shln, weeds	2	50.0%				1					1		
8/17	29	right	110.21	shln	2	0.0%		1		1							
8/17	30	right	110.2	shln	11	18.2%	4	3		1			1		1		1

Table A2.5.(continued) Duffy seining collections from 8/17/99. Fish collected in isolated pools are highlighted.

8/17	31	right	110.2	isopool	1	0.0%				1							
8/17	32	right	110.1	shln	10	0.0%		8		2							
8/17	33	right	109.9	riffle	5	80.0%		1							2		2
8/17	34	right	109.7	shln, weeds	45	82.2%		6		1			1		23		14
8/17	35	right	109.6	shln, weeds	13	76.9%		3							3		7
8/17	36	right	109.56	shln	133	95.5%	2	1	1				1	1	111		16
8/17	37	right	109.52	shln	2	100%											2
8/17	38	island	109.5	shln, cobble	12	25.0%		9									3
8/17	39	island	109.5	shln, cobble	30	6.7%	23	4		1							2
8/17	40	right	109.4	shln, cobble	11	0.0%	8	3									
8/17	41	right	109.4	shln, cobble	3	0.0%		3									
				TOTAL FISH	1145	70.7%	38	229	8	16	29	7	8	1	733	1	75
				Percent			3%	20%	1%	1%	3%	1%	1%	0%	64%	0%	7%
				MEAN LENGTH	CM		52	35	51	47	37	218	43	55	37		34
				n for Mean length			6	76	6	15	7	7	8	1	36	0	25
				Total -ISOPOOL	507		38	138	1	14	23	7	3	1	207	1	74
				% -ISOPOOL			7%	27%	0%	3%	5%	1%	1%	0%	41%	0%	15%

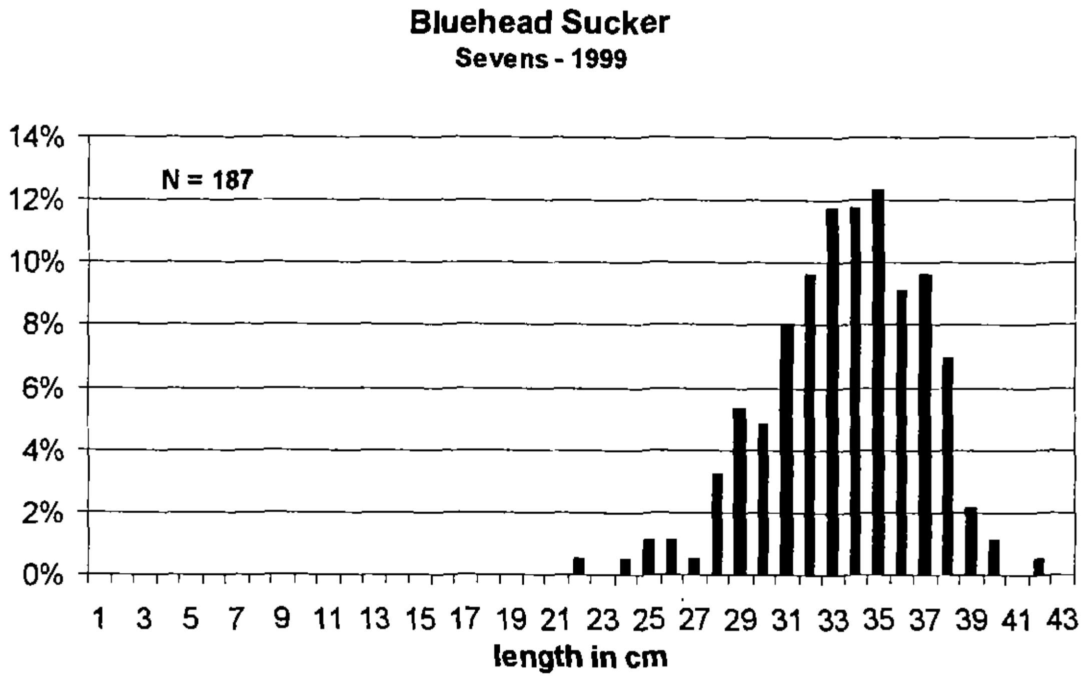

Figure 1. Bluehead Sucker length frequency at the Sevens site, September 1999, Yampa River.

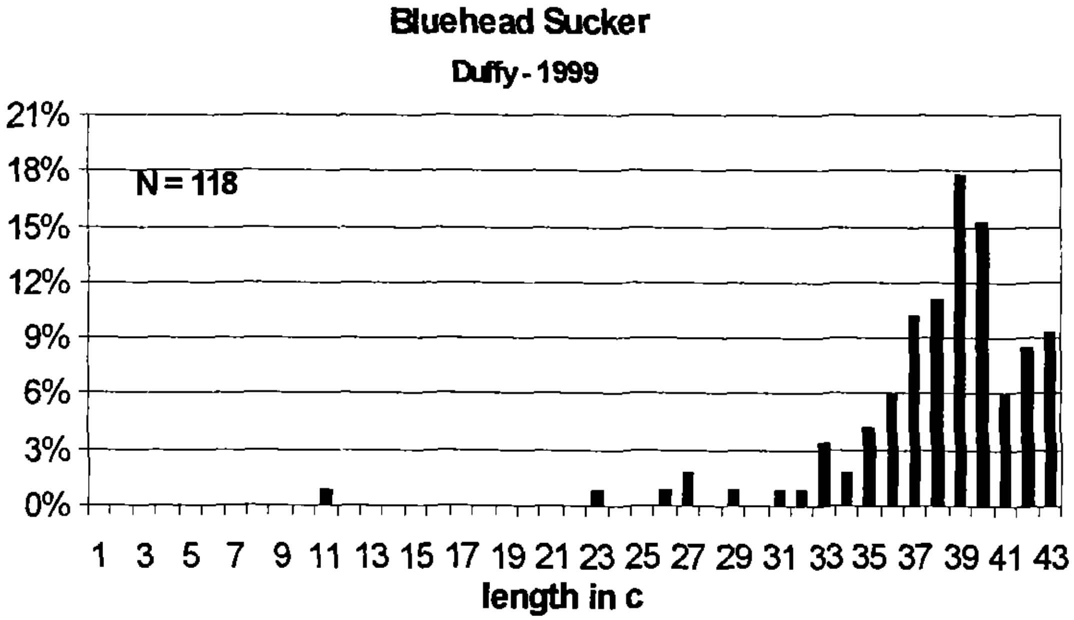

Figure 2. Bluehead Sucker length frequency at the Duffy site, September 1999, Yampa River.

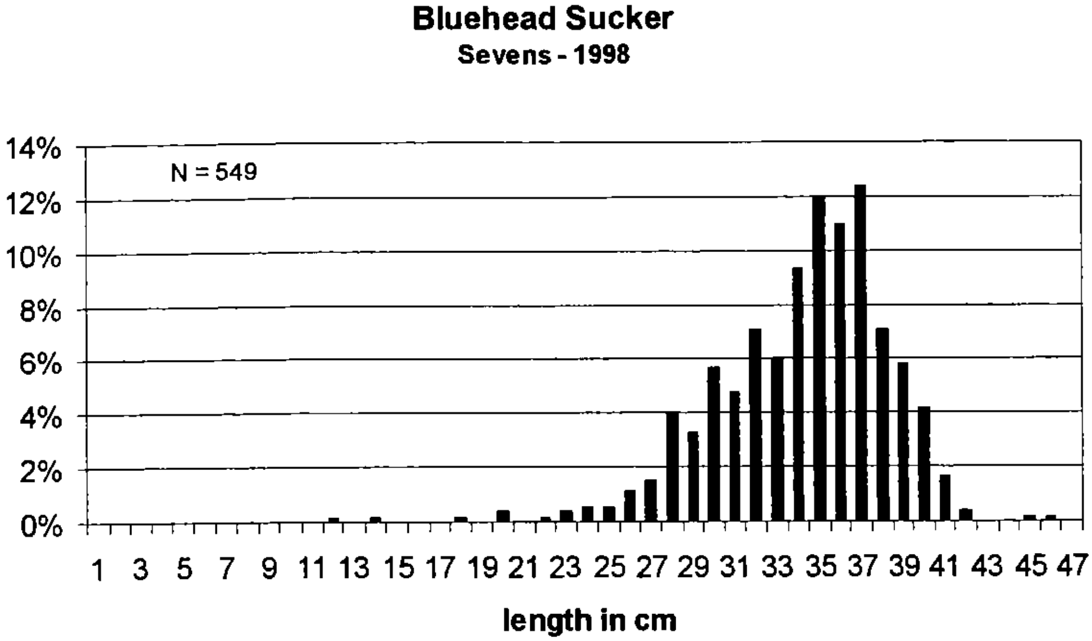

Figure 3. Bluehead Sucker length frequency at the Sevens site, September 1998, Yampa River.

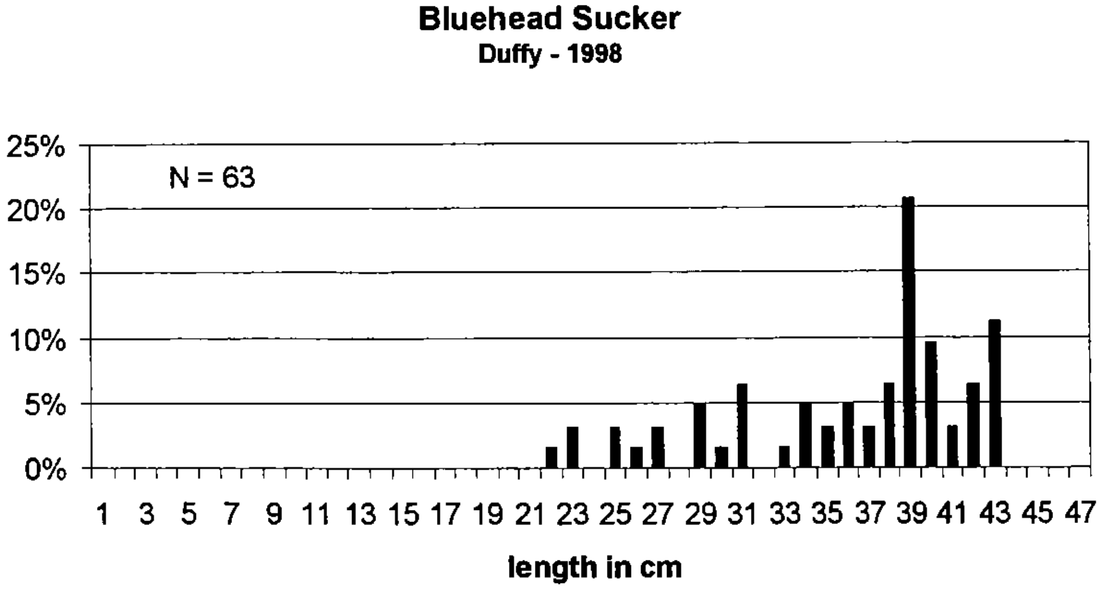

Figure 4. Bluehead Sucker length frequency at the Duffy site, September 1998, Yampa River.

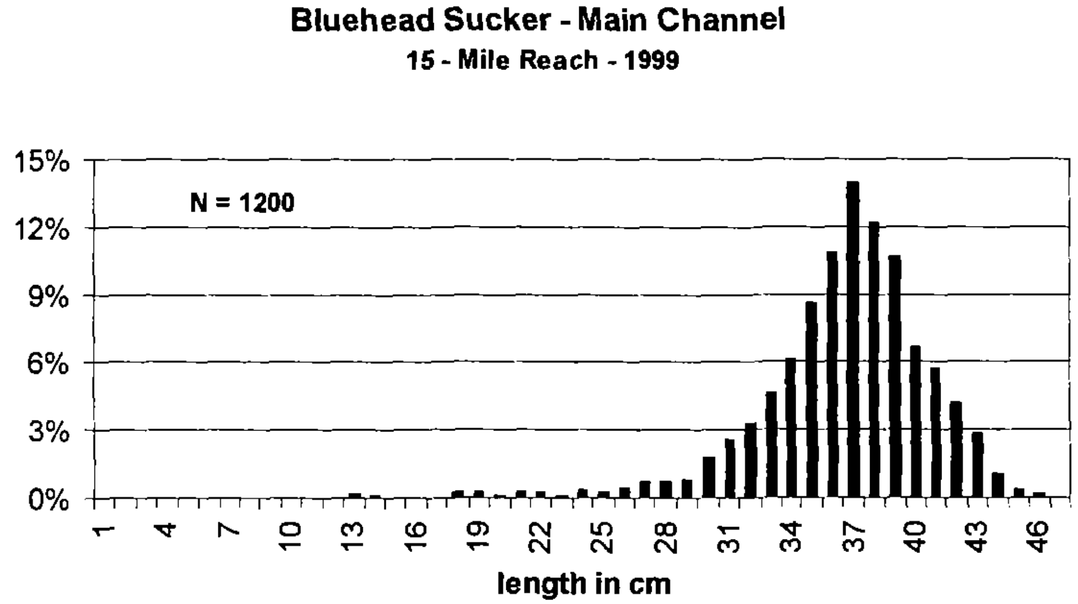

Figure 5. Bluehead Sucker length frequency at the Main Channel site, October 1999, Colorado River.

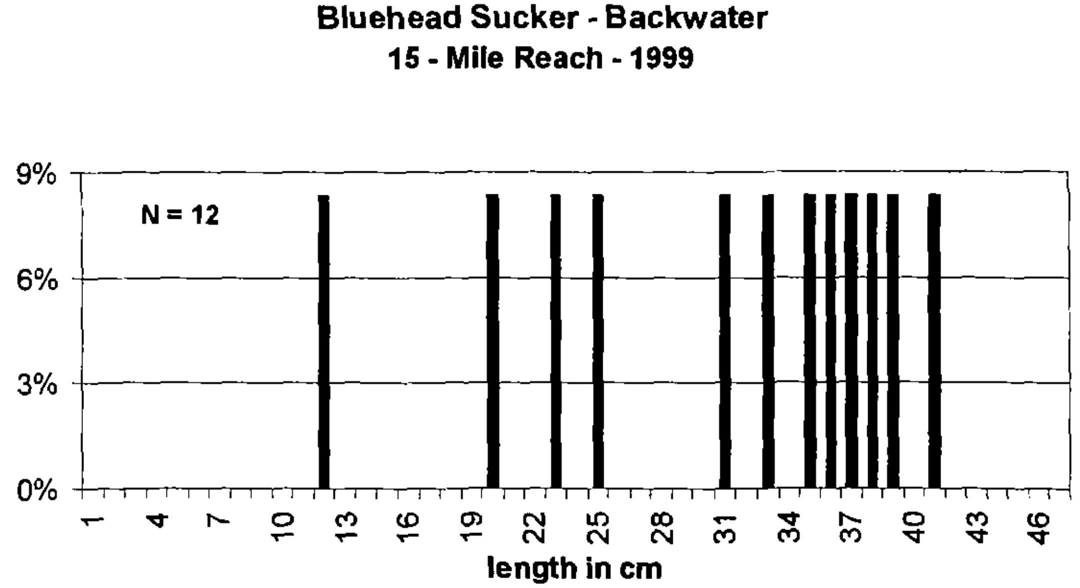

Figure 6. Bluehead Sucker length frequency at the Backwater site, October 1999, Colorado River.

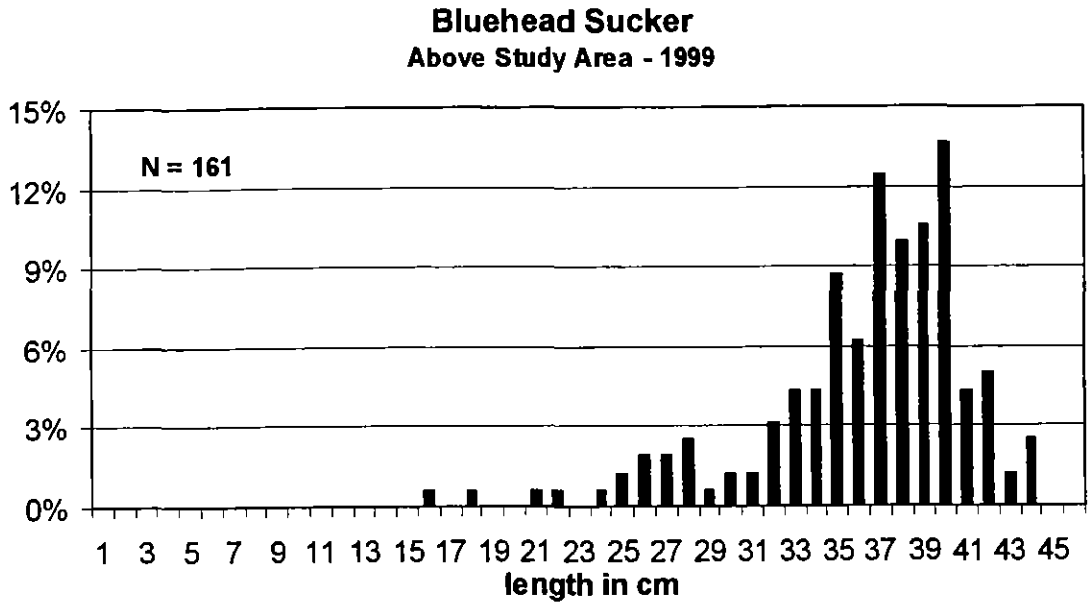

Figure 7. Bluehead Sucker length frequency Above the study area, October 1999, Colorado River.

