II. IMPACTS OF STREAM FLOW ALTERATIONS ON THE NATIVE FISH ASSEMBLAGE AND THEIR HABITAT AVAILABILITY AS DETERMINED BY 2D MODELING AND THE USE OF FISH POPULATION DATA TO SUPPORT INSTREAM FLOW RECOMMENDATIONS FOR THE SECTIONS OF THE YAMPA, COLORADO, GUNNISON AND DOLORES RIVERS IN COLORADO

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IMPACTS OF STREAM FLOW ALTERATIONS ON THE NATIVE FISH ASSEMBLAGE AND THEIR HABITAT AVAILABILITY AS DETERMINED BY 2D MODELING AND THE USE OF FISH POPULATION DATA TO SUPPORT INSTREAM FLOW RECOMMENDATIONS FOR THE SECTIONS OF THE YAMPA, COLORADO, GUNNISON AND DOLORES RIVERS IN COLORADO

EXECUTIVE SUMMARY

In 1999 the Colorado Water Conservation Board (CWCB) asked the Colorado Division of Wildlife (CDOW) to provide biologically justified instream flow recommendations for the Yampa and Colorado Rivers. This research project, 'Riverine Fish-Flow Investigation', evaluated the use of two-dimensional (2D) flow models for determining habitat preferences of native fish and for developing instream flows for the Yampa River.

The first paper of this project completion report, Stewart and Anderson (2007), described the approach, methods and results of using 2D modeling for relating flow and fish habitat availability. The current report summarized and evaluated fish community structures at each of the 2D modeling sites. Trends in native fish abundance along sections of four rivers in western Colorado – the Yampa, Colorado, Gunnison and Dolores – were related to stream flow and habitat characteristics at eight study sites. The purpose of this report is to provide community scale biological justifications for the instream flow recommendations that utilized a 2D modeling process that focused on two common native sucker species, the flannelmouth and bluehead sucker.

Changes in hydrograph over time have been linked to declines in native fish abundance, suggesting that alterations in native fish assemblages could be consistent with altered hydrographs for each river. From 2000 to 2004 drought conditions led to severe reductions in flow on the Yampa and Dolores Rivers. Fish sampling during those years quantified changes in fish communities following severely reduced flows. Pre- and post- drought fish data documented the persistence of the native fish assemblage under a wide range of flow conditions. Although the four rivers exhibited very different flow regimes, the fish data were consistent with model projections made using the 2D methodology (Stewart and Anderson 2007).

Abundances of bluehead sucker, (*Catostomus discobolus*), flannelmouth sucker (*Catostomus latipinnis*) and roundtail chub (*Gila robusta*) were much higher in moderate to high base flow rivers. Higher base flows were associated with greater availability of riffle habitats and increased fish biomass. Spring runoff flows were secondary to base flows in maintenance of native species diversity and biomass. Some evidence suggested that spring runoff flows were related to the reproductive success of bluehead sucker. Reduced spring runoff flows resulted in obvious geomorphic impacts on the Dolores River, but not on the Gunnison River.

Reduced base flows on the Yampa River were associated with dramatic increases in certain nonnative species, decreases in total fish biomass, increased rates of predation and increased rates of white sucker hybridization with flannelmouth and bluehead sucker. Increased abundance of nonnative species was usually associated with negative impacts to the native species assemblage. In fact, by 2004 all native fish species were rare in the upper Yampa River and nonnative species were proving highly problematic to the recovery of native fish.

The abundance of bluehead sucker was a reliable indicator for adequate base flows and habitat maintenance for the native fish assemblage. Bluehead sucker habitat peaked at flows of 600 to 1,200 cfs for the Colorado, Gunnison and Yampa Rivers. That flow range was also associated with high habitat diversity and high native fish biomass. The research findings validated the assumption that flows that maintained adequate bluehead sucker abundance (about 25 percent of the community) will also maintain adequate habitat for flannelmouth sucker and roundtail chub habitat and also probably for rare and endangered native fish.

INTRODUCTION

Maintaining stream flows for native fish management has become a priority for both state (Espegren 1998) and federal agencies (McAda 2003) in Colorado. Instream flow recommendations serve to identify the maximum amount of water that can be removed from a stream without adversely altering its ecosystem and natural processes (Annear et al. 2002). Extended periods of reduced flows can alter fish assemblages and lower carrying capacity for native fishes (Travnichek et al. 1995).

A primary objective of this research project was to determine habitat suitability criteria for three native species still common to western Colorado – bluehead sucker, flannelmouth sucker and roundtail chub – for use in developing instream flow recommendations (Stewart and Anderson 2006, Special Report A). The research in this report (Part I) identified habitat preferences for bluehead and flannelmouth sucker from populations in the Yampa and Colorado Rivers using a GIS approach that employed two-dimensional (2D) flow models of depth and velocity. Bluehead sucker were highly associated with the availability of moderately deep riffle habitats whereas flannelmouth sucker were associated with deep runs (Anderson and Stewart 2003). Roundtail chub were found to occupy multiple habitats, but the research did not include a method for developing habitat suitability criteria for species that utilize multiple habitats.

The Yampa and Colorado rivers exhibited similar channel morphology but the Yampa had lower base flows. Together the two rivers were in the low and moderate flow ranges for native fish habitat availability. Habitat suitability criteria for bluehead and flannelmouth sucker, developed from the Colorado and Yampa Rivers (Anderson and Stewart 2003), were also valid when used to predict bluehead and flannelmouth sucker biomass at two sites on the Gunnison River.

Evidence of valid suitability criteria is obtained when biomass estimates from field observations match the model results. Because pre-drought fish biomass data were available, the 2002 Colorado of record drought provided an opportunity to assess impacts on native fish biomass during periods of severely reduced flows. Declines in native fish abundance would strongly suggest that changes in the native fish assemblage were a response to altered base flow regimes.

The primary objectives of this analysis were to identify patterns in native fish persistence and to relate native fish abundance in each site to its flow and habitat conditions. The basic assumption of the research was that difference in bluehead sucker and flannelmouth sucker biomass under different flow scenarios would conform to 2D model predictions given habitat suitability criteria were correctly identified.