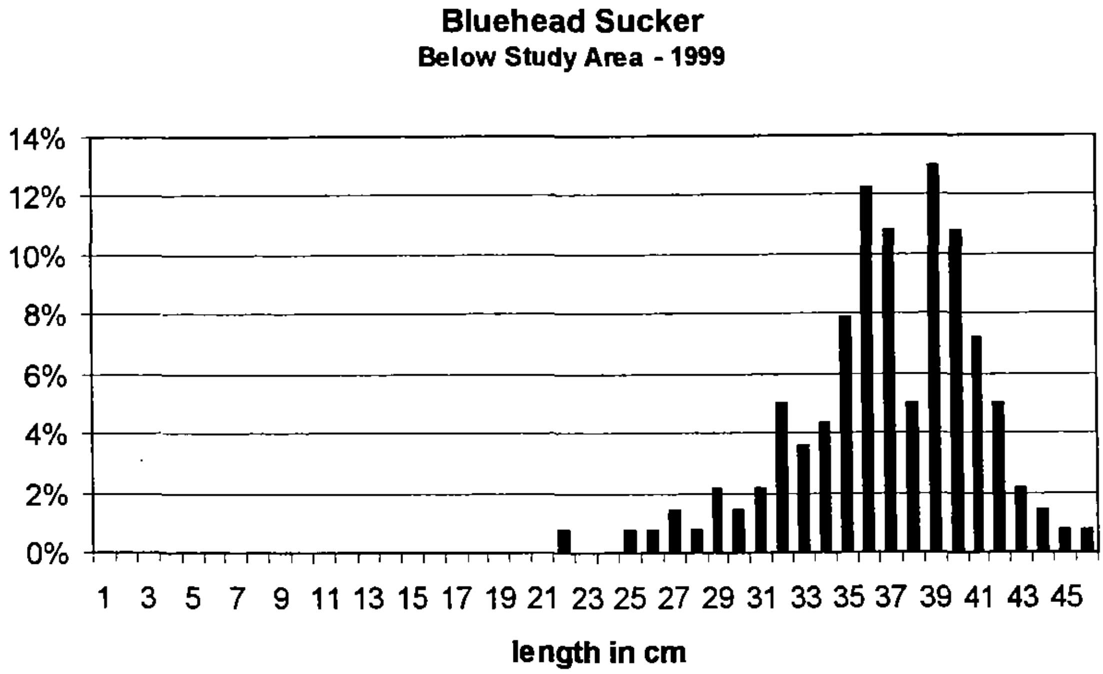

Figure 8. Bluehead Sucker length frequency Below the study area, October 1999, Colorado River.

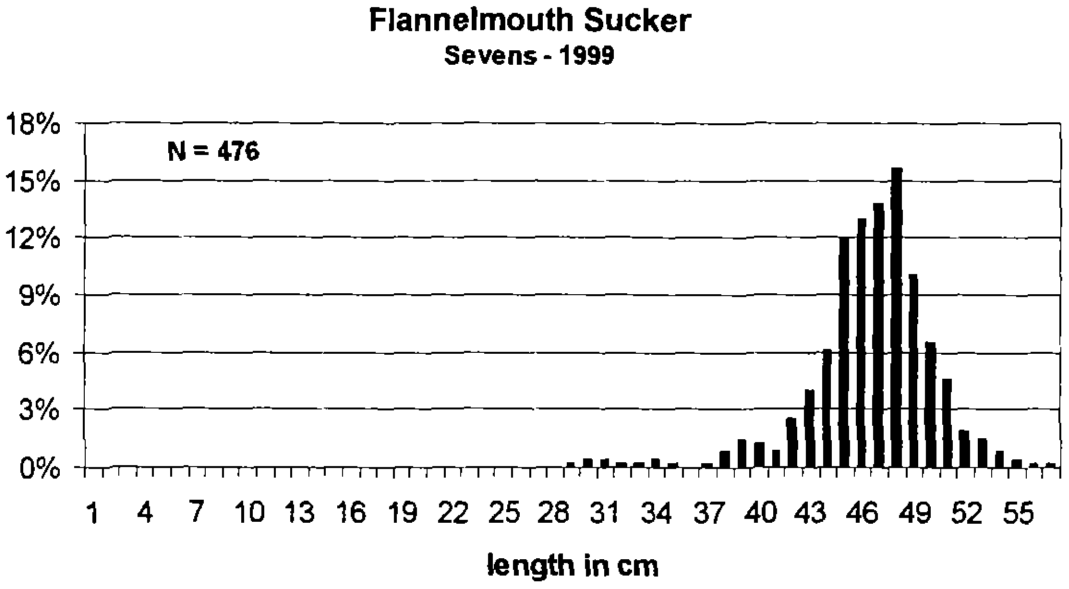

Figure 9. Flannelmouth Sucker length frequency at the Sevens site, September 1999, Yampa River.

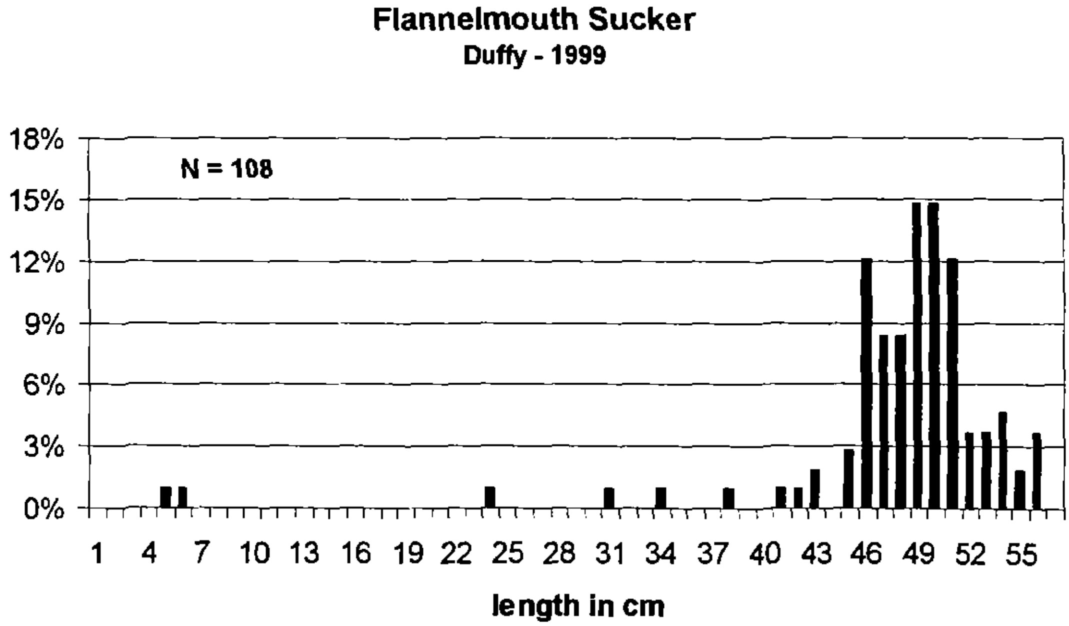

Figure 10. Flannelmouth Sucker length frequency at the Duffy site, September 1999, Yampa River.

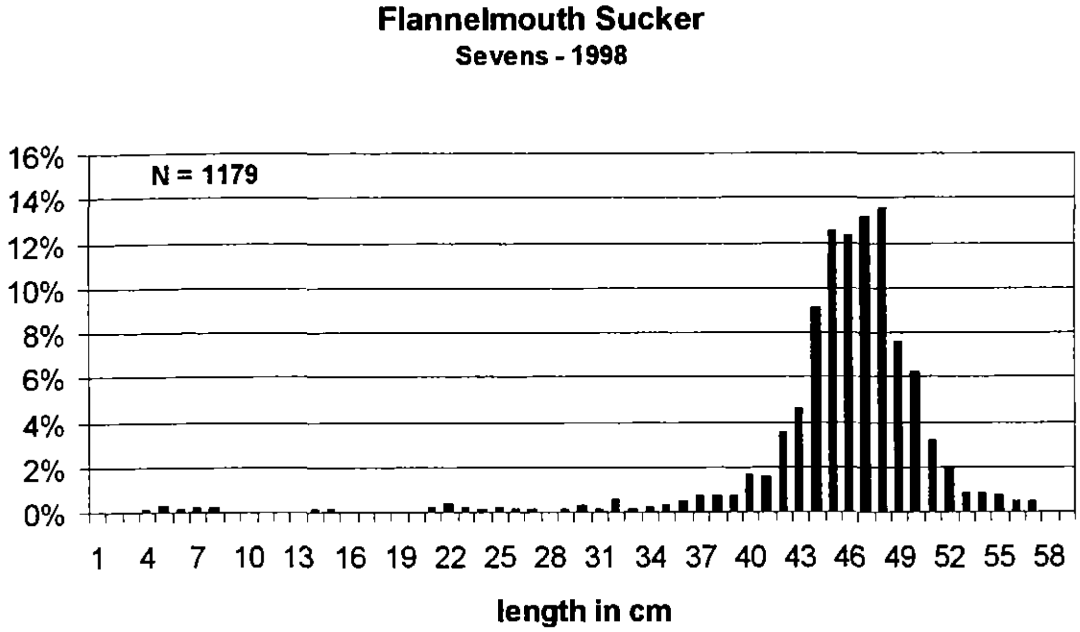

Figure 11. Flannelmouth Sucker length frequency at the Sevens site, September 1998, Yampa River.

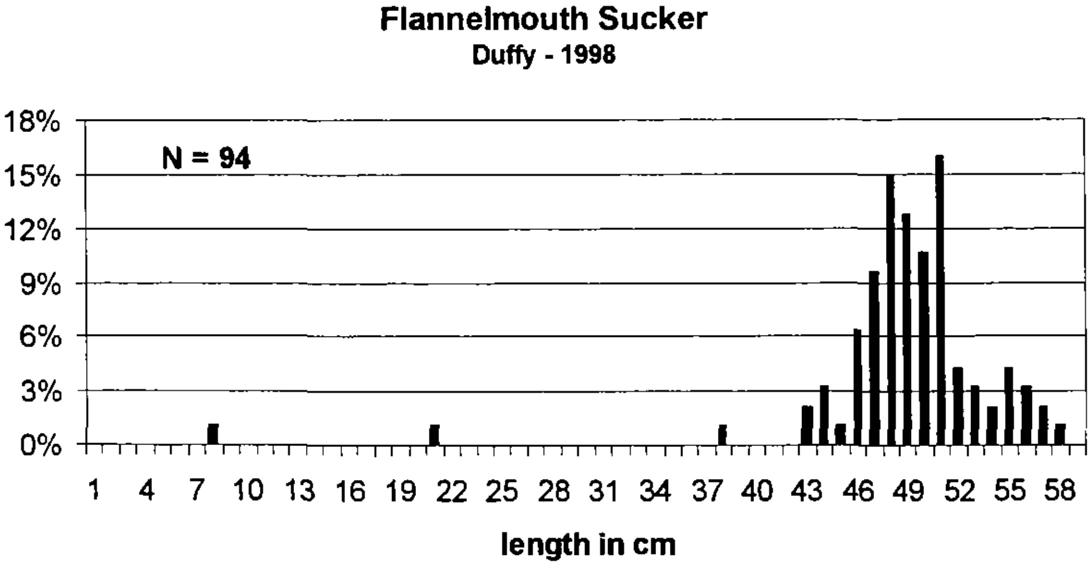

Figure 12. Flannelmouth Sucker length frequency at the Duffy site, September 1998, Yampa River.

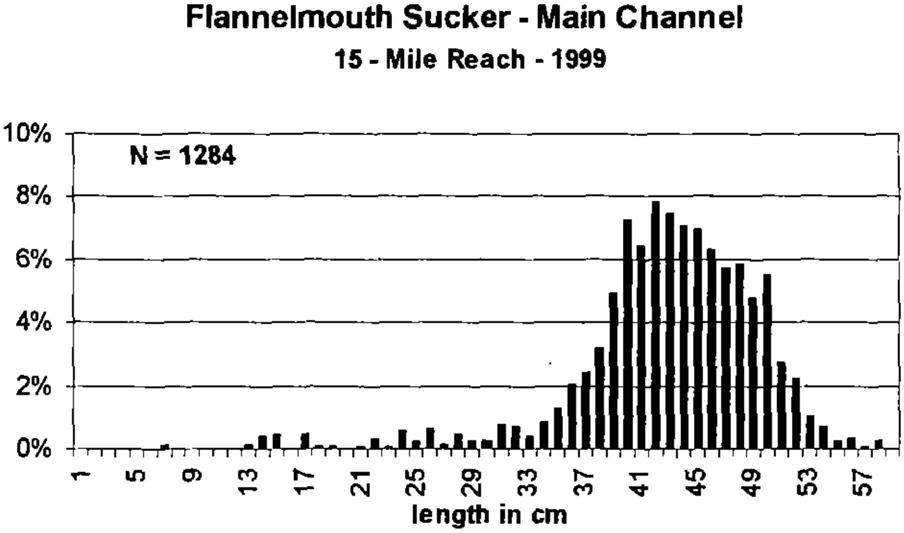

Figure 13. Flannelmouth Sucker length frequency at the Main Channel site, October 1999, Colorado River.

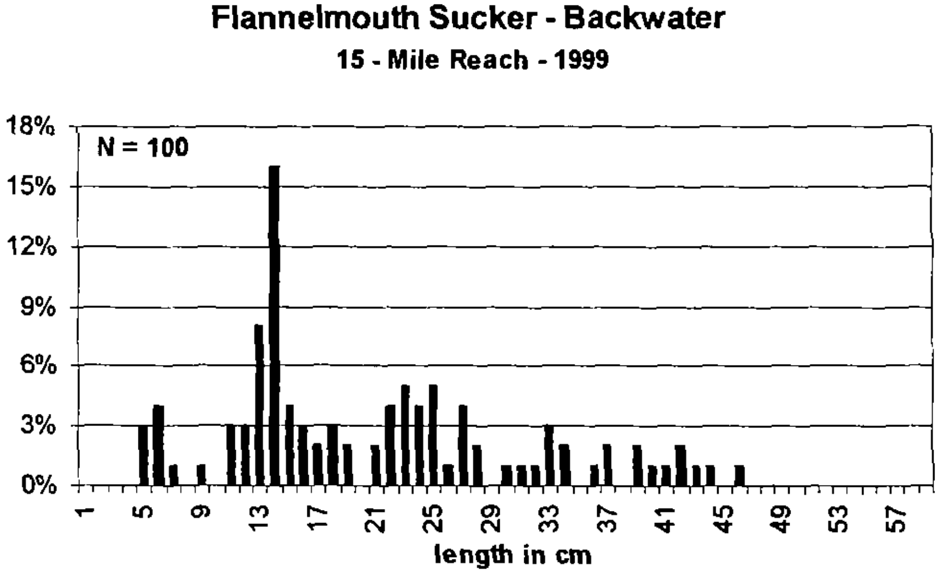

Figure 14. Flannelmouth Sucker length frequency at the Backwater site, October 1999, Colorado River.

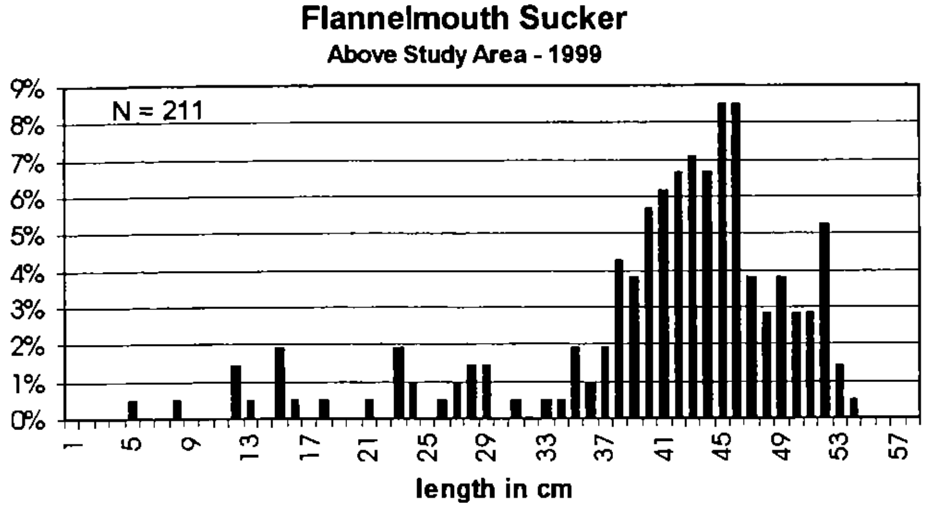

Figure 15. Flannelmouth Sucker length frequency Above the study area, October 1999, Colorado River.

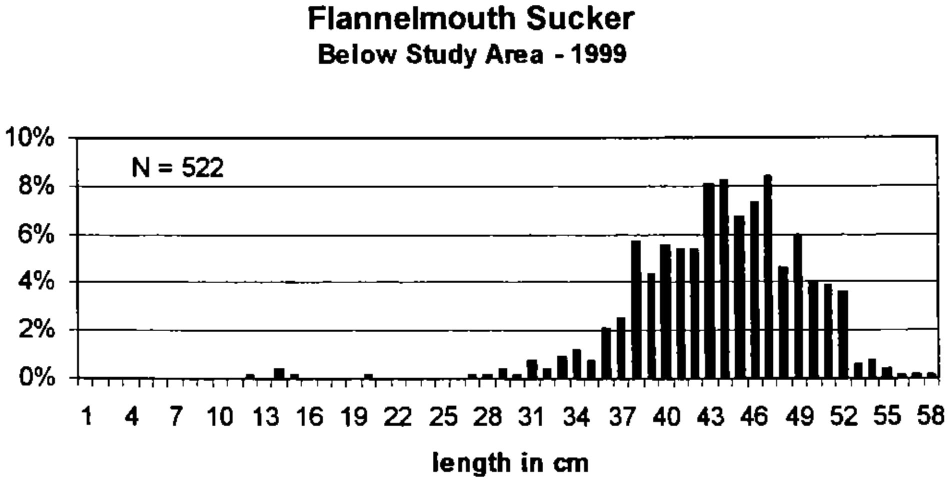

Figure 16. Flannelmouth Sucker length frequency Below the study area, October 1999, Colorado River.

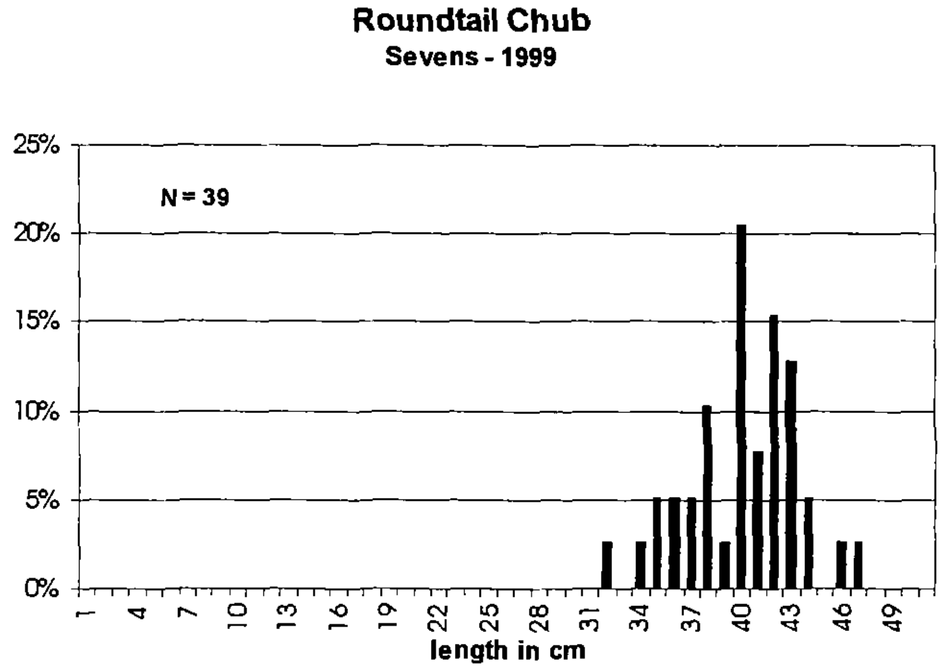

Figure 17. Roundtail Chub length frequency at the Sevens site, September 1999, Yampa River.