Efforts to promote the ecological integrity of river ecosystems have relied on mimicry of the natural flow regime (Burdick 1995, Modde and Smith 1995, Poff et al. 1997). Tyus and Karp (1989) speculated that the higher persistence of native fishes in the Yampa River was associated with maintenance of habitats sustained by a relatively unaltered regime of fluctuating seasonal and annual flows. This hypothesis – that native fish persistence will be higher in rivers with lesser degrees of altered hydrographs – is not very useful in identifying specific flow management options. Some flow alterations may be beneficial and not all hydrographic phases are equivalent in their biological impacts.

Periodic drops in base flows have been a natural occurrence in Colorado. Quantifying the impacts of sustained periods of reduced flow requires data for both fish abundance and habitat composition under altered and unaltered flow conditions. Long term flow reductions may facilitate establishment of nonnative fish species. Nonnative fish have been found to negatively affect the structure and biomass of native fish assemblages (Courtenay and Moyle 1992, Scoppettone 1993). Nonnative fishes impact native fish populations through competition for limited resources, predation and hybridization.

The complexity of examining impacts of reduced flows on native fish is greatly amplified when nonnative fish are a major component of a fish assemblage. When nonnative fishes are only a minor component of the fish community, temporary or even long term flow reductions may not impose lasting consequences on native fish, because their abundance will likely increase when their habitats are restored. However, when severe and prolonged flow reductions result in a major expansion of nonnative fish species, the native fish assemblage may not be able to recover even if natural flows return.

The Yampa, Colorado, Gunnison and Dolores rivers originally had typical snowmelt-driven annual hydrographs. Water development projects have altered the hydrographs of all four rivers, which are now distinctive for their runoff and base flow periods. Originally, the four rivers had the same native fish assemblage, but today each now includes several nonnative species. The persistence of native fish in these rivers should provide insights into the consequences of these altered hydrographs, the recent drought and species introductions. More specifically, the persistence of bluehead and flannelmouth sucker in rivers with different flow regimes should validate the reliability of the 2D modeling results.

STUDY AREA

Yampa River

Site Locations

The Yampa River, the largest tributary of the Green River, flows westward through northwestern Colorado. Three study sites were established upstream of the confluence with the Little Snake River (Figure II-1). From its confluence with the Green River to the town of Craig, the Yampa River has been designated critical habitat for four federally endangered fish species.

The Duffy study site began at RM 109 and was 7.2 km in length. The Sevens site began at RM 64 and was 2.9 km long. Electro-fishing crews sampled both Duffy and Sevens in 1998, 1999, 2000, 2001, 2003 and 2004. A third site, Lily Park began at RM 52 and was 3.1 km in length. Fish were sampled at Lily Park in 2000, 2001, 2003 and 2004. No sampling took place on the Yampa in 2002.

Site Hydrology

The Yampa River maintains relatively natural spring flows, with volume reduced by an average of six percent during the months of April, May and June (Modde et al. 1999). At the Deerlodge gage (RM 50), which is downstream of the Little Snake River confluence, the Yampa drains an area of 7,660 mi^2 (19,839 km^2) and the annual average flow was 2,049 cfs (58.0 cms) from 1983 to 2004. We used the Maybell gage (09251000) at RM 85.8 to represent flows for the three study sites. The drainage area at the Maybell gage is 3,410 mi^2 (8,832 km^2) and the mean annual flow was 1,548 cfs (44.35 cms) from 1917 to 2005.

Bankfull flow determined from bed profile data at the Maybell gage was approximately 9,000 cfs (258 cms) (Andrews 1980). Recent channel surveys from Sevens and Lily Park indicate a bankfull flow of 11,000 cfs (315 cms) (Richard and Anderson 2007). Peak