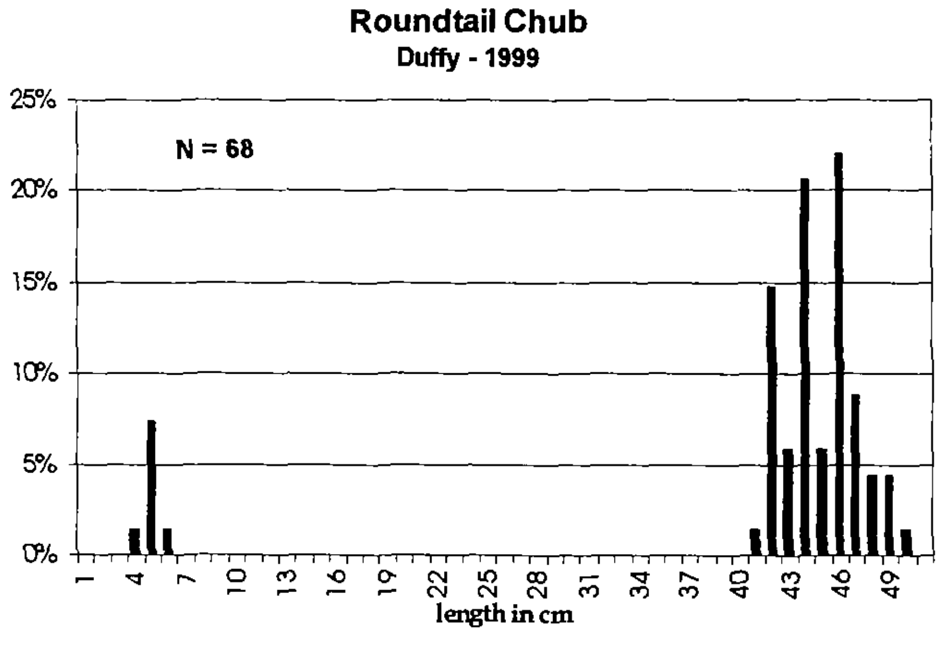

Figure 18.Roundtail Chub length frequency at the Duffy site, September 1999, Yampa River.

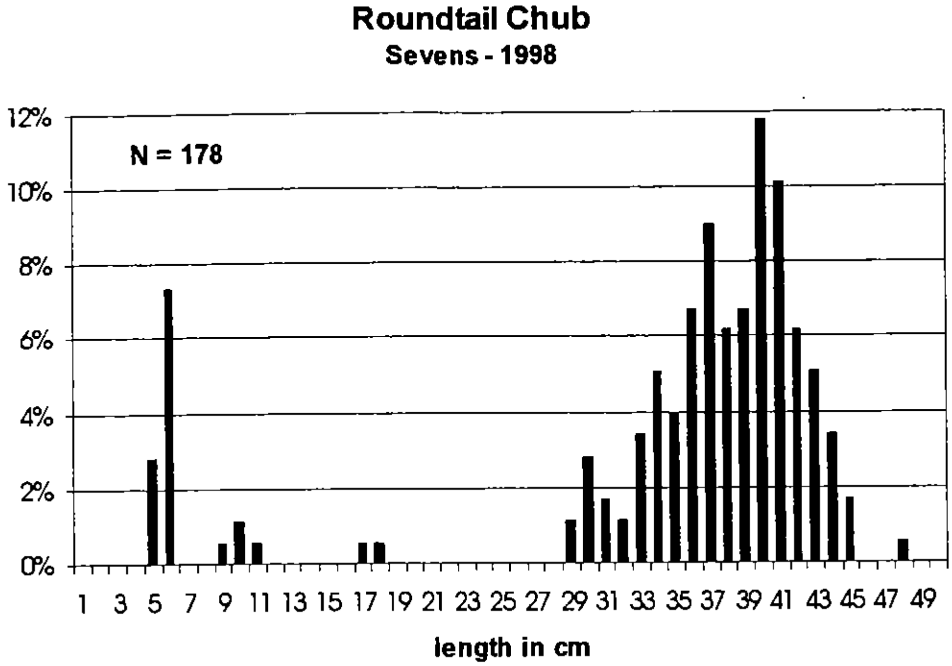

Figure 19. Roundtail Chub length frequency at the Sevens site, September 1998, Yampa River.

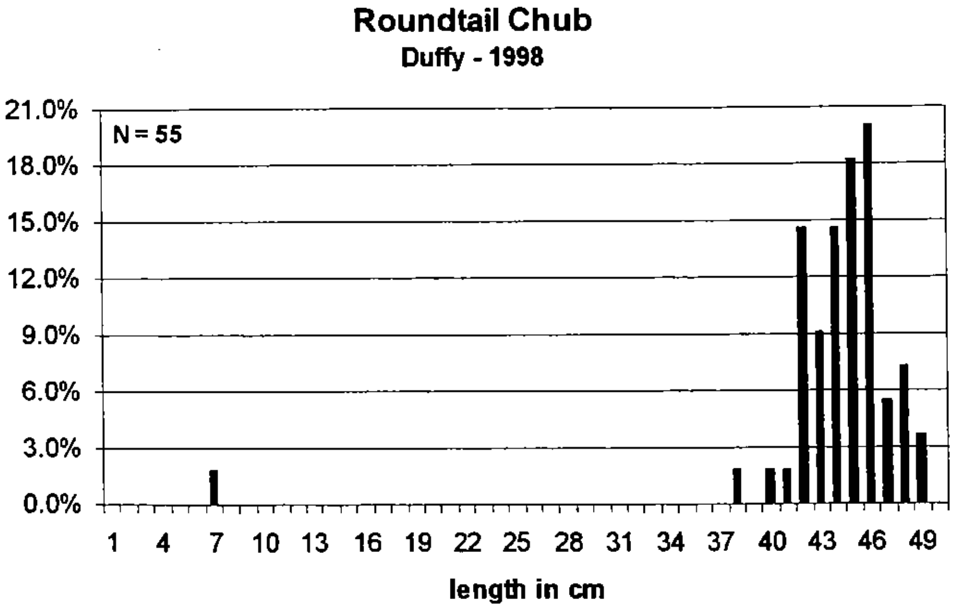

Figure 20. Roundtail Chub length frequency at the Duffy site, September 1998, Yampa River.

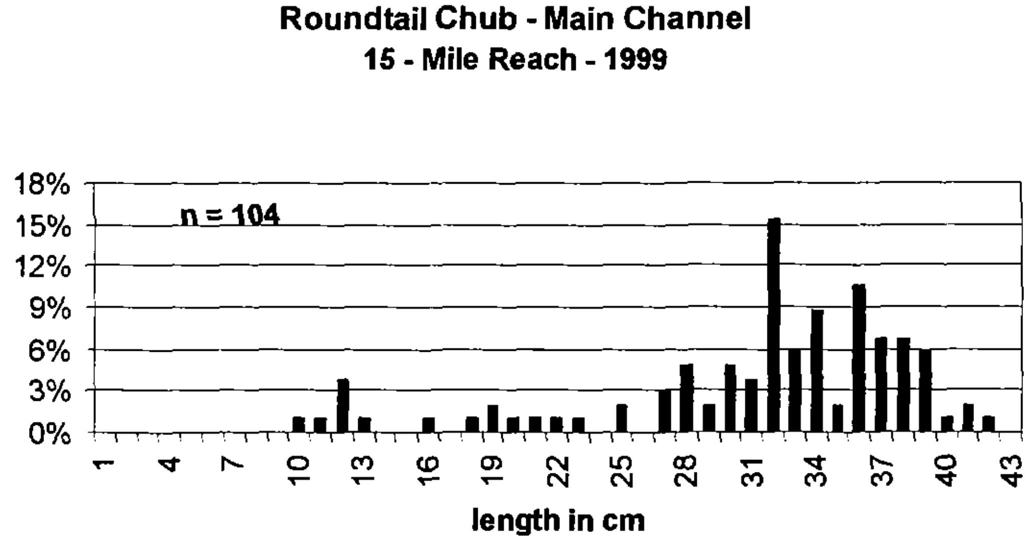

Figure 21. Roundtail Chub length frequency at the Main channel site, October 1999, Colorado River.

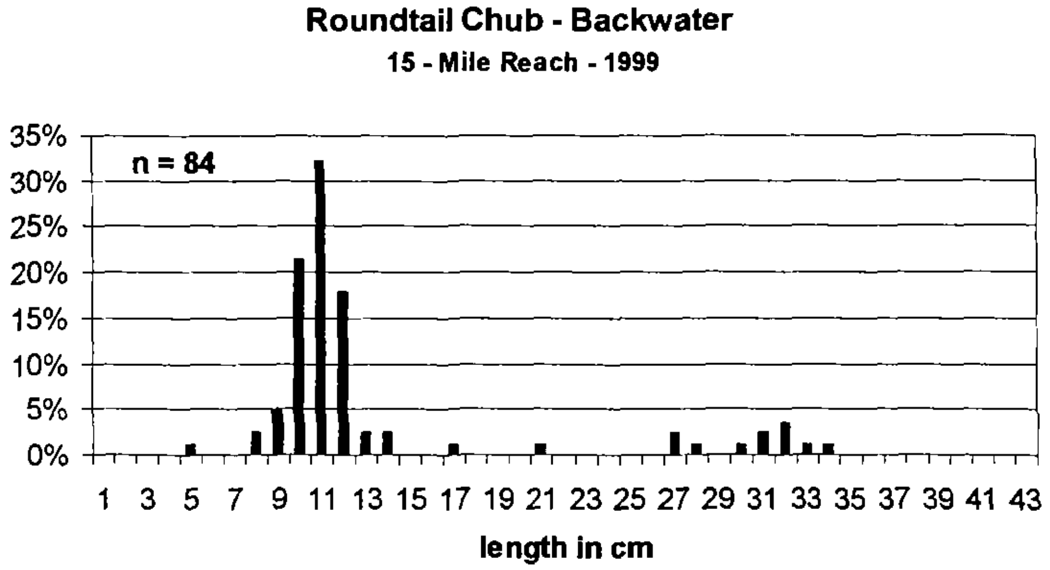

Figure 22. Roundtail Chub length frequency at the Backwater site, October 1999, Colorado River.

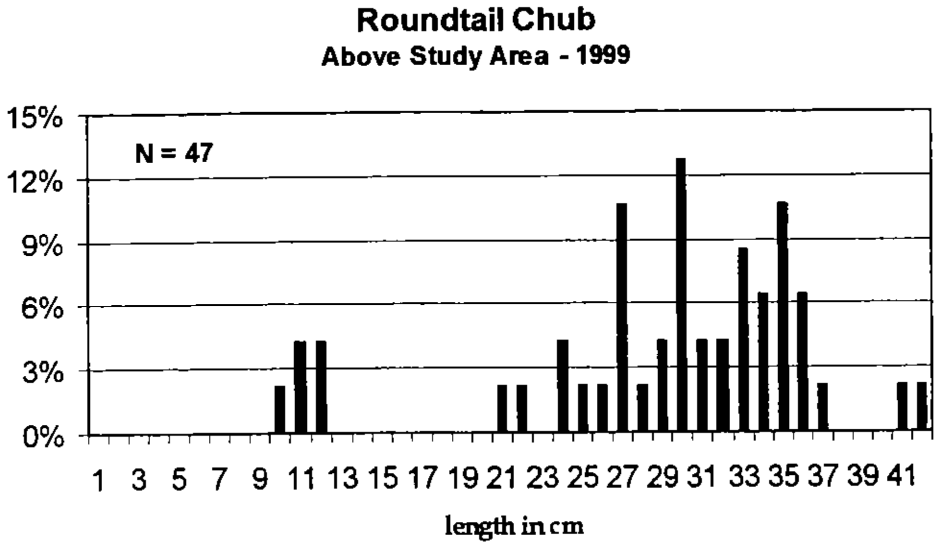

Figure 23. Roundtail Chub length frequency Above the study area, October 1999, Colorado River.

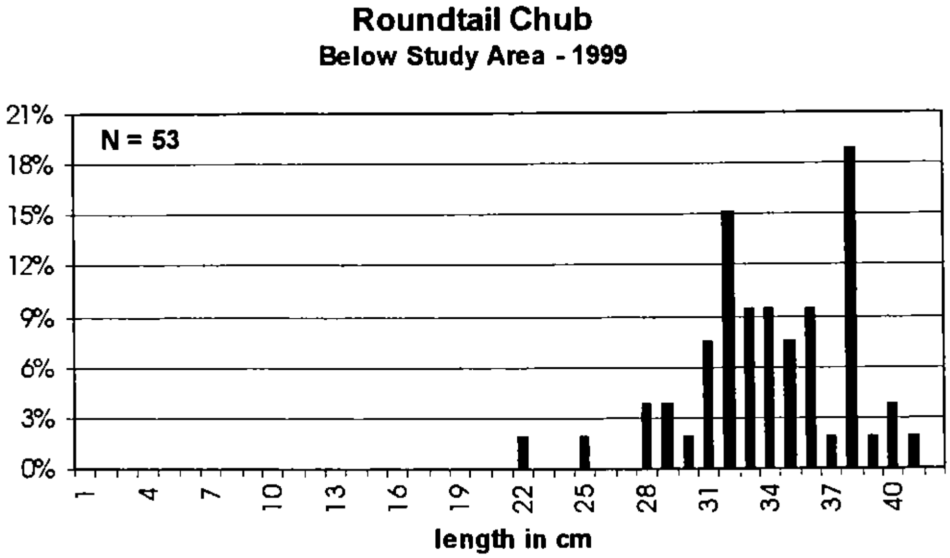

Figure 24. Roundtail Chub length frequency Below the study area, October 1999, Colorado River.

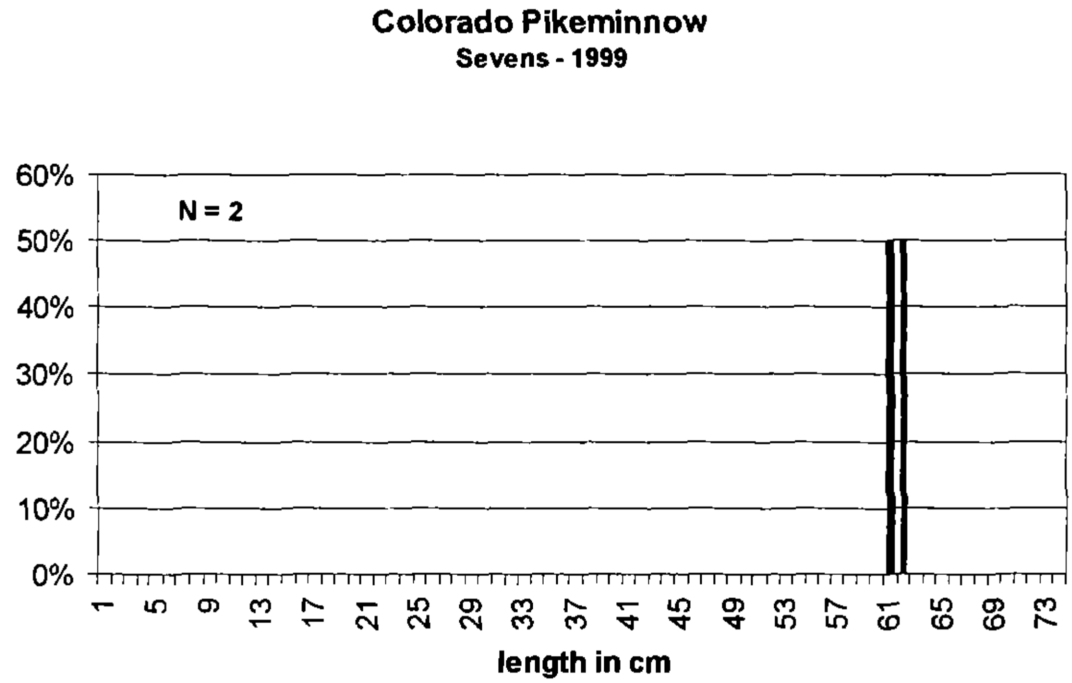

Figure 25. Colorado Pikeminnow length frequency at the Sevens site, September 1999, Yampa River.

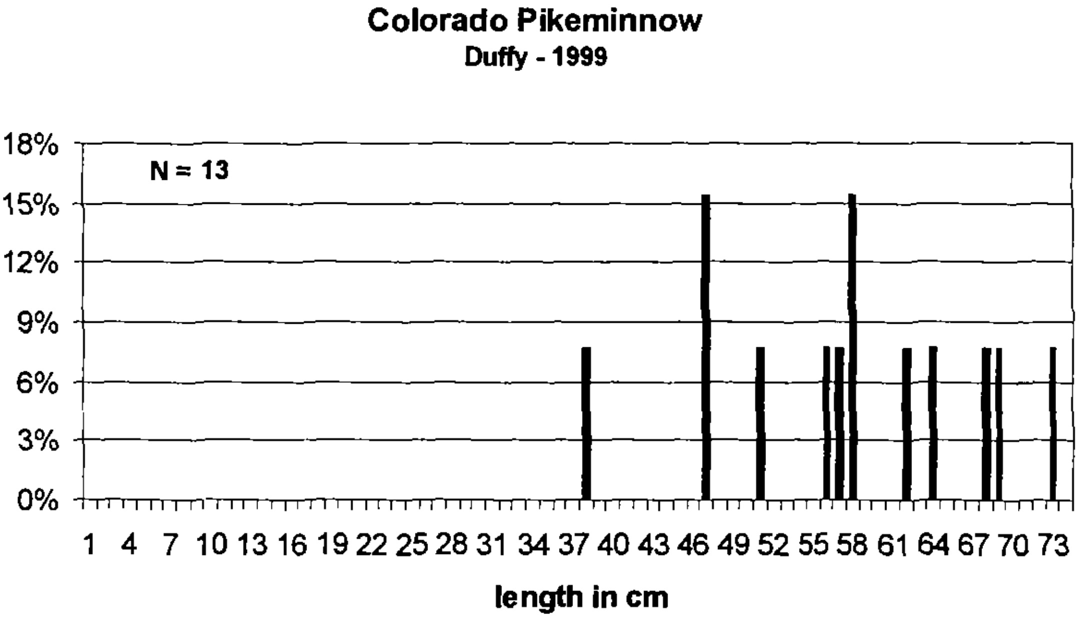

Figure 26. Colorado Pikeminnow length frequency at the Duffy site, September 1999, Yampa River.