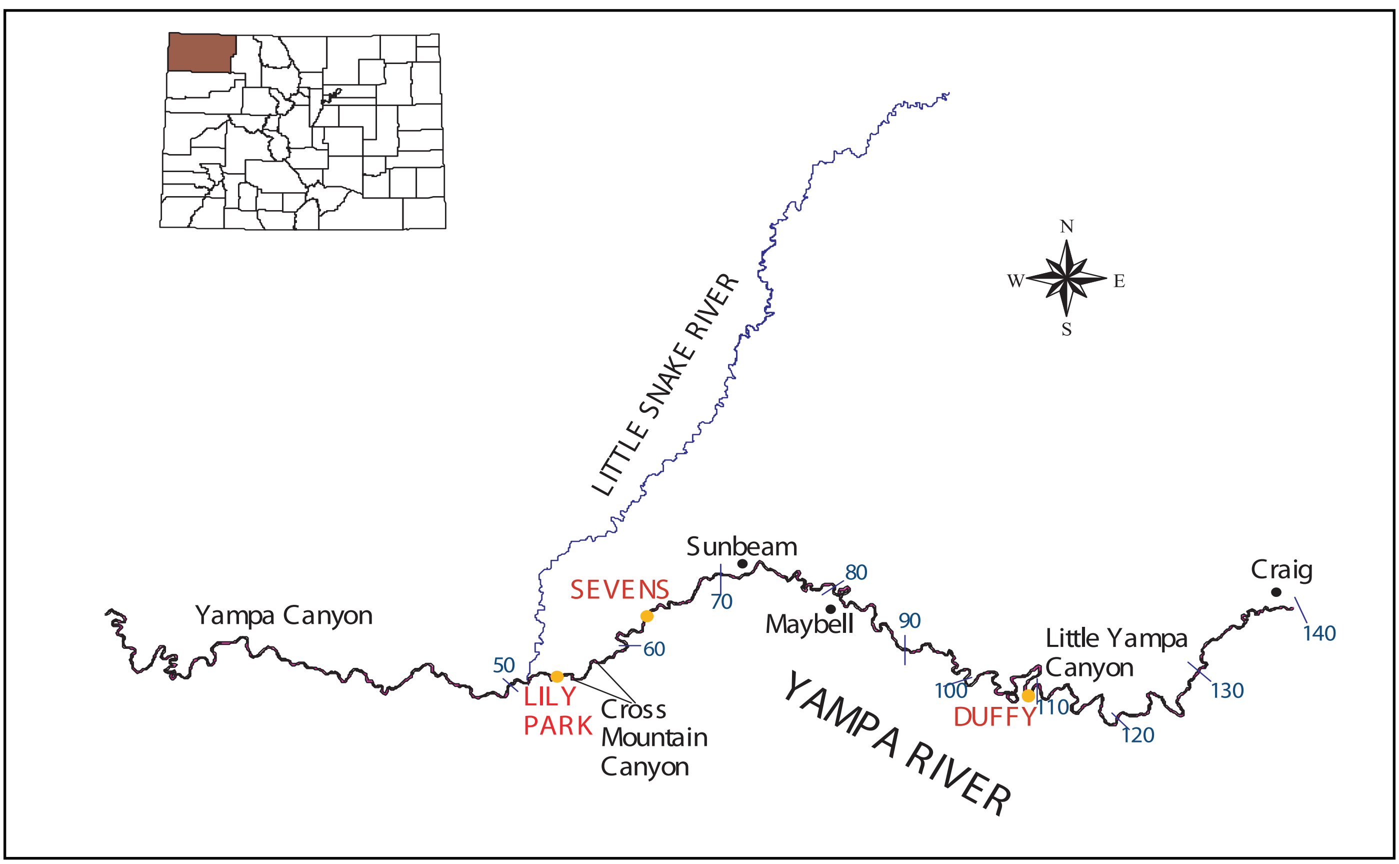

FIGURE II-1. Yampa River study site locations: Duffy, Sevens (RM 64) and Lily Park.

flows at the Maybell gage in 1998, 1999 and 2000 were similar to the median peak flow of 9,930 cfs (281.2 cms) from 1917 – 2004 (Figure A1-1). During 2001, 2002 and 2004 peak flows were lower. In 2002 peak flow was only 3,420 cfs (96.9 cms) (Figure A1-5).

Yampa River base flows are generally low relative to peak and mean annual flows. Base flows below 250 cfs (7.1 cms) were infrequent in 1998 and 1999 but base flows below 100 cfs were common from 2000 to 2004 (Figure A1-9). The median minimum mean daily flow from the Maybell gage is 119 cfs (3.37 cms). Annual minimum flows for 1998 through 2004 were 115, 166, 30, 50, 1.8, 43 and 22 cfs, respectively (3.2, 4.7, 0.8, 1.4, 0.05, 1.2 and 0.6 cms) (Figure A1-13).

Colorado River

Site Locations

The 15-Mile Reach of the Colorado River extends from Palisade, Colorado (RM 185) downstream to the confluence of the Gunnison River at about RM 170 (Figure II-2). Two major upstream diversions divert flow from the river during the irrigation season (April 1 to November 1) and flows during irrigation season at the Palisade Gage are typically 1,200 to 1,600 cfs (34 and 45 cms) less than those upstream of the diversions. Winter (November to March) flows in the 15-Mile Reach typically exceed 2,000 cfs (56 cms). High flows in winter result from deliveries to senior water rights. The 15-Mile Reach of the Colorado River is included in critical habitat for endangered Colorado pikeminnow (*Ptychocheilus lucius*) and razorback sucker (*Xyrauchen texanus*).

Two study sites were in the 15-Mile Reach: Clifton and Corn Lake. Clifton extended from RM 177.7 to RM 180.4 and has a total length of 4.2 km (Figure II-2). Corn Lake was from RM 177.5 downstream to RM 175.3 and was 3.9 km in length. Field crews sampled fish in 1999, 2000, 2001, 2003 and 2004 at Corn Lake, but Clifton was sampled in 2000, 2001 and 2003.