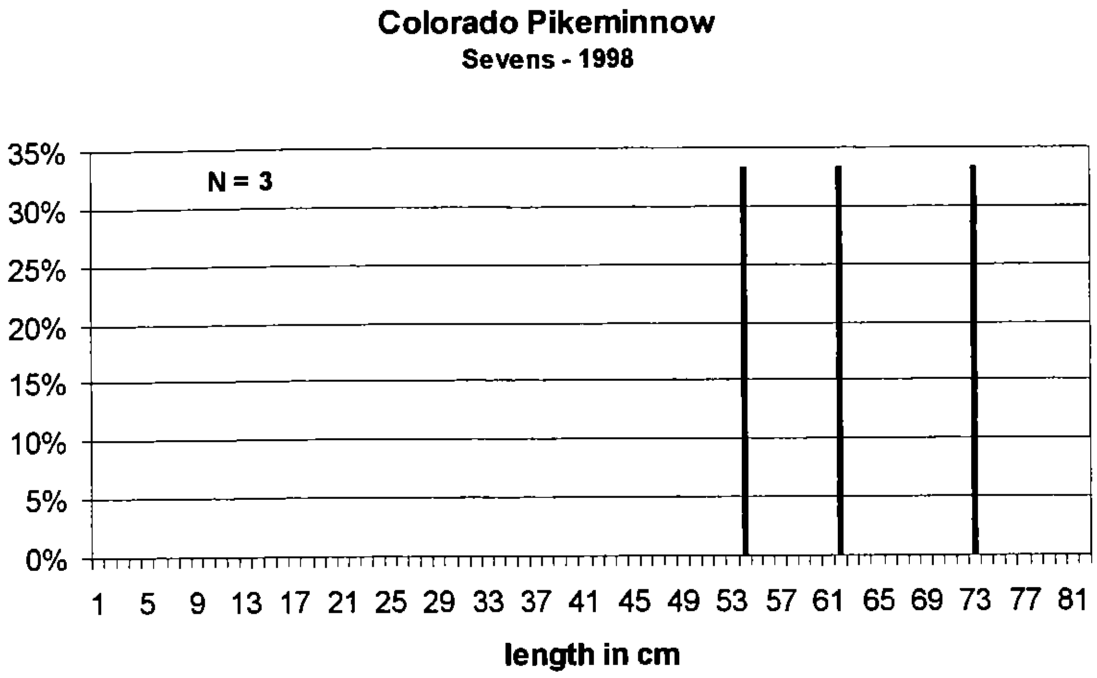

Figure 27. Colorado Pikeminnow length frequency at the Sevens site, September 1998, Yampa River.

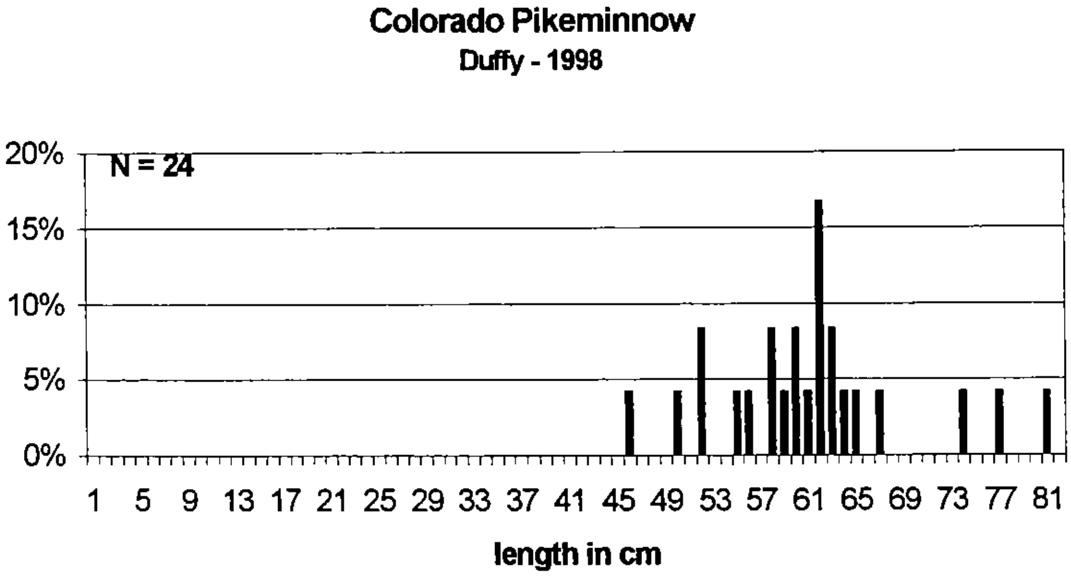

Figure 28. Colorado Pikeminnow length frequency at the Duffy site, September 1998, Yampa River.

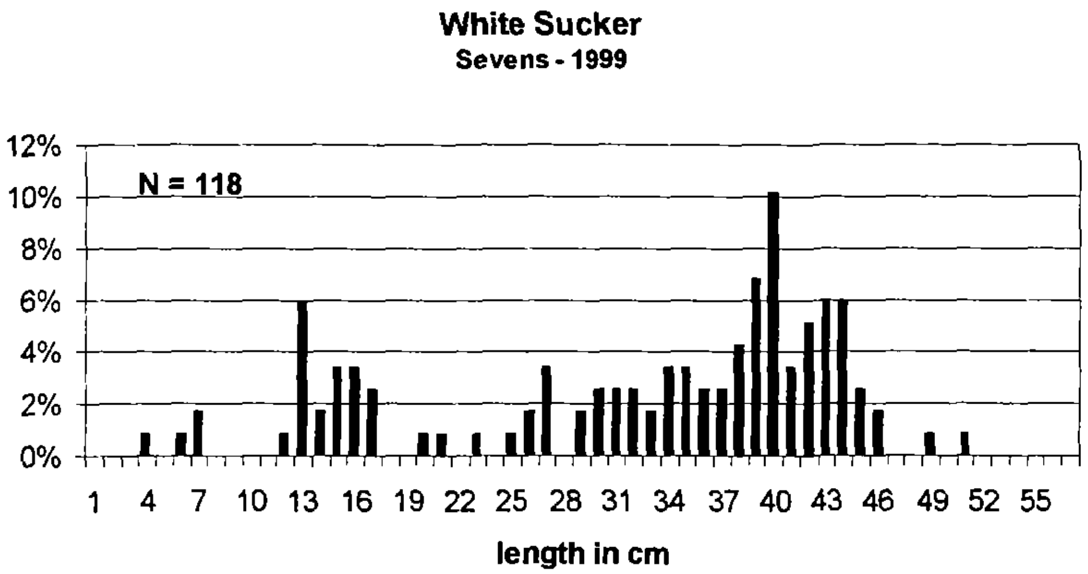

Figure 29. White Sucker length frequency at the Sevens site, September 1999, Yampa River.

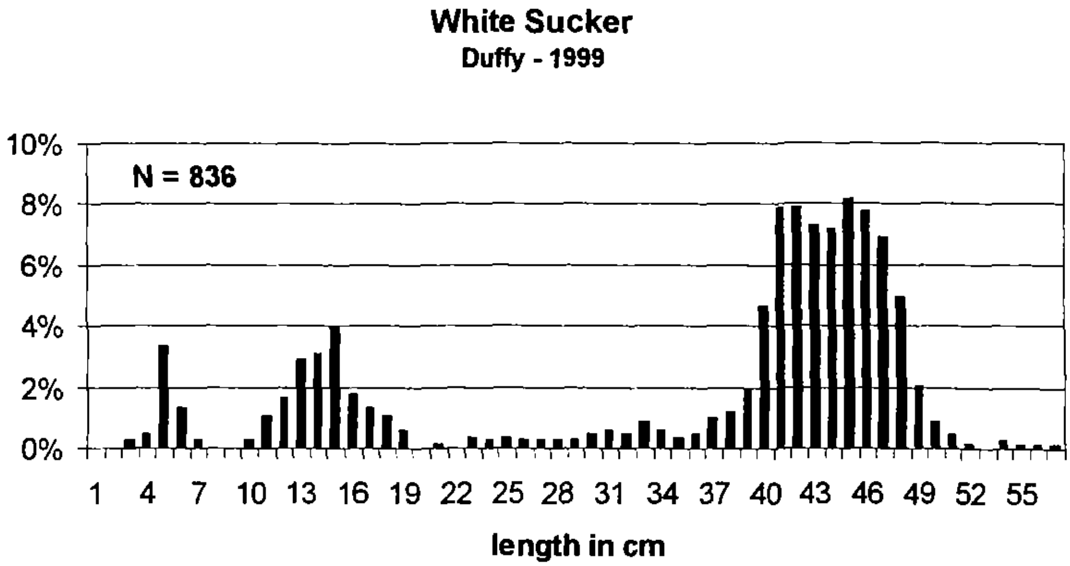

Figure 30. White Sucker length frequency at the Duffy site, September 1999, Yampa River.

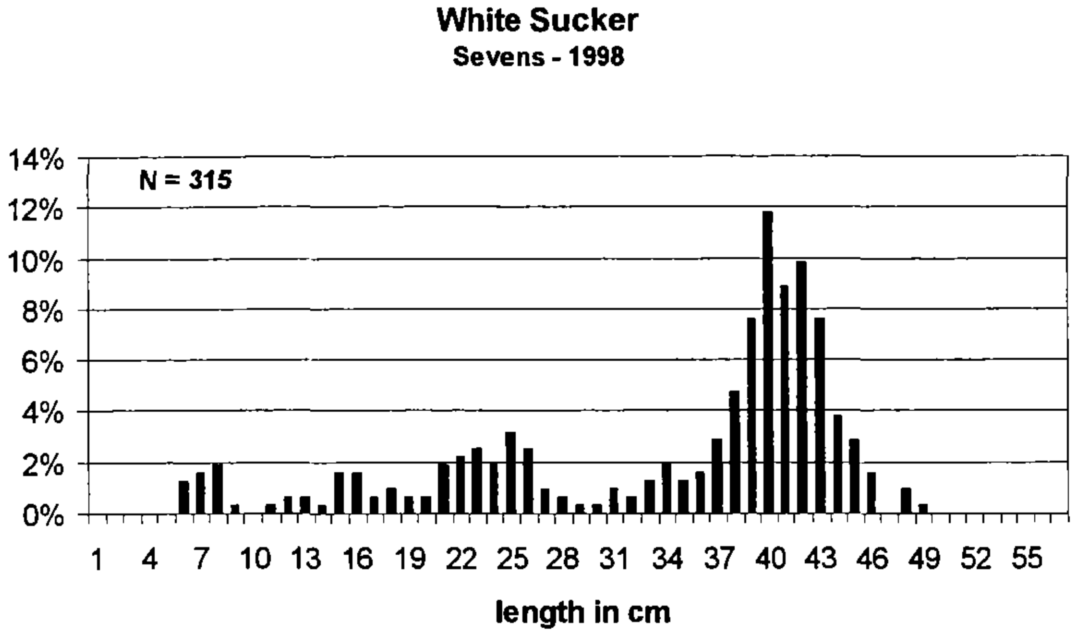

Figure 31. White Sucker length frequency at the Sevens site, September 1998, Yampa River.

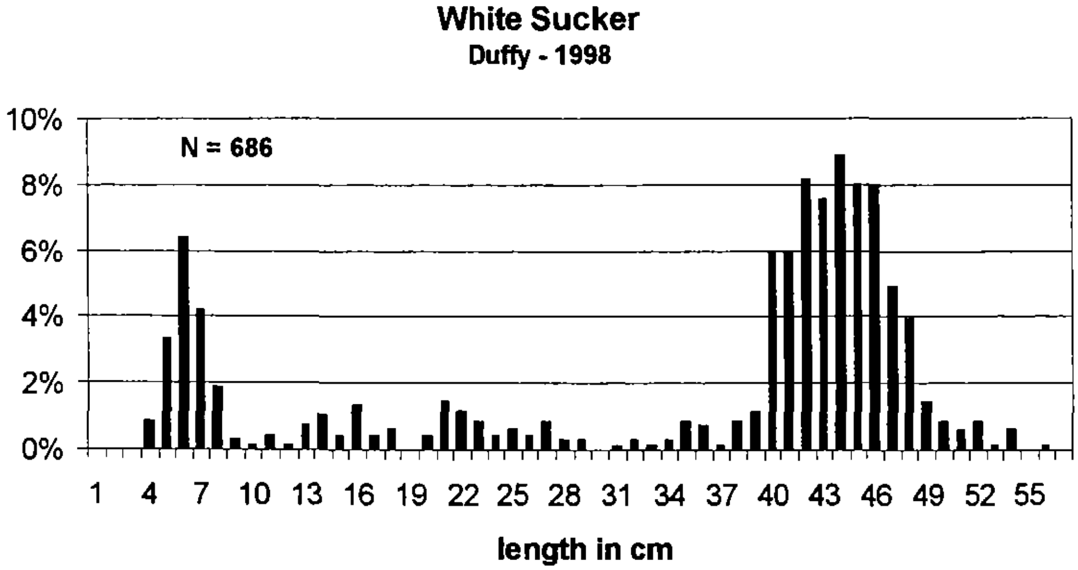

Figure 32. White Sucker length frequency at the Duffy site, September 1998, Yampa River.

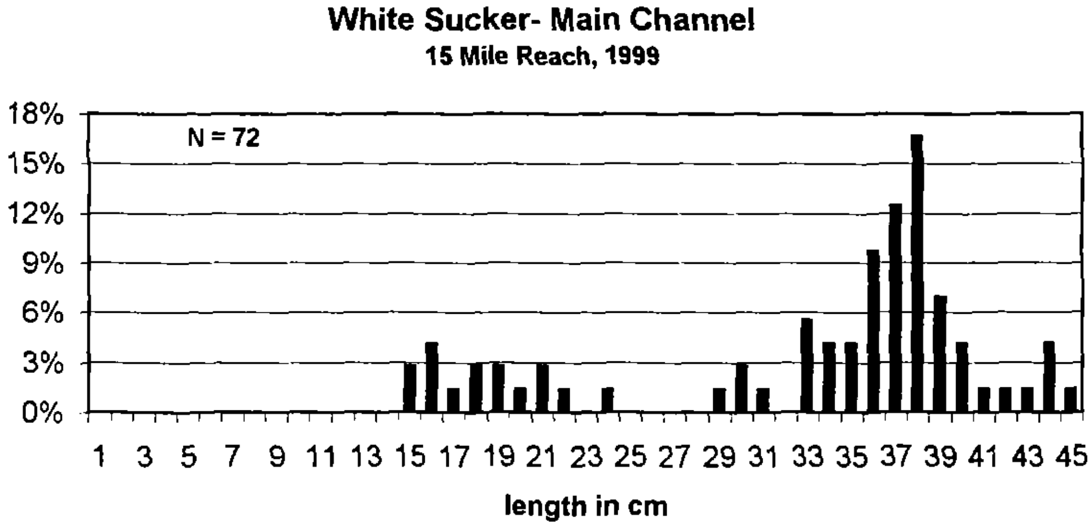

Figure 33. White Sucker length frequency at the Main Channel site, October 1999, Colorado River.

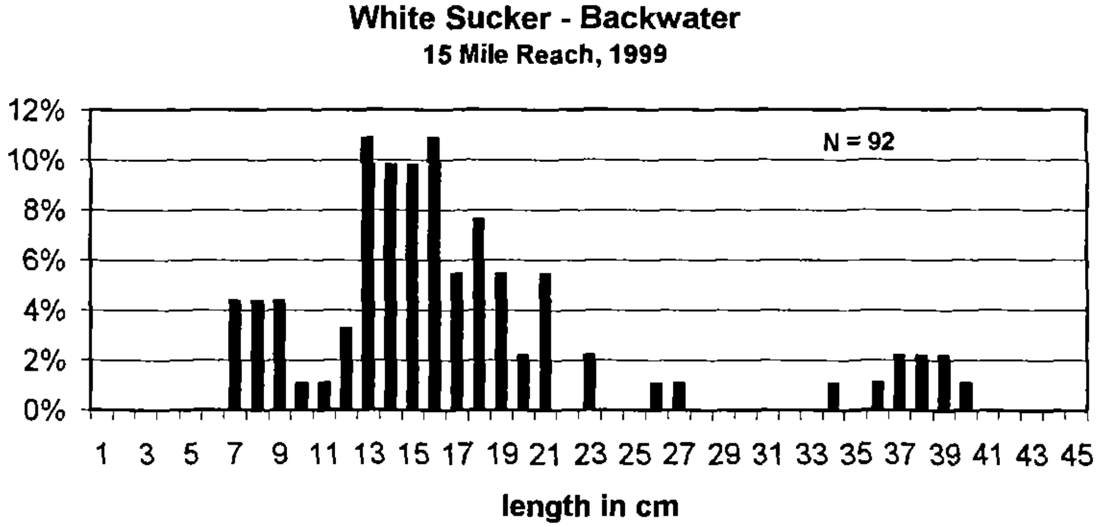

Figure 34. White Sucker length frequency at the Backwater site, October 1999, Colorado River.