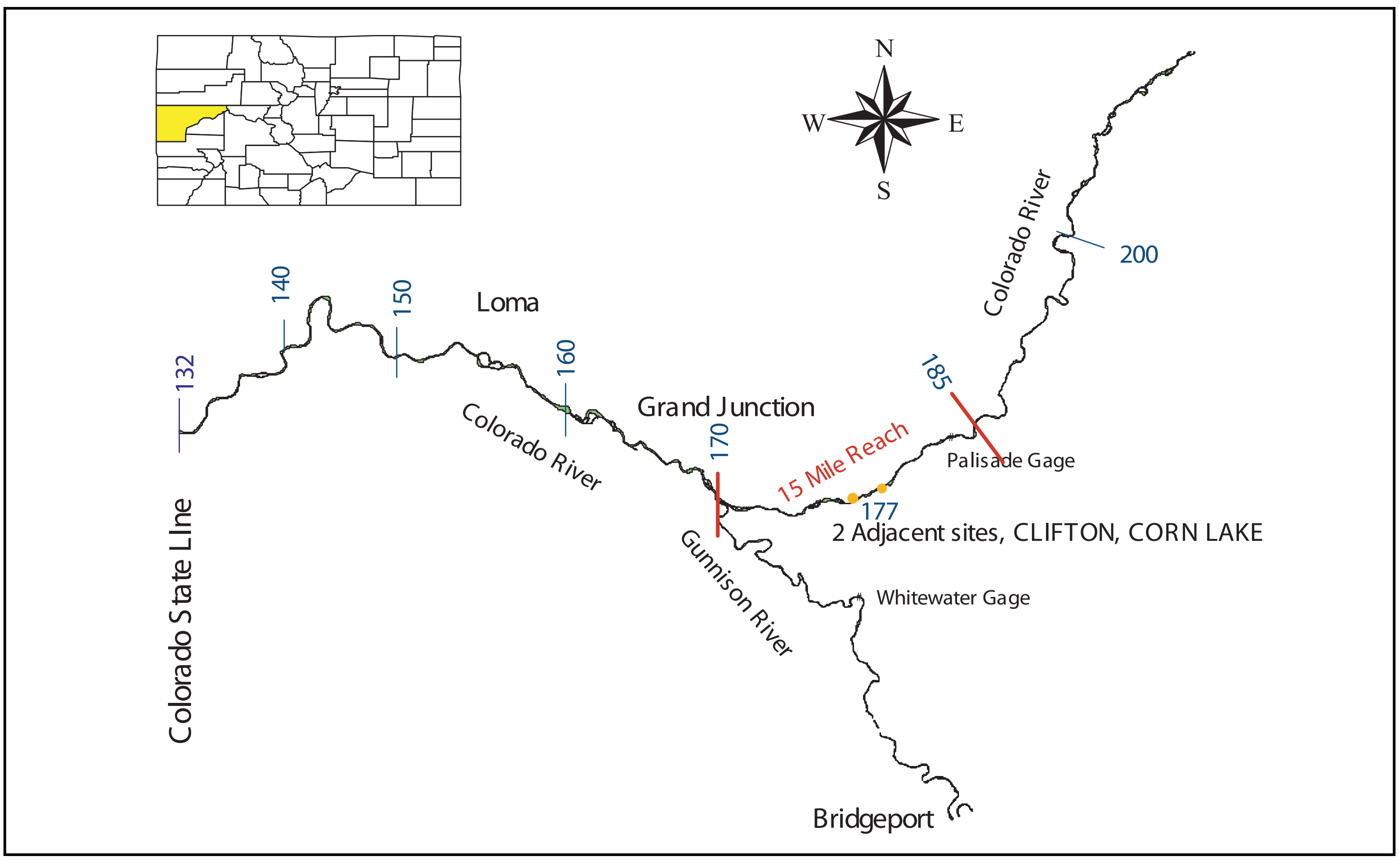

FIGURE II-2. Colorado River study site locations in the 15-Mile Reach for Corn Lake and Clifton, Colorado.

Site Hydrology

The Colorado River upstream of the confluence of the Gunnison River has a drainage area of 8,753 mi^2 (22,670 km^2) and mean annual flow of 2,822 cfs (79.9 cms) during 1991 to 2004. Pitlick et al. (1999) determined bankfull flow for the 15-Mile Reach to be near 22,000 cfs (621 cms).

The median annual peak flow for the 14-year Palisade gage (09106150) history was 13,250 cfs (375.2 cms) (Figure A1-2). Drought conditions reduced peaks flows in 2002 and 2004. The annual peak in 2002 was only 2,780 cfs (78.7 cms), the lowest for the period of record (Figure A1-6).

Base flows above 800 cfs (22.7 cms) are normal in the 15-Mile Reach. The 14-year median minimum flow for the Palisade gage is 543 cfs (15.4 cms). Flows were very low in 2002, typically under 100 cfs (2.8 cms) and less than normal in 2003 and 2004 (Figure A1-10). Minimum summer/fall flows (mean-daily) recorded at the Palisade Gage for 1998 through 2004 were 980, 1240, 543, 477, 58, 342 and 341 cfs, respectively (27.7, 35.1, 15.4, 13.5, 1.6, 9.7 and 9.7 cms) (Figure A2-14).

Gunnison River

Site Locations

The Gunnison River is the largest tributary to the upper Colorado River and its confluence with the Colorado River is located in the city of Grand Junction, CO. From its mouth upstream to the confluence of the Uncompahgre River at the town of Delta, the Gunnison has been designated critical habitat for endangered Colorado pikeminnow and razorback sucker (McAda 2003).

Two study sites were on the Gunnison: Delta and Escalante. The Delta study site extended from the Uncompahgre River confluence (RM 56.3) downstream 3.9 km to the county road bridge (Figure II-3). The Escalante site was from Escalante Bridge (RM 42.7) downstream about 4.4 km to Hail Mary rapids (Figure II-3).

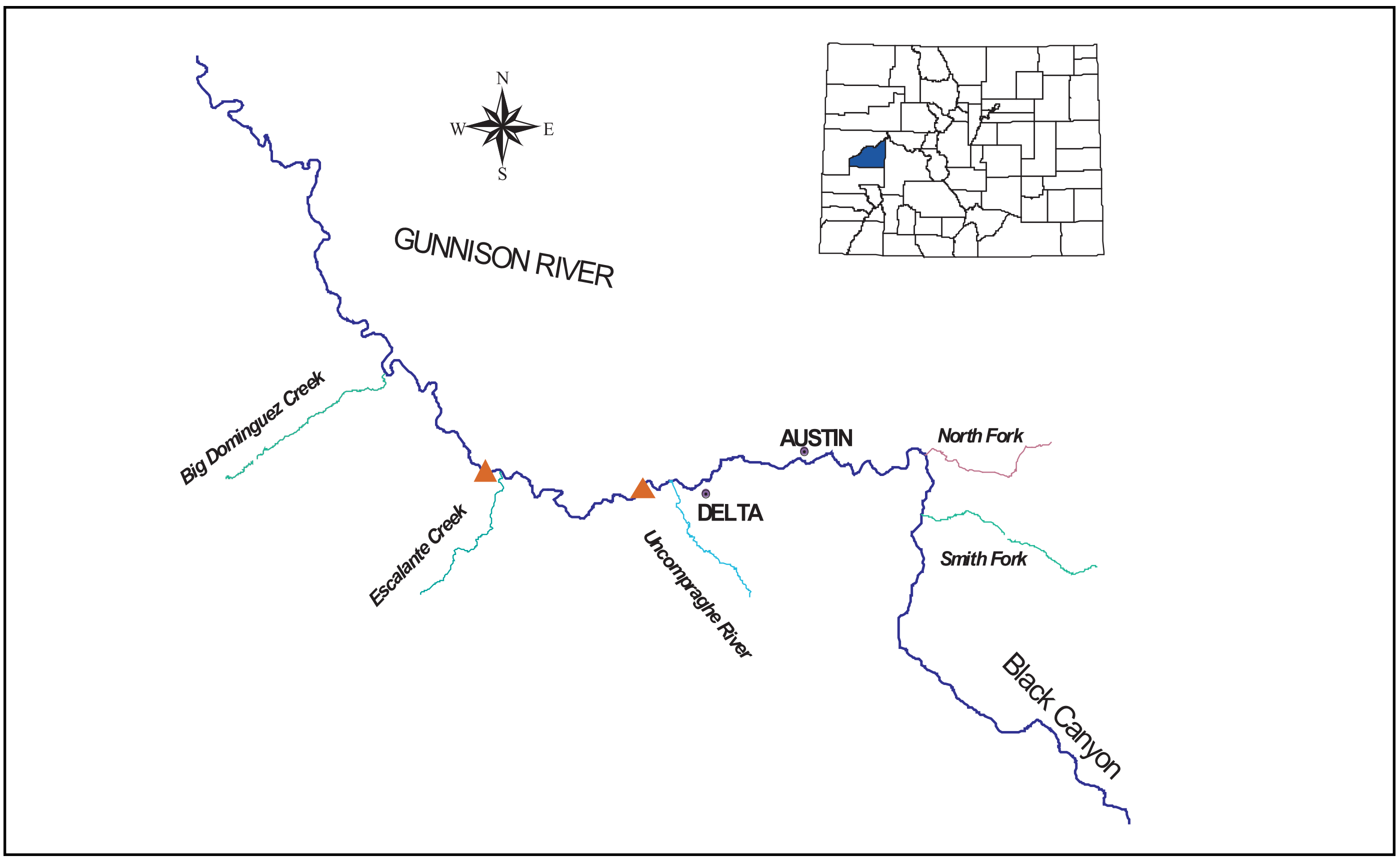

FIGURE II-3. Gunnison River study site locations: Delta and Escalante (gages are 1 km upstream of Delta and on Uncompahgre upstream of confluence).

Site Hydrology

Flow alterations for the lower Gunnison River are best described by examination of Whitewater gage (09152500) flow records, which is the most downstream gage located about 12 km upstream of its confluence with the Colorado River. The drainage area at the Whitewater gage was 7,928 mi^2 (20,534 km^2) and mean annual flow was 2,556 cfs (72.4 cms) for 1897 to 2004. The Aspinall Unit reservoirs (Blue Mesa, Morrow Point and Crystal) were completed by the United States Bureau of Reclamation between 1966 and 1976. Mean annual flow was little changed by the project: the average mean annual flow from 1897 to 1965 was 2,611 cfs (73.9 cms); it was 2,477 cfs (70.1 cms) from 1966 to 2004. The average mean annual flow from 1977 to 2004 was 2,567 cfs (72.7 cms).

Gunnison River peak flows at Whitewater were substantially reduced after completion of the Aspinall project. The median peak (mean daily) flow from 1897 to 1965 was 15,000 cfs (424.8 cms) compared to 7,355 cfs (208.3 cms) from 1966 to 2005. Minimum flows have substantially increased since 1965. The Whitewater gage median minimum (mean daily) flow from 1897 to 1965 was 456 cfs (12.9 cms) compared to 864 cfs (24.5 cms) from 1966 to 2005.

Pitlick et al. (1999) determined bankfull flow was 14,600 cfs (414 cms) at Whitewater, which was common prior to 1965 but was rarely exceeded after 1966. The bankfull flow for the Delta and Escalante portions of the Gunnison River was 13,300 cfs (377 cms) (Pitlick et al. 1999).

The hydrographs for both the Delta and Escalante sites were obtained by summing daily flows from two gages (the Gunnison River's Delta gage and the Uncompahgre River's Delta gage), instead of utilizing Whitewater gage flow records. The Delta and Uncompaghre gages were nearer the study sites than the downstream Whitewater gage.

The USGS Delta Gage (09144250) is located about three km upstream of the Uncompahgre River confluence. The Gunnison River drainage area at is 5,626 mi^2 (14,571 km^2). The period of record for the Delta gage is from 1977 to the present and the mean annual flow is 1,978 cfs (56.0 cms). The Uncompahgre gage (09149500) has a drainage area of 1,115 mi (2,888 km). The period of record for this gage is from 1939 to present, with a mean annual flow of 301 cfs (8.5 cms).

From 1977 to 2005 the median peak (mean daily) flow for the combined Delta and Uncompahgre gages was 6,192 cfs (175.4 cms) (Figure A1-3) and it was 7,510 cfs (212.7 cms) for the Whitewater gage. The statewide drought started in 2000 and peak and spring runoff flows were very low in both 2002 and 2004 (Figures A2-3 and 5). Peak flow was only 1,454 cfs (41.2 cms) in 2002 at the Delta and Uncompahgre gages (Figure A1-7).

Gunnison River base flows in the study reach generally exceed 800 cfs (22.7 cms), but they were as low as 600 cfs (17.0 cms) in 2002 and 2003 (Figures A1-11 and A1-15). From 1998 to 2005 summer/fall minimum mean daily flows for the summed data from the Delta and Uncompahgre gages were 1062, 1303, 1026, 832, 543, 622, 633 cfs and 1,012 cfs, respectively (30.1, 36.9, 29.1, 23.6, 15.4, 19.7, 18.0, 25.4 cms) (Figure A1-15).

Pitlick et al (1999) reported the mean bankfull width was 73.4 m and mean slope was 0.12 percent at the Whitewater gage; the mean bankfull width was 73 m and mean slope was 0.19 percent at the Delta site; mean bankfull width was 68 m and mean slope was 0.12 percent slope at the Escalante site.

Dolores River

Site Location

The Dolores River headwaters are in the San Juan Mountains of southwestern Colorado. The river flows northward about 320 km to its confluence with the Colorado River in Utah. From its mouth upstream to the Bradfield Bridge, the river has a large roundtail chub population, making it potentially important for conservation of this species. Although Colorado pikeminnow have been collected in the Dolores near its mouth (Valdez et al. 1992), the Dolores is not critical habitat for endangered fish species.

The study site, located in the Big Gypsum Valley, began at the Bureau of Land Management boat launch and ended just upstream of the county road bridge, which is 3.3 km downstream (Figure II-4).

The site is about 72 river miles (116 km) downstream from McPhee Reservoir and about 16 miles (26 km) downstream of Disappointment Creek. Disappointment Creek puts a high volume of fine sediments into the Dolores during runoff and storm events.