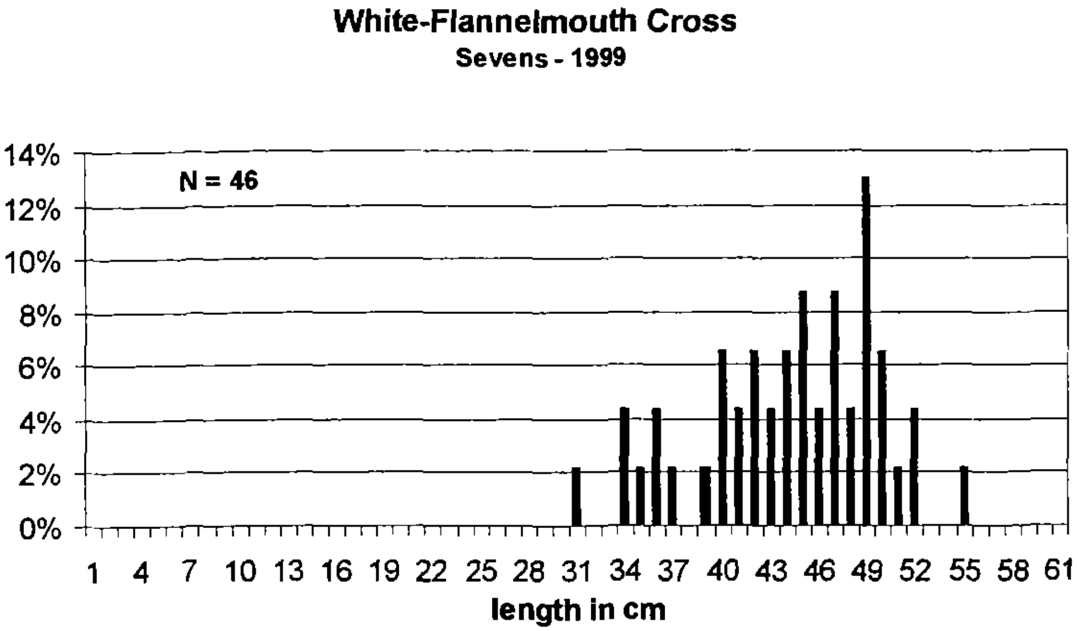

Figure 35. White-Flannelmouth Cross length frequency at the Sevens site, September 1999, Yampa River.

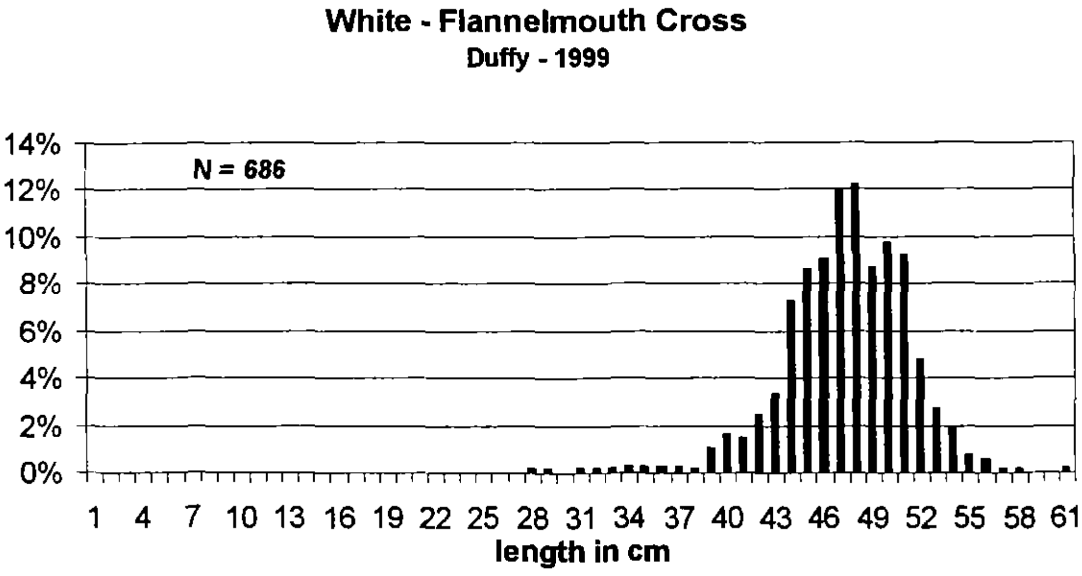

Figure 36. White-Flannelmouth Cross length frequency at the Duffy site, September 1999, Yampa River.

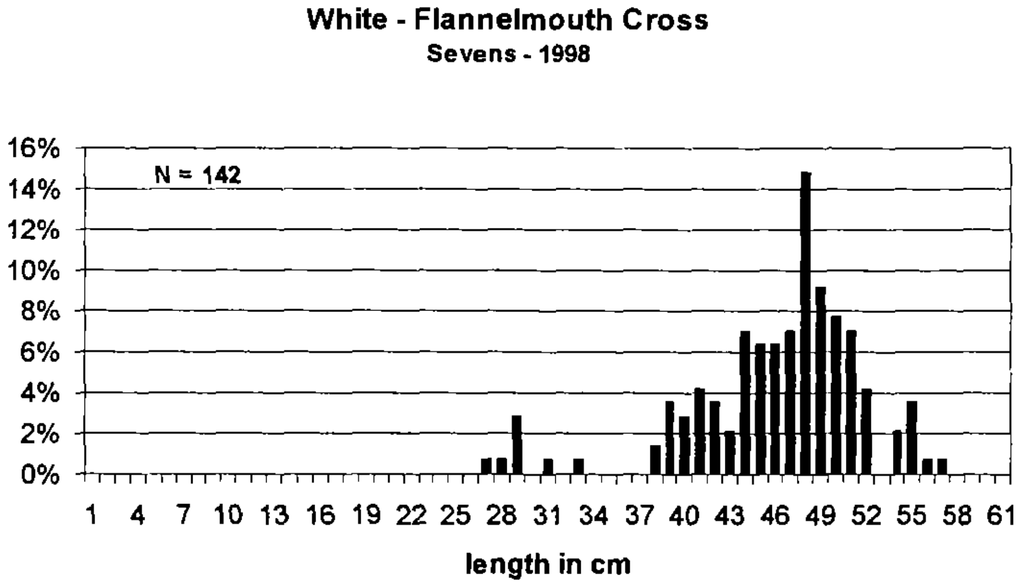

Figure 37. White-Flannelmouth Cross length frequency at the Sevens site, September 1998, Yampa River.

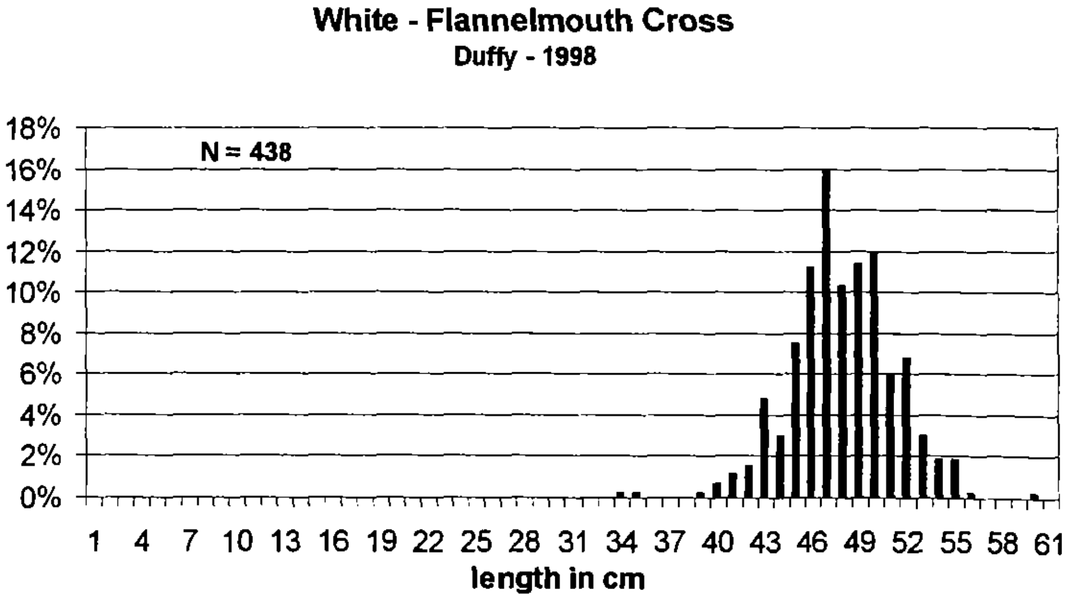

Figure 38. White-Flannelmouth Cross length frequency at the Duffy site, September 1998, Yampa River.

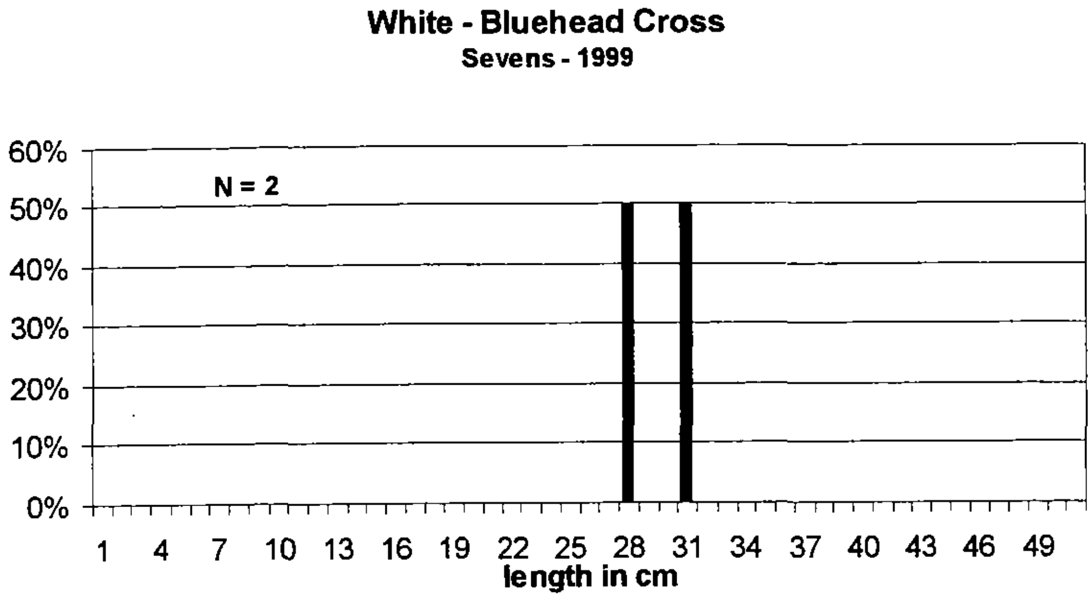

Figure 39. White-Bluehead Cross length frequency at the Sevens site, September 1999, Yampa River.

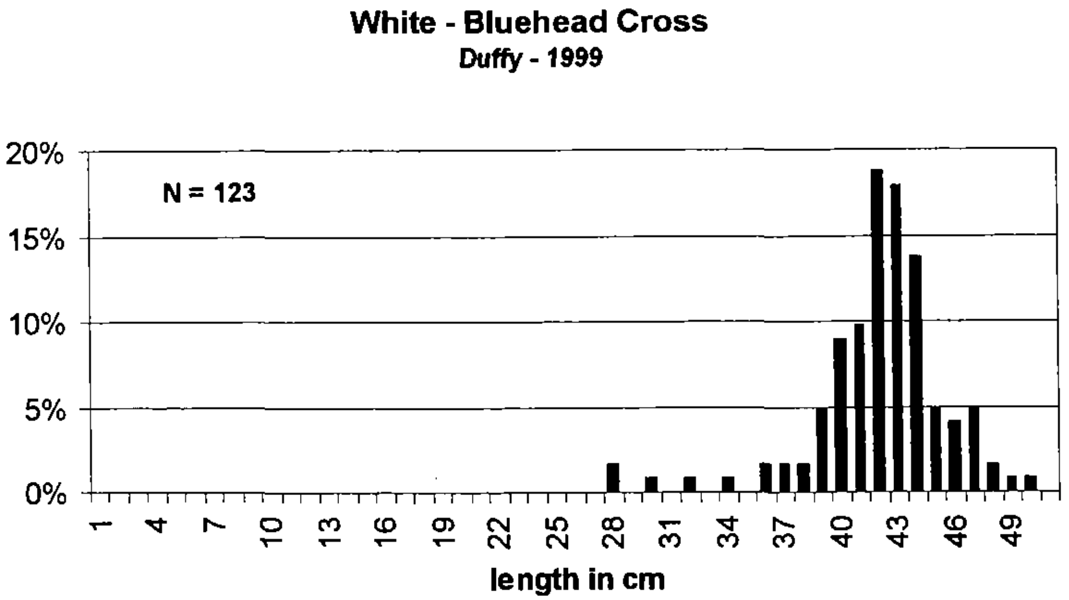

Figure 40. White-Bluehead Cross length frequency at the Duffy site, September 1999, Yampa River.

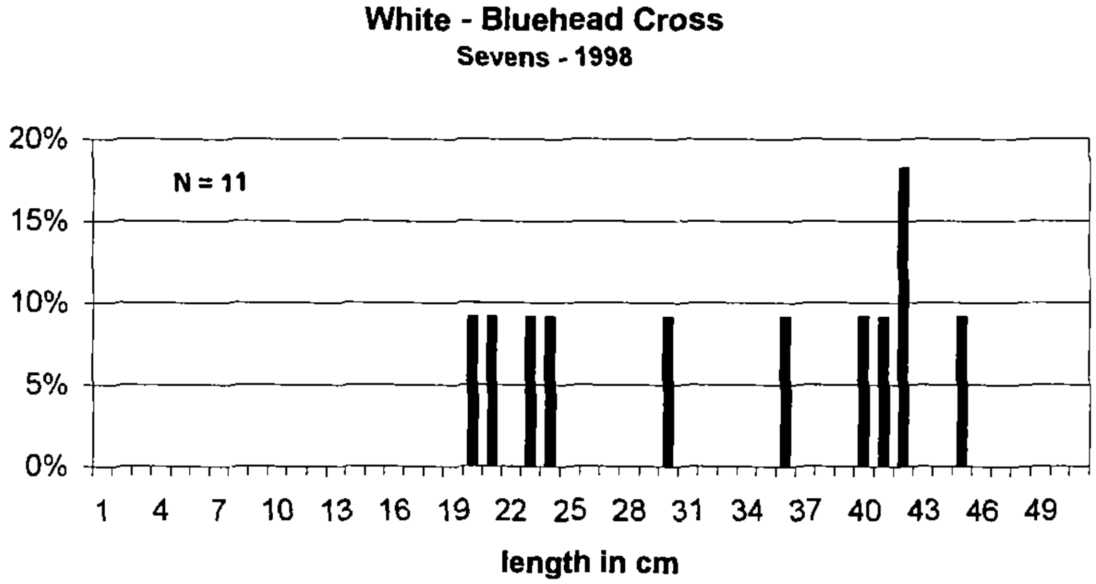

Figure 41. White-Bluehead Cross length frequency at the Sevens site, September 1998, Yampa River.

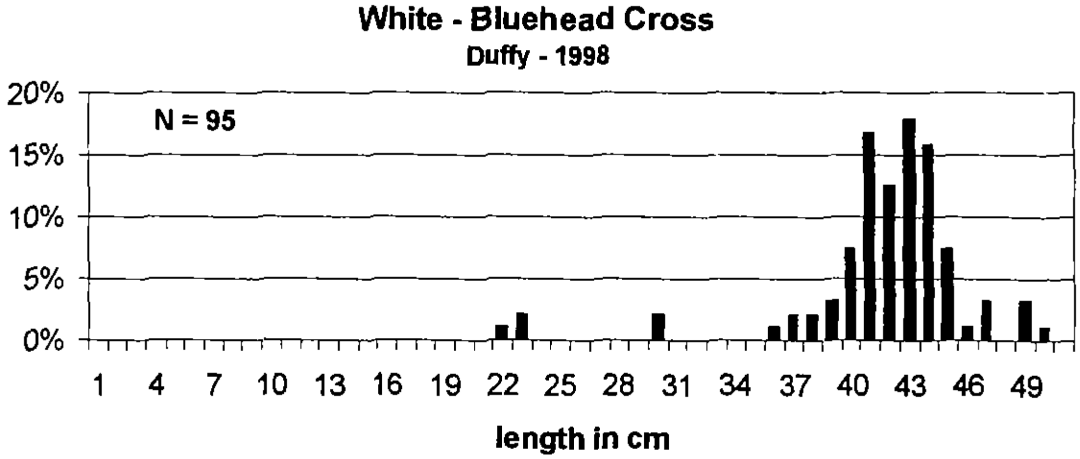

Figure 42. White-Bluehead Cross length frequency at the Duffy site, September 1998, Yampa River.

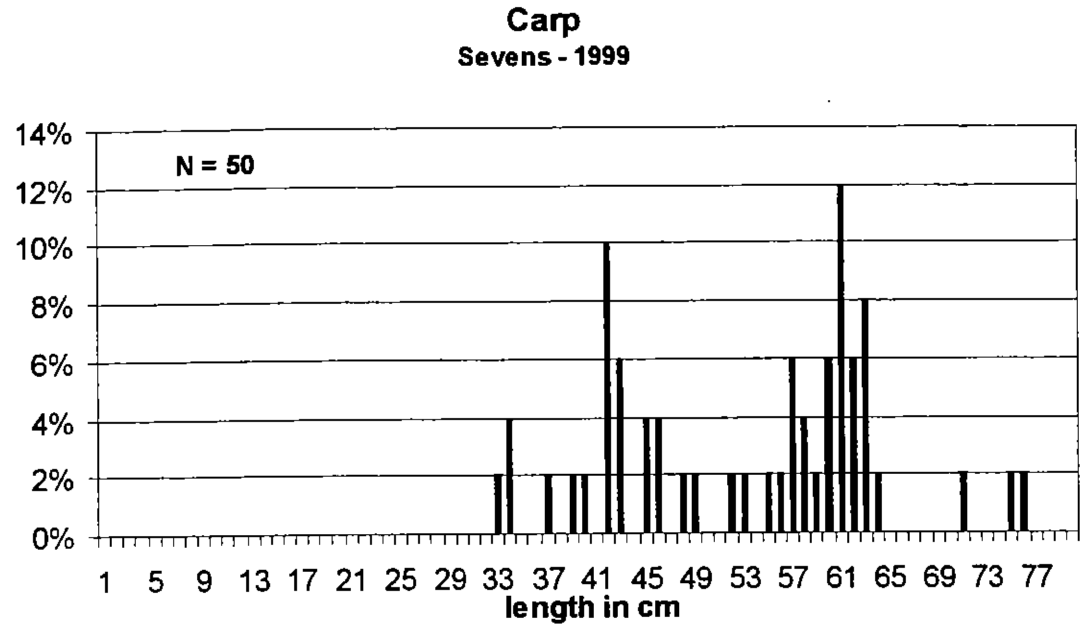

Figure 43. Carp length frequency at the Sevens site, September 1999, Yampa River.