Site Hydrology

Two canals diverted virtually the entire Dolores River flow (up to approximately 1,400 cfs or 40 cms) during the irrigation season (April to October) from 1886 to 1984 (Dolores River Dialogue 2006a). In 1985 McPhee Dam began storing water for the Dolores River Project, a system of canals, tunnels and laterals used to deliver water for irrigation. Before the damming the Dolores River, the hydrograph showed very low base flows (about 2 cfs or 0.05 cms) during the irrigation season. Since 1985 McPhee Reservoir outflows have usually been above 25 cfs (0.7 cms). On the other hand, spring runoff has been much lower in magnitude and duration than before completion of the dam.

McPhee Reservoir has a storage capacity of 381,000 AF (470,000 dam^3), which is similar to the 30-year average annual Dolores River inflow of 397,000 AF (490,000 dam^3). Total user demand is about 240,000 AF (296,000 dam^3) per year. McPhee's regulated outflow is a volume of water called 'the fish pool' which is approximately 29,300 AF (36,100 dam^3), equivalent to a mean annual flow of 40 cfs (1.1 cms). Inflow that cannot be stored or diverted is called "the spill". Since 1985 there have been seven years when demand exceeded the inflow and there was no spill. Spring outflow peaks ranged from 34 to 177 cfs (1.0 to 5.0 cms) during years with no spill, while inflows ranged from 563 to 2,159 cfs (15.9 to 61.1 cms). The median inflow and outflow peaks after 1985 were 2,941 and 2,009 cfs, respectively (83.3 and 56.9 cms). Demand reduces outflow relative to inflow by about 40 percent during high flow years and by about 85 percent during dry years.

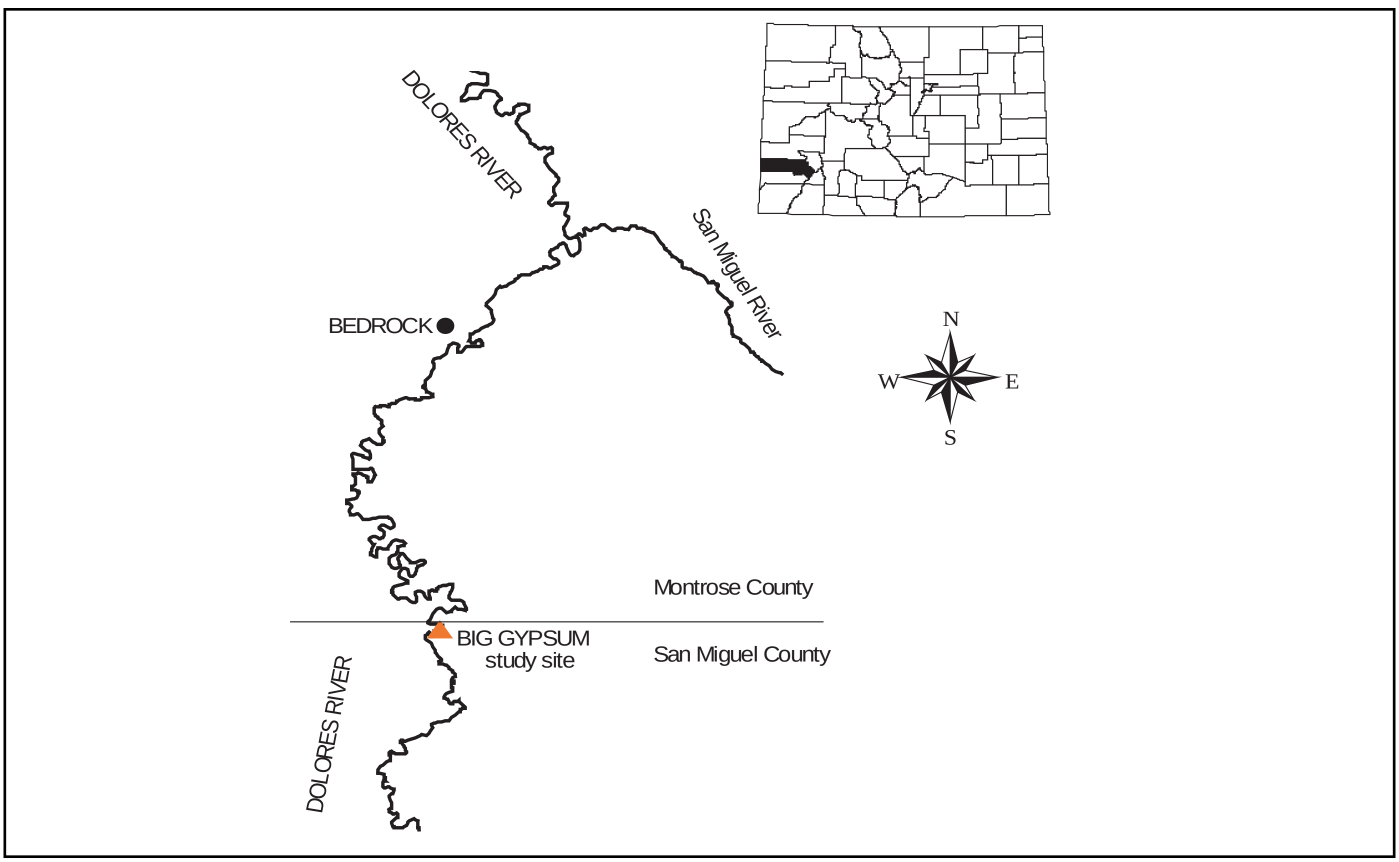

FIGURE II-4. Dolores River study site location: Big Gypsum.

The USGS Bedrock gage (09169500), used to represent flow conditions at the Big Gypsum site, is located about 58 km downstream of the Big Gypsum study site and about 174 km downstream of McPhee dam. The Dolores has a drainage area at Bedrock of 2,024 mi^2 (5,242 km^2). Mean annual stream flow at Bedrock was 516 cfs (14.6 cms) before 1985 and 284 cfs (8.0 cms) from 1985 to 2004. We did not attempt to determine natural flow levels by adding back diversions and reservoir storage to gage records.

The highest annual peak (mean daily) recorded at Bedrock was 8,150 cfs (230.8 cms) in 1973. The median annual peak flow for the 32-year Bedrock gage history was 3,095 cfs (87.7 cms) (Figure A1-4). Bankfull flow at Big Gypsum was determined to be near 2,800 cfs (79.3 cms) (Richard and Anderson 2006).