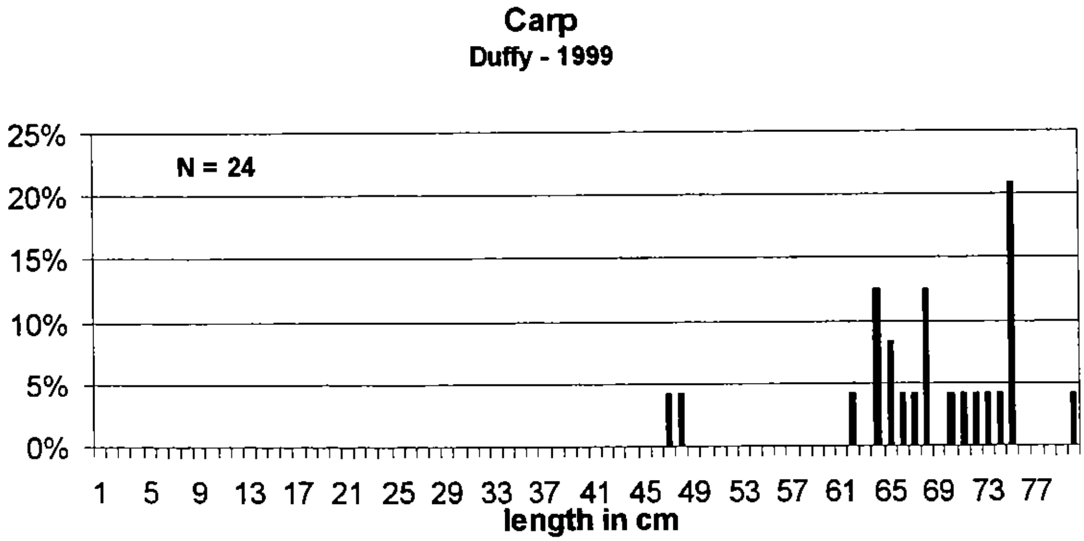

Figure 44. Carp length frequency at the Duffy site, September 1999, Yampa River.

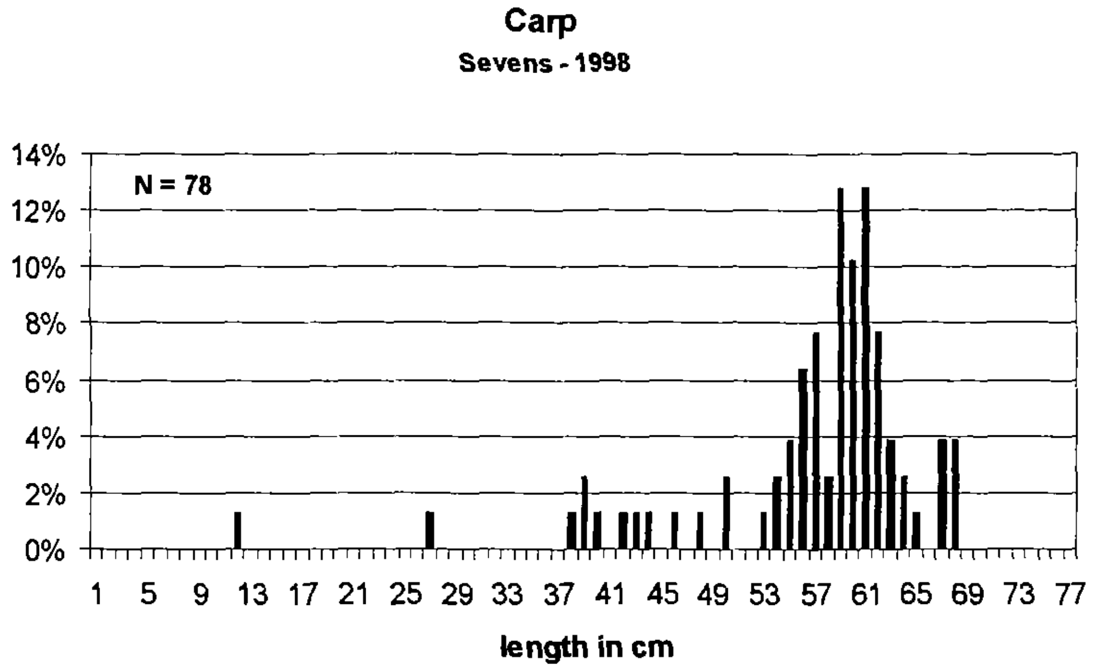

Figure 45. Carp length frequency at the Sevens site, September 1998, Yampa River.

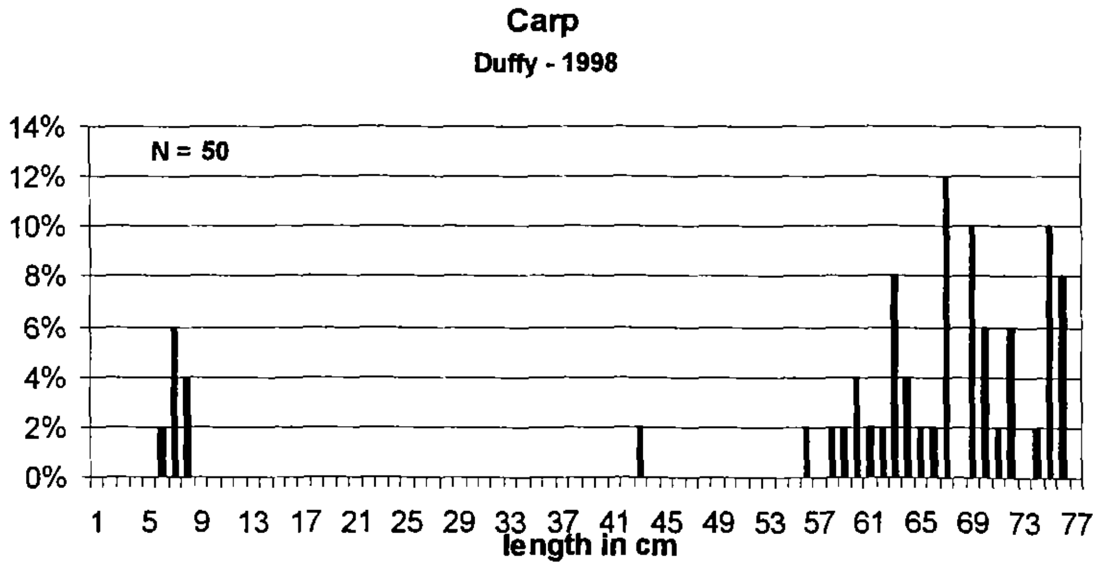

Figure 46. Carp length frequency at the Duffy site, September 1998, Yampa River.

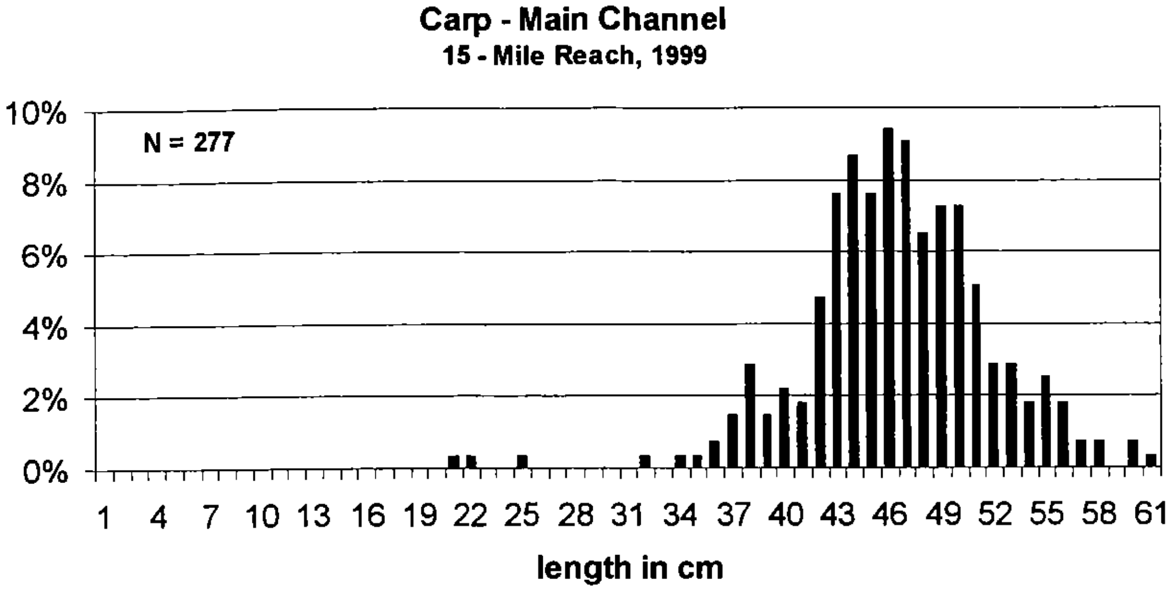

Figure 47. Carp length frequency at the Main Channel site, October 1999, Colorado River.

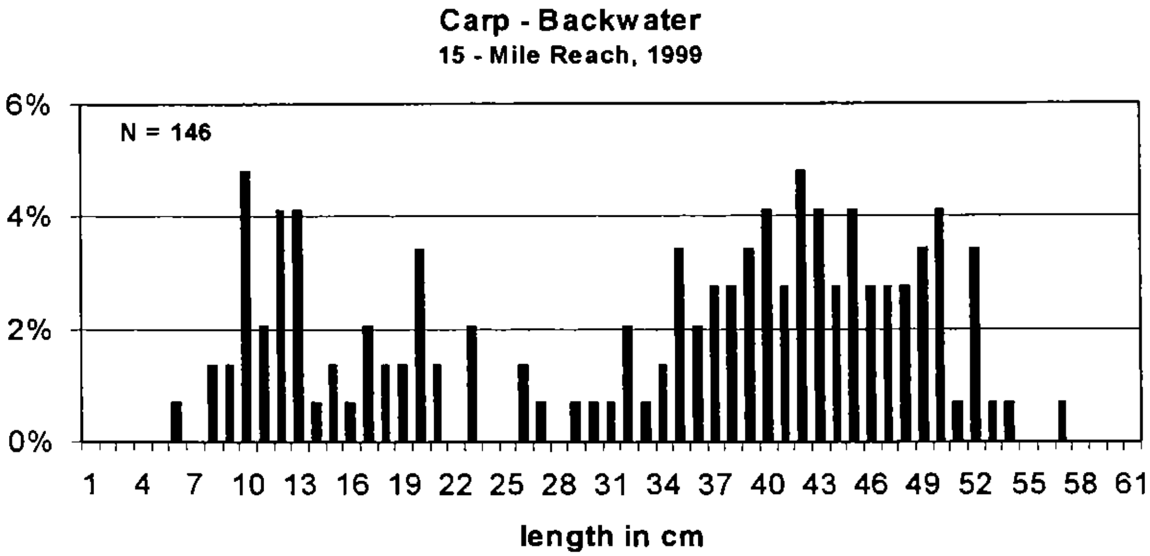

Figure 48. Carp length frequency at the Backwater site, October 1999, Colorado River.

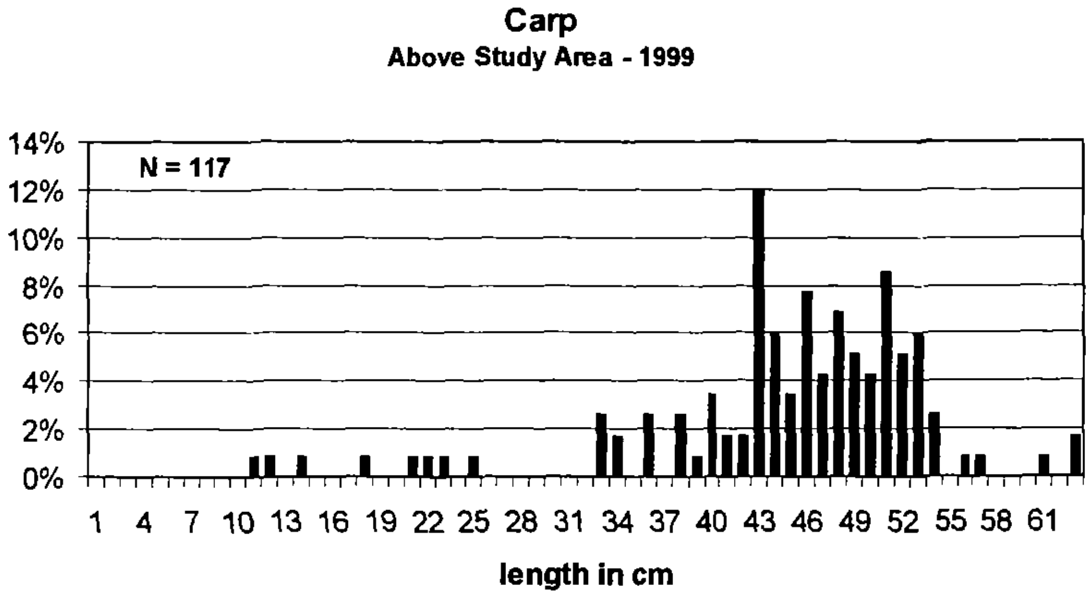

Figure 49. Carp length frequency at the Above the study area, October 1999, Colorado River.

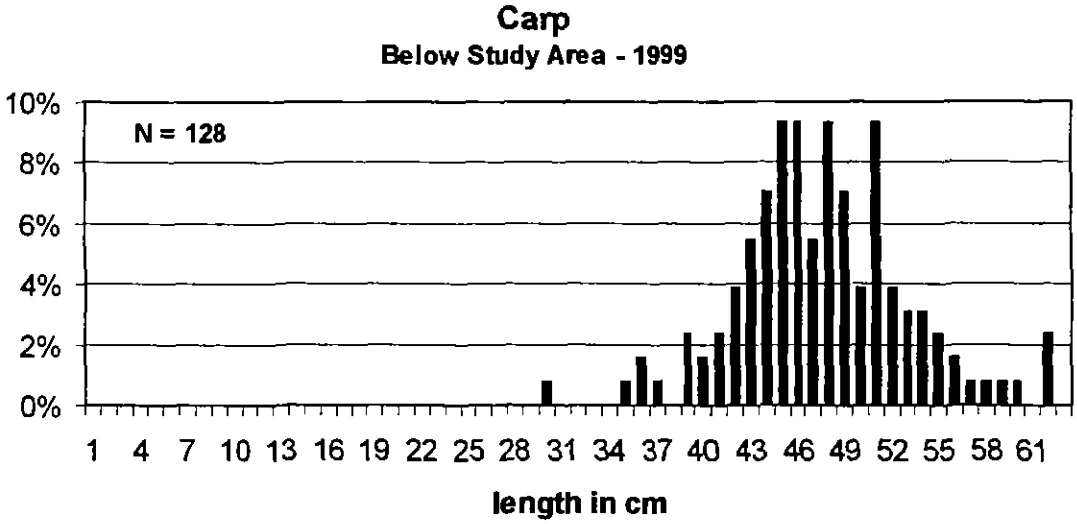

Figure 50. Carp length frequency Below the study area, October 1999, Colorado River.

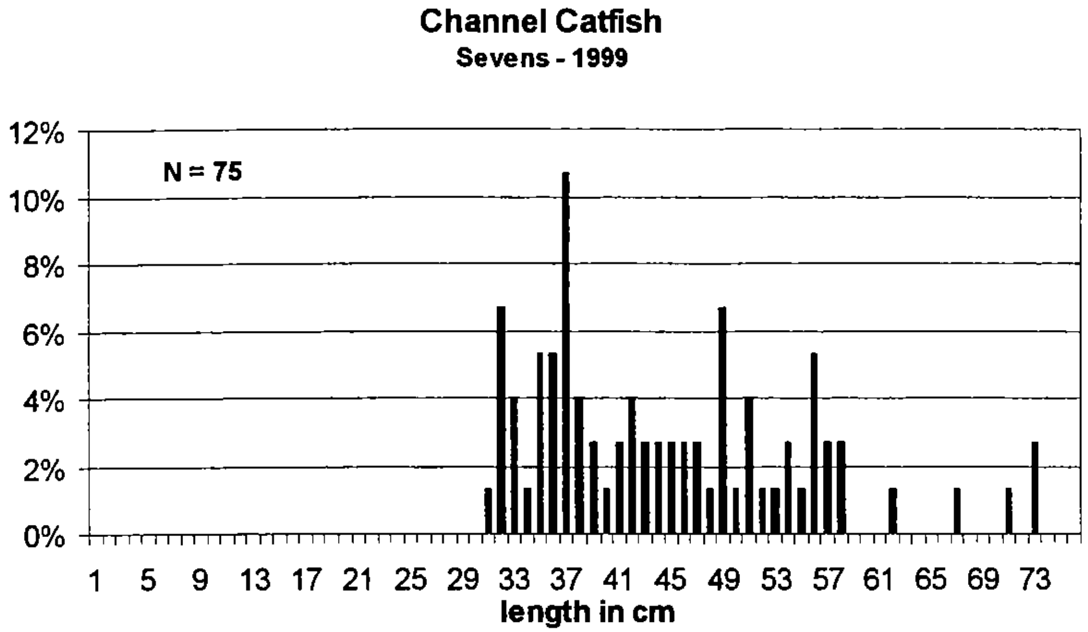

Figure 51. Channel Catfish length frequency at Sevens site, September 1999, Yampa River.

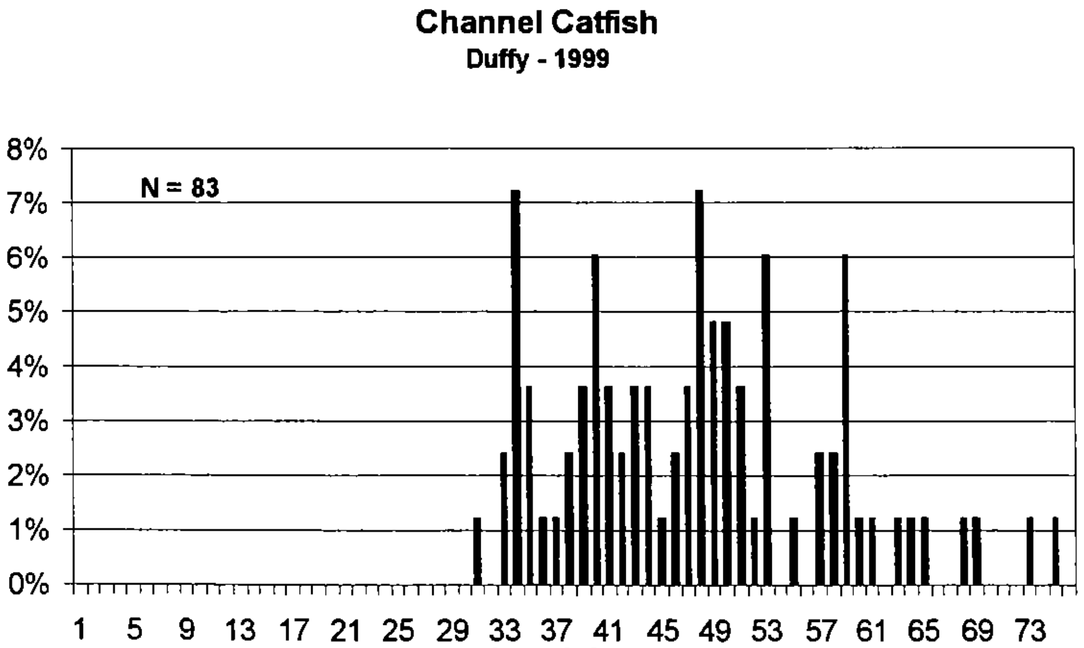

Figure 52. Channel Catfish length frequency at Duffy site, September 1999, Yampa River.

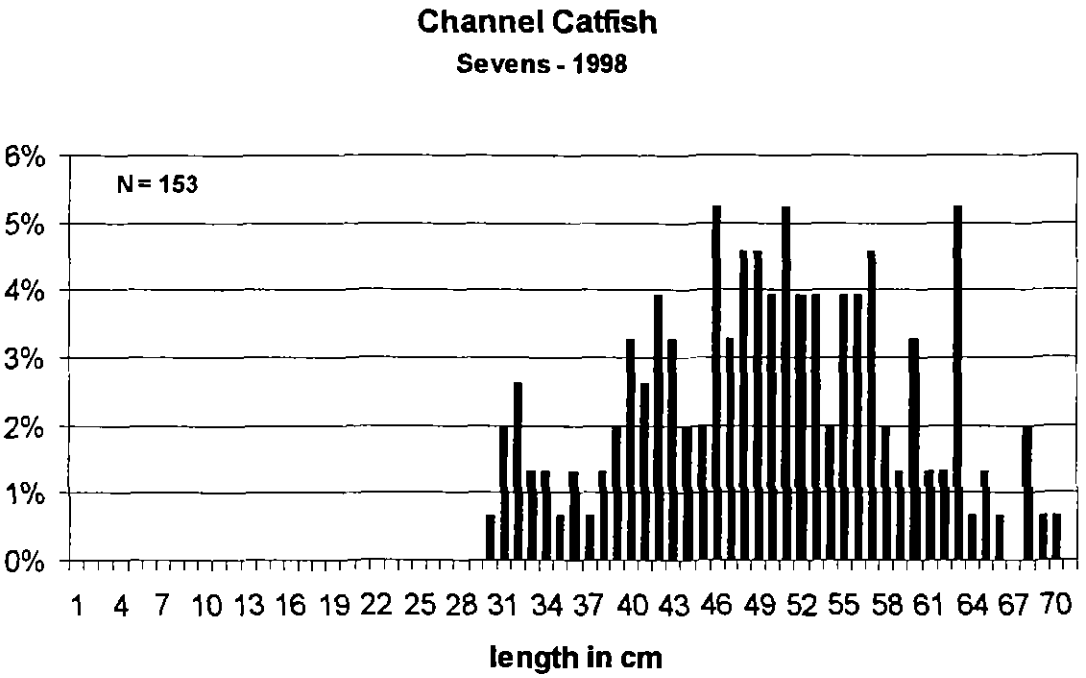

Figure 53. Channel Catfish length frequency at Sevens site, September 1998, Yampa River.

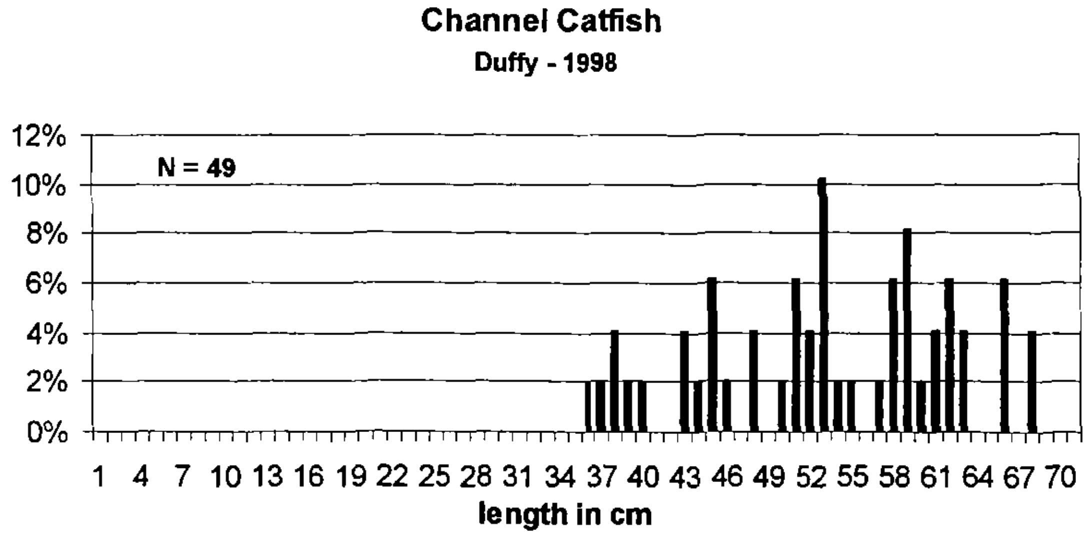

Figure 54. Channel Catfish length frequency at Duffy site, September 1998, Yampa River.

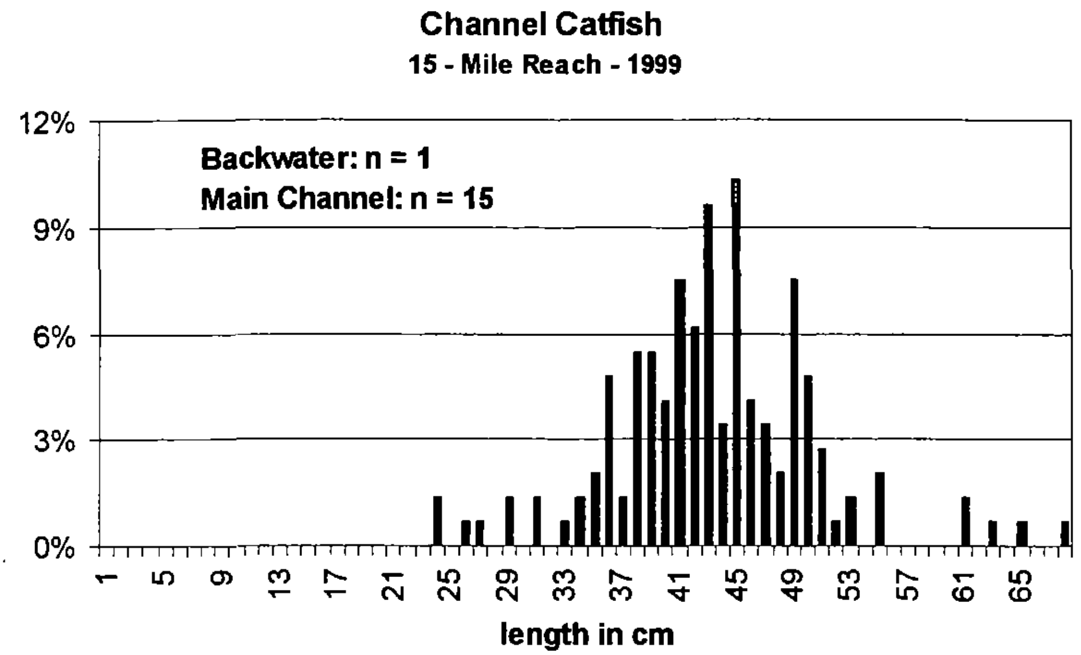

Figure 55. Channel Catfish length frequency at the Main Channel and Backwater sites, October 1999, Colorado River.

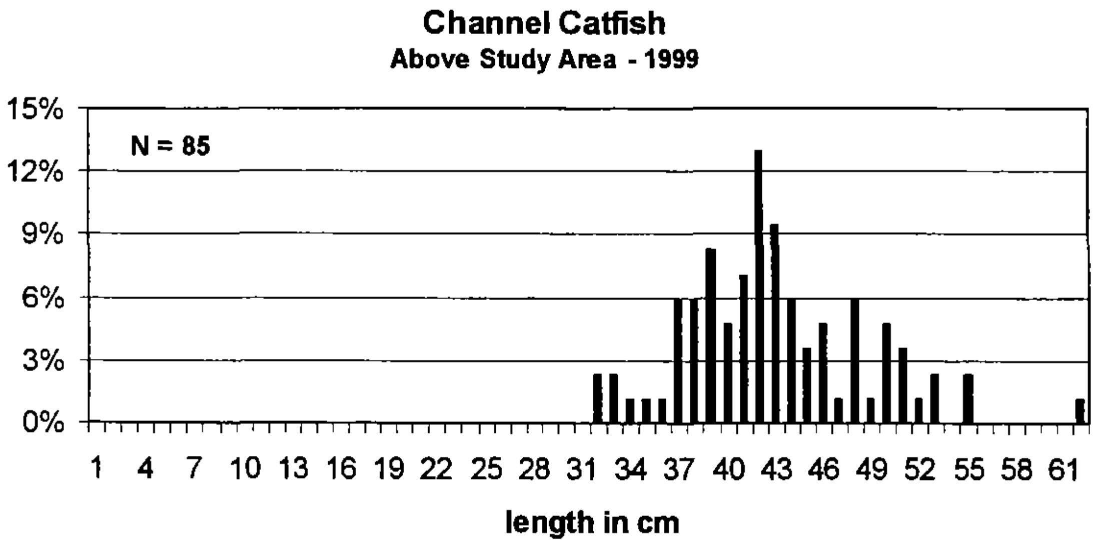

Figure 56. Channel Catfish length frequency Above the study area, October 1999, Colorado River.

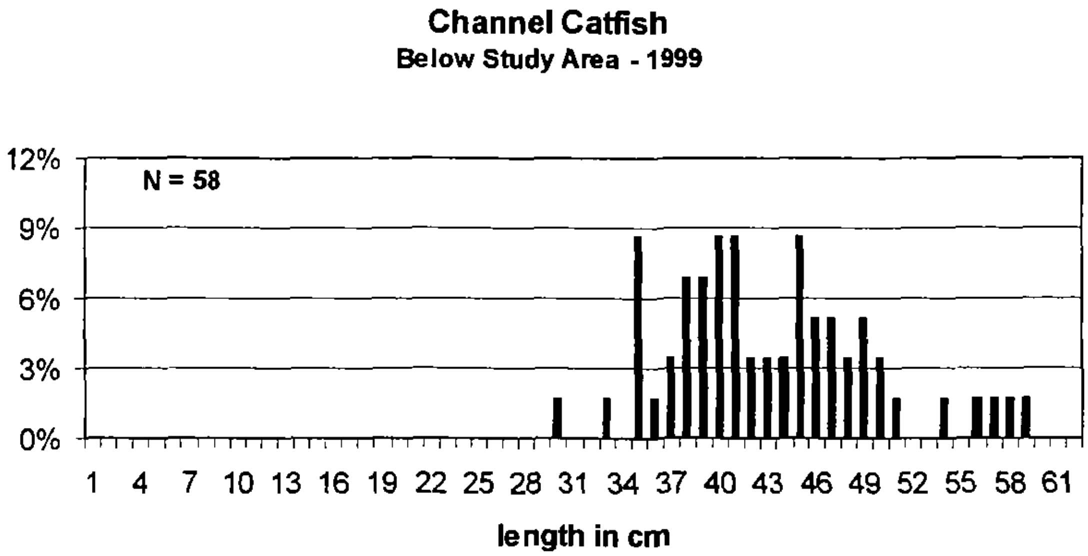

Figure 57. Channel Catfish length frequency Below the study area, October 1999, Colorado River.

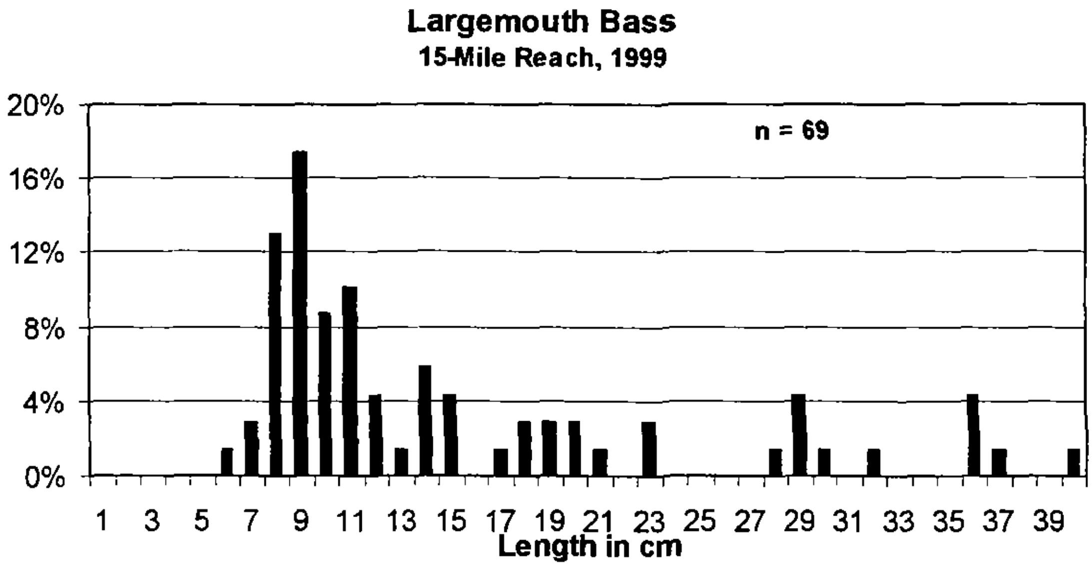

Figure 58. Largemouth Bass length frequency at the Main Channel and Backwater sites, October 1999, Colorado River.

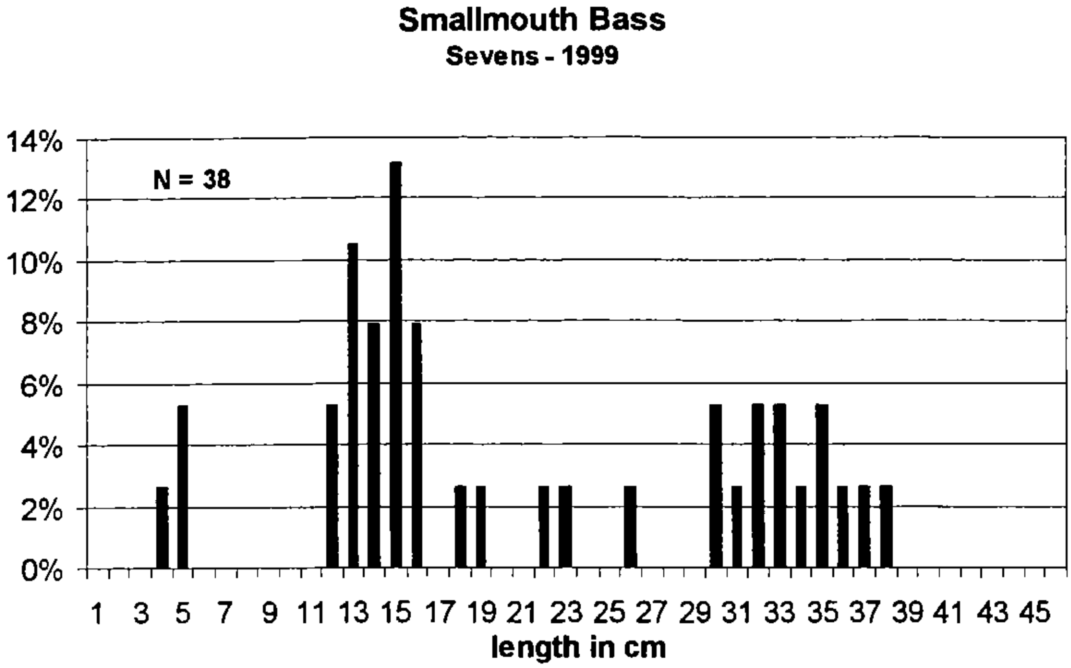

Figure 59. Smallmouth Bass length frequency at the Sevens site, September 1999, Yampa River.

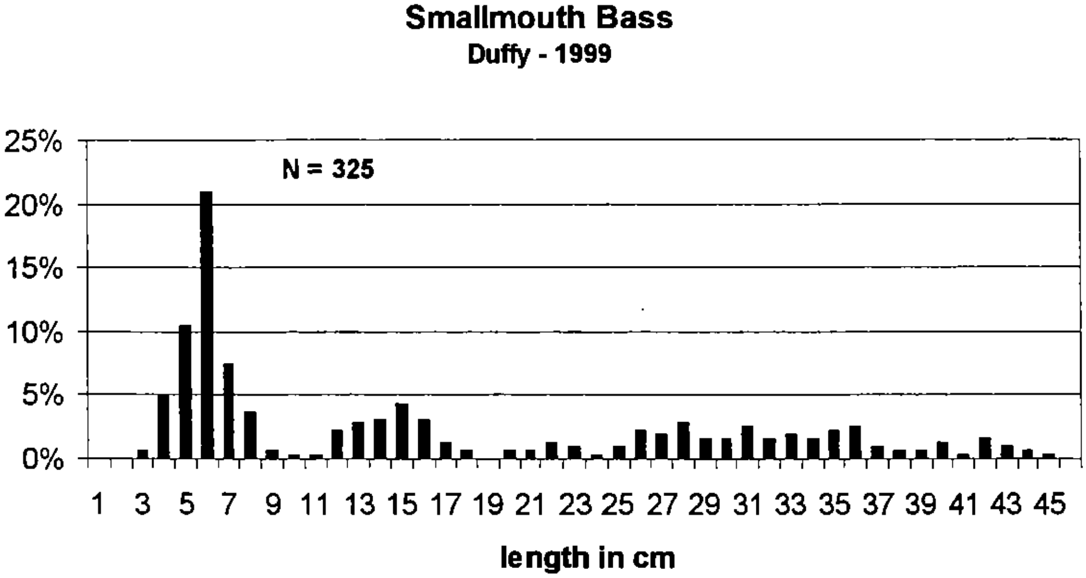

Figure 60. Smallmouth Bass length frequency at the Duffy site, September 1999, Yampa River.