During the drought of the early 2000s peak and spring runoff flows were captured by reservoir storage. Peaks (mean daily flow) for 1998 through 2005 were 3,560, 3,100, 1,170, 522, 54, 323, 307 and 5,060 cfs, respectively (100.8, 87.8, 33.1,14.8, 1.5, 9.1, 8.6 and 143.3 cms) (Figure A1-8 and A1-16). Lowered mainstem runoff flows during the drought meant sediments from tributaries accumulated in the channel instead of being flushed.

The “fish pool” shares allocation shortages with other water project users. During the drought years 2002 and 2003, reservoir or “fish pool” releases were greatly reduced. Annual minimum (mean daily) flows recorded at the Bedrock gage for 1998 through 2005 were 21, 32, 25, 24, 1.4, 6.4, 20 and 31 cfs respectively (0.6, 0.9, 0.7, 0.7, 0.04, 0.2, 0.6 and 0.9 cms) (Figure A1-12).

METHODS

Fish Collections

Field crews collected fish using a raft fitted with pulsed DC current electrofishing gear and a single forward anode array. The raft was maneuvered by either oars or a battery powered trolling motor. Stunned fish were collected by two netters. Fish were identified to species. White sucker (*Catostomus commersoni*) and hybrid suckers (*C. c.* x *C. latipinnis and C. c.* x *C. discobolus*) were identified based on distinguishing characteristics of parental species. All fish were measured to the nearest millimeter for total length. Fish over 150 mm were marked and released for recapture data. A series of fish were weighed to the nearest gram allowing length-weight relationships to be determined for each common species in the sample.

Density estimates with ninety-five percent confidence intervals were made for all fish species based on recapture frequency of fish over 150 mm. The Darroch multiple mark method was used to estimate density (Everhart and Youngs 1981). The total-fish estimate combined all species. Recapture probabilities differ by species, which means the total-fish recapture probability may fluctuate between years if there are changes in species composition. For rare species or in the event of one or no recaptures, we calculated a density estimate by dividing the number fish collected by the mean recapture probability determined for less common species. We based the biomass estimates on length-weight regressions determined from samples taken in each study river.

The z-test with an alpha of 0.05 was used to test for differences in density estimates across years at each study site. For sites with three or more years of sampling, we used the Bonferroni inequality correction to control the overall significance level (.05) for the simultaneous comparison of all pairs of years (D. Bowden, Colorado State University, pers. comm.). For example, at Duffy and Sevens, stations with four years of data, the z value (2.631) corresponds to an alpha of 0.05.

Habitat Quantification

We quantified habitat availability as a function of flow by creating 16 mesohabitat categories (Table II-1). Meso-habitats are usually defined in general categories as pools, runs, riffles and rapids and is based on the mean velocity of the habitat type. Pools have low velocities, runs are moderate, riffles have swift currents and rapids are fastest velocities. We defined pool velocities from zero to 0.149 m/sec, runs from 0.15 to 0.6 m/sec, riffles from 0.61 to 1.5 m/sec and rapids had velocities over 1.5 m/sec. Habitat usability is also a function of depth. We divided pools and runs into five depth categories, riffles into four and rapids into two (Table II-1).

We determined the surface area of each of these 16 mesohabitat types for a series of flows using ArcInfo. Solution files (2D model output) were imported into ArcInfo and mesohabitat types were based on 1-meter x 1-meter depth and velocity grids. Each mesohabitat's surface area was determined by summing the number of grids that fell into each habitat category (Anderson and Stewart 2003 and CD Appendix, Habitat – 2D modeling). Using a mesohabitat's surface area as a measure of habitat abundance, we used the Shannon Diversity method (Stewart 2000) to indicate habitat diversity as a function of flow.

TABLE II-1. Depth and velocity criteria used to define meso-habitat types.

No.	Mesohabitat Type	Depth (m)	Velocity (m/s)
1	Wetted pool	0.01 – 0.2	< 0.15
2	Shoal pool	0.21 – 0.5	< 0.15
3	Shallow pool	0.51 – 1.0	< 0.15
4	Medi pool	1.1 – 2.0	< 0.15
5	Deep pool	> 2.0	< 0.15
6	Wetted run	.01 – 0.2	0.15 – 0.6
7	Shoal run	0.21 – 0.5	0.15 – 0.6
8	Shallow run	0.51 – 1.0	0.15 – 0.6
9	Medi run	1.1 – 2.0	0.15 – 0.6
10	Deep run	> 2.0	0.15 – 0.6
11	Shallow riffle	≤ 0.2	0.61 – 1.5
12	Riffle	0.21 – 0.5	0.61 – 1.5
13	Deep riffle	0.51 – 1.0	0.61 – 1.5
14	Very deep riffle	> 1.0	0.61 – 1.5
15	Shallow rapid	≤ 0.5	> 1.51
16	Deep rapid	> 0.5	> 1.51

RESULTS

Fish Analysis

Duffy, Yampa River

Native fish (>15 cm TL) species were uncommon to rare at Duffy during all years of sampling, composing only 13 to 16 percent of all fish collected during the first three years (1998 -2000) and only seven to nine percent in 2003 and 2004 (Table A2-1, top panel). Duffy had the lowest prevalence of native fish of any study site (Table II-2). Pure bluehead and flannelmouth sucker were about 10 percent of the catch in 1998 and 1999 (pre-drought) but only five percent in 2003. Duffy had the highest occurrence of the nonnative white sucker. White suckers, including hybrids with flannelmouth and bluehead suckers were over 70 percent of the catch during the first three years but declined during drought years. The nonnative smallmouth bass (*Micropterus dolomieu*) increased during the drought years and became the most common species in 2004 at 44 percent.

The total fish density estimates at Duffy were significantly (alpha = 0.05) higher before 2002 than after 2002 (Table A2-1, middle panel). Density estimates for flannelmouth sucker, bluehead sucker and roundtail chub were highest in 1998 and 1999 (pre-drought) and lowest in 2003 and 2004. White sucker + hybrids, common carp (*Cyprinus carpio*) and northern pike (*Esox lucius*) also declined in density after 2002. Smallmouth bass was the only species to increase in density during the dry years of 2001 to 2004.