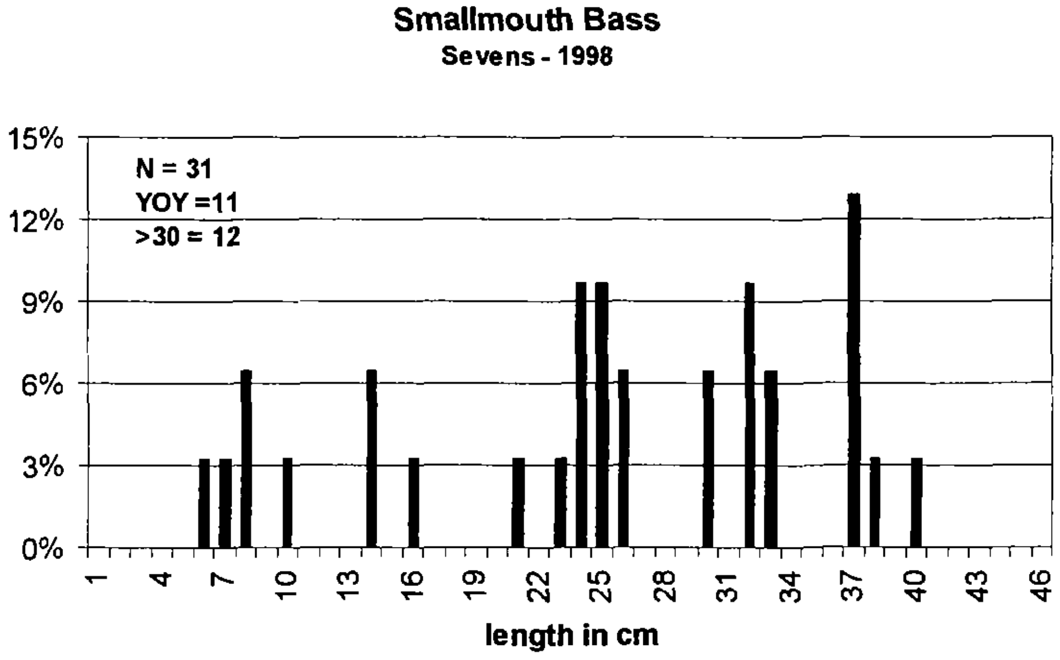

Figure 61. Smallmouth Bass length frequency at the Sevens site, September 1998, Yampa River.

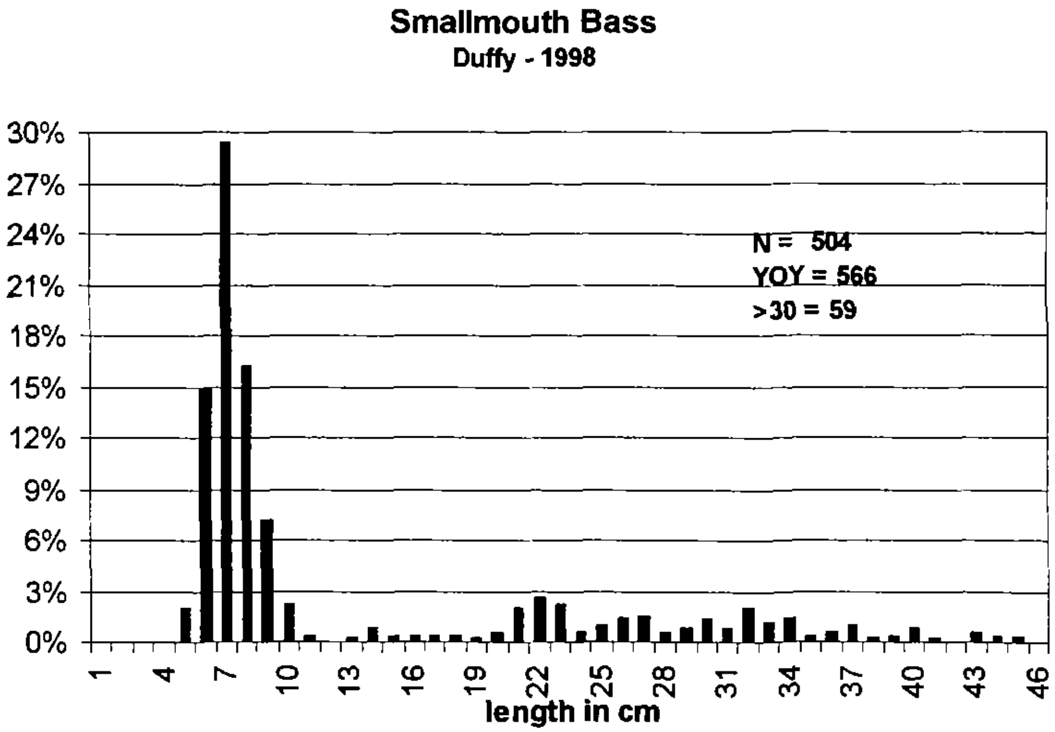

Figure 62. Smallmouth Bass length frequency at the Duffy site, September 1998, Yampa River.

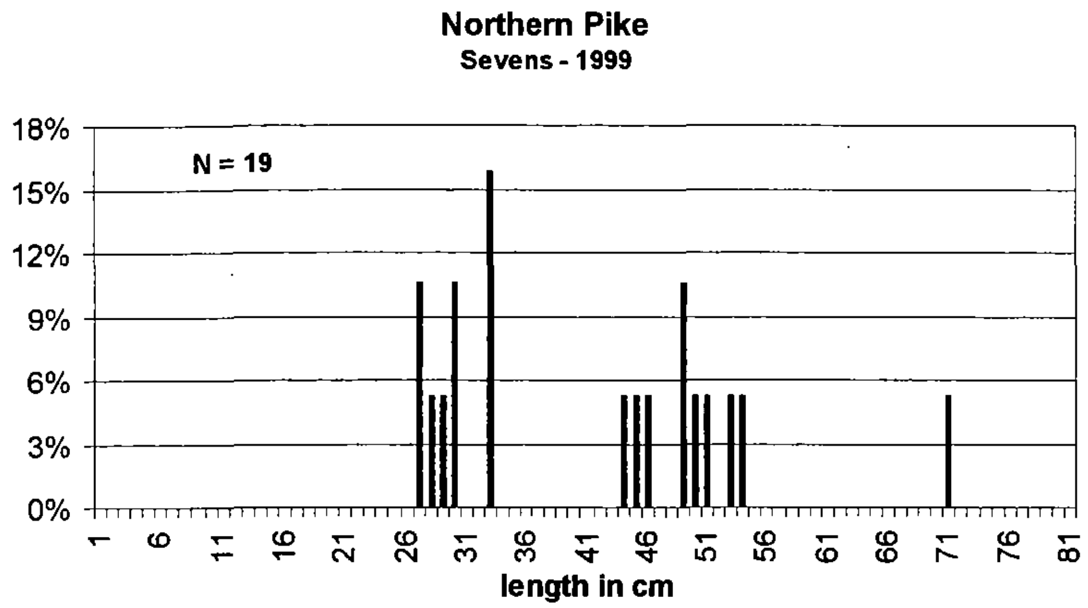

Figure 63. Northern Pike length frequency at the Sevens site, September 1999, Yampa River.

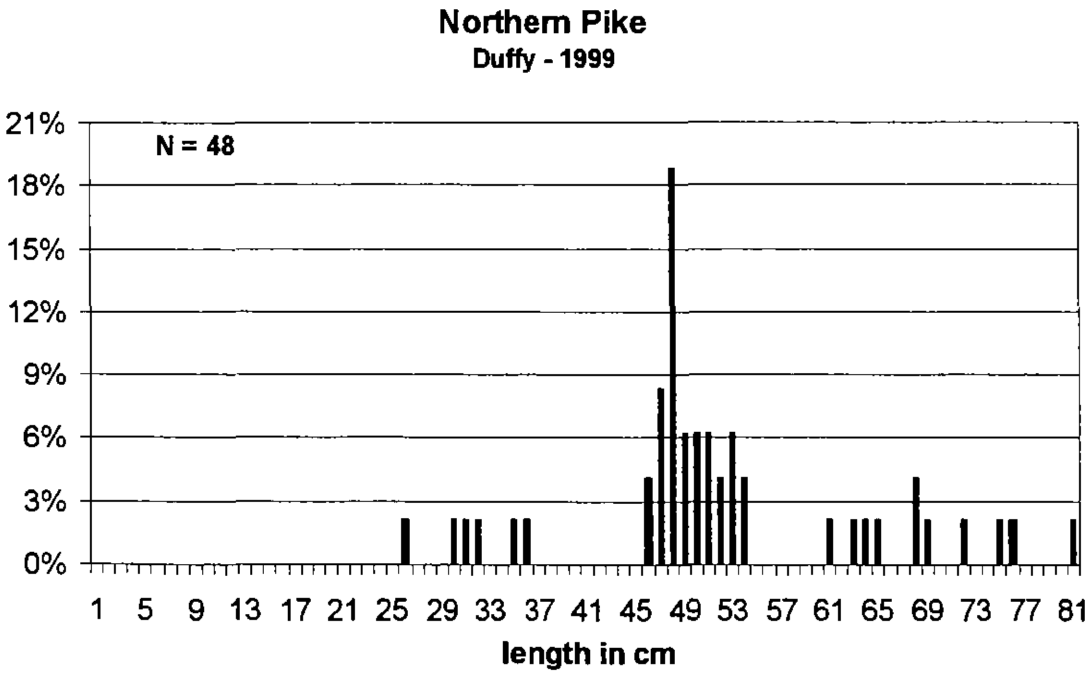

Figure 64. Northern Pike length frequency at the Duffy site, September 1999, Yampa River.

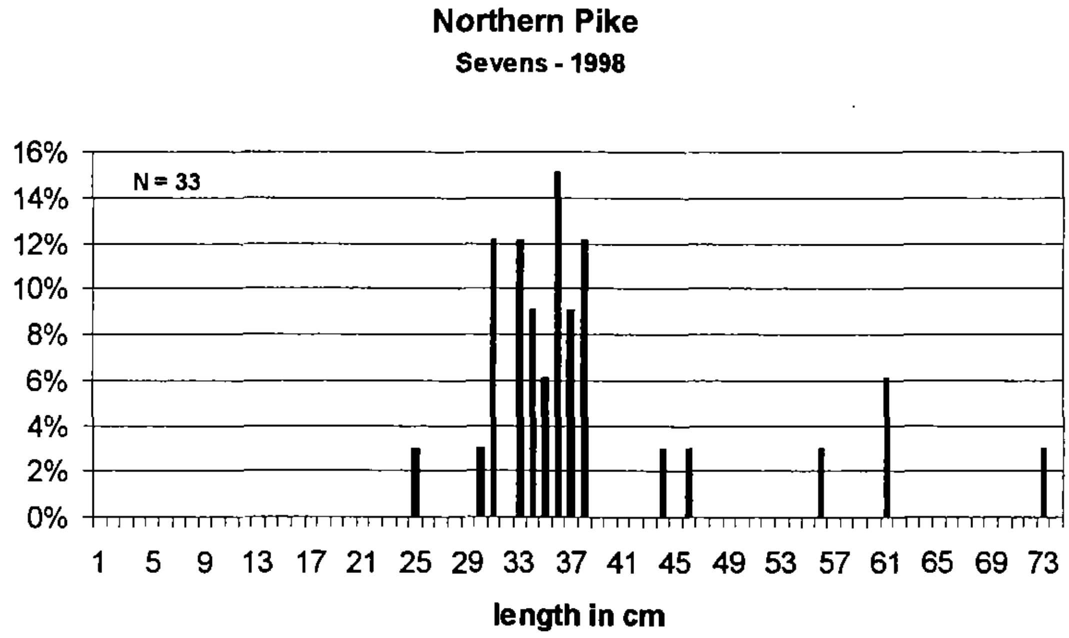

Figure 65. Northern Pike length frequency at the Sevens site, September 1998, Yampa River.

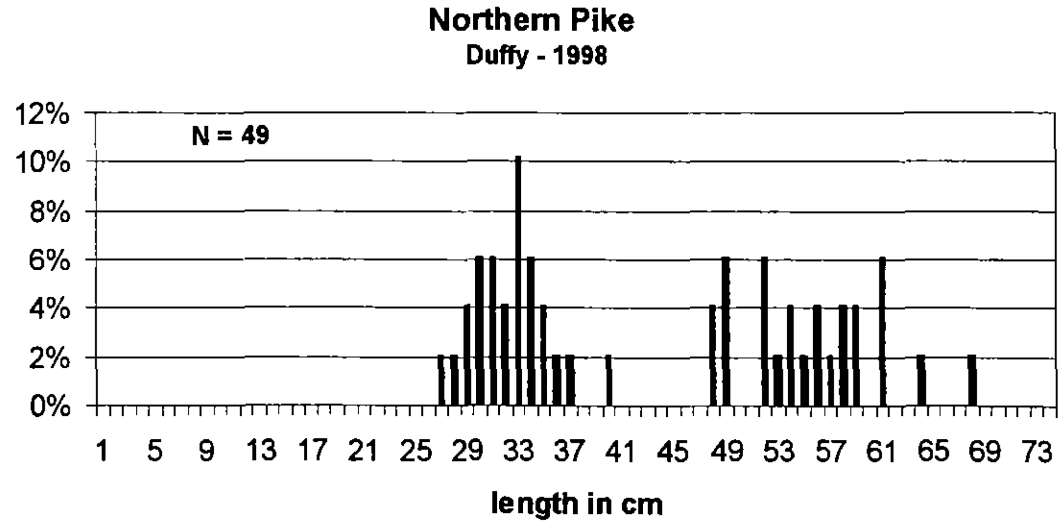

Figure 66. Northern Pike length frequency at the Duffy site, September 1998, Yampa River.

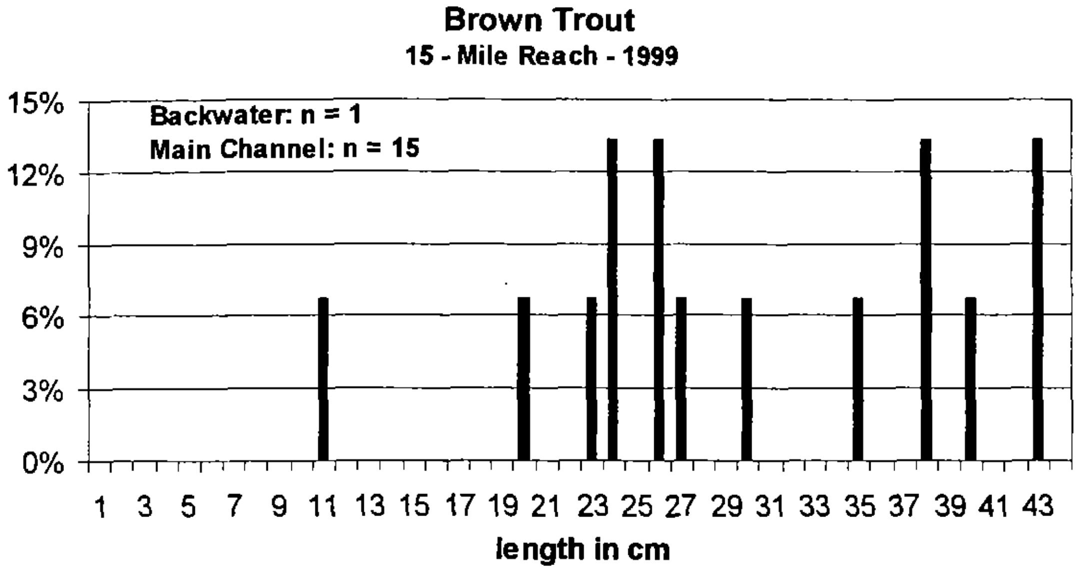

Figure 67. Brown Trout length frequency at the Main Channel and Backwater sites, October 1999, Colorado River.

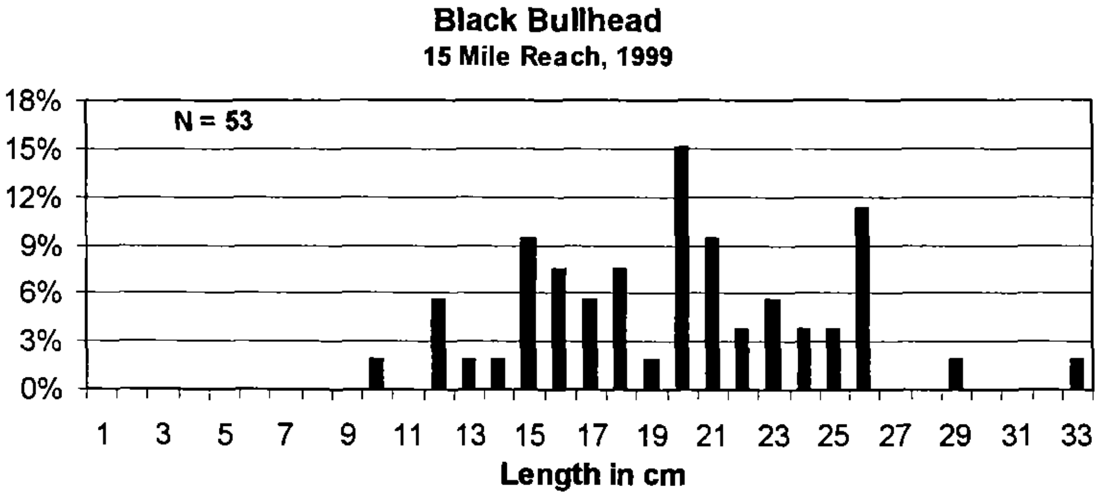

Figure 68. Black Bullhead length frequency at the Main Channel and Backwater sites, October 1999, Colorado River.