Total fish biomass was poor at Duffy even prior to the drought (Table II-3). Biomass for most species was lower after 2002 (Table A2-1). White sucker + hybrids comprised about 72 percent of the total fish biomass before 2002 at about 40kg/ha and dropped to 11 kg/ha in 2004. Bluehead sucker biomass was negligible in 2004 at only 0.1 kg/ha.

Flows and channel geomorphology determine habitat availability. Typically pre-drought base flows had been near 250 cfs in the Yampa. The channel geomorphology at Duffy was generally wide and shallow relative to other sites (Table II-4). Duffy had the highest width/depth ratio, a low gradient, slow mean velocity and sand and gravel substrates. Pool and run habitats were 94 percent of the total area and riffles only 6 percent at 250 cfs (7.0 cfs) (Table II-5). During the drought, when flows were less than 150 cfs (4.3 cms), preferred native sucker habitat was negligible

Sevens, Yampa River

The proportion of native fish (>15 cm TL) at Sevens was stable from 1998 to 2001, with a four-year mean of 72 percent, which was relatively high for the Yampa River (Table II-2). Native fish declined to 42 percent in 2003, the third year of the drought and to 29 percent in 2004.

Before the drought Sevens had a very high flannelmouth sucker percentage, ranging from 48 to 53 percent between 1998 and 2001 (Table A2-2, top panel). Flannelmouth sucker dropped to 37 percent in 2003 and 26 percent in 2004. Bluehead sucker averaged 21 percent of the catch for the first three years, indicating that this species was stable prior to the drought. During the subsequent years with reduced flows bluehead sucker dropped to 13 percent in 2001 and only two percent in 2003 and 2004. White sucker + hybrids were around 15 percent for the first four years but grew to 36 percent in 2003 and 2004. Smallmouth bass were uncommon (about two percent) before 2002 but rose to 13 percent in 2003 and 23 percent in 2004.

Total fish density estimates for Sevens were significantly (alpha = 0.05) higher in 1998 (179/ha) and 1999 (179/ha) than in subsequent drought years (Table A2-2). Density and biomass for all native fish were lowest in 2003 and 2004. Flannelmouth sucker biomass was about 66 kg/ha in 1998 and 1999 but dropped to about 24 kg/ha by 2004 (Table II-3). Bluehead sucker biomass dropped at the greatest rate, from about 16 kg/ha (1998 to 2000) to 5 kg/ha in 2001 and then 0.6 kg/ha in 2003. Native sucker > 35 cm became rarer during the drought years of 2000 to 2003 (see Appendix Length Frequency, on included data disk).

The density and biomass estimates for white sucker + hybrids and common carp were highest in

2003 (Table A2-2), because of exceptionally high recruitment of yearling (10 to 20 cm) white sucker and carp. The strong 2002 white sucker and carp year class suggested relaxed predation that year, since age-1+ white sucker and common carp were not common in other years. Smallmouth bass was the only species to exhibit increased density and biomass in 2003 and 2004 (Table A2-2), indicating a positive response to reduced flows and altered thermal conditions (Table II-4).

Sevens had the lowest gradient (0.05 percent) of all study sites (Table II-4). The river was also wide and shallow relative to the higher volume Colorado and Gunnison rivers. Sevens had a low mean velocity and high width/depth ratio. At 250 cfs only two percent of the site was riffle and rapid habitat; two-thirds of the site was in the shallower run habitat types (Table II-5). The substrate at Sevens was mostly sand and gravel. Field crews observed active bank cutting and enlargement of sand dune substrates during the survey period.

Lily Park, Yampa River

Native species comprised about 57 percent of the fish assemblage at Lily Park in 2000, the first year of the drought (Table A2-3). Flannelmouth sucker was the most common species (fish > 15 cm) at Lily Park from 2000 to 2004 at nearly 50 percent (Table II-2). Bluehead sucker was the third most common species in 2000, 2001 and 2003 at about eight percent in those years (Table A2-3). Lily Park had by far the highest composition of channel catfish (*Ictalurus punctatus*), at any site, which varied between 40 and 18 percent. Smallmouth bass had a strong increase in relative abundance by 2004. Four species at Lily Park were less than or near one percent of the catch: roundtail chub, Colorado pikeminnow, northern pike and white sucker + hybrids.

Density estimates for total fish, flannelmouth sucker, bluehead sucker and channel catfish were highest in 2000 (Table A2-3) and were significant (alpha = 0.05) for total fish and flannelmouth sucker. The 2004 flannelmouth sucker density estimate was significantly lower than the estimates for 2000 and 2001. Bluehead sucker estimates were significantly lower for 2004 than for 2000. Channel catfish density estimates exhibited high variability across years and were significantly different (alpha = 0.05) between 2000 and 2001 and between 2001 and 2004. Although smallmouth bass estimates and catch rates rose in successive years, they were not significant (alpha = 0.05) due to low recapture rates.

The biomass estimate for flannelmouth sucker was very high at Lily Park in 2000, comparable to the estimates for the Colorado River (Table II-3). Biomass estimates of total fish, flannelmouth sucker and bluehead sucker declined progressively and were lowest in 2004 (Table A2-3). Channel catfish biomass was highest in 2000 (224 kg/ha) but was 54 kg/ha in 2004. In spite of increasing relative abundance and density estimates for smallmouth bass, biomass remained fairly constant over the years because of fewer fish > 29 cm.

Bluehead sucker and flannelmouth sucker mean lengths and the proportion of fish > 40 cm were higher before 2002. In 2000 about 70 percent of flannelmouth sucker were > 40 cm and 21 percent were > 45 cm. In 2003 those figures fell to 36 percent and two percent, respectively. Bluehead sucker > 35 cm were abundant in 2000 at 49 percent but less common in 2003 at 29 percent.

Larger channel catfish were also rarer after 2002. Seventy-two percent of channel catfish were from 30 to 39 cm in 2000, but only 48 percent in 2001 and 13 percent in 2003. In 2000 only one percent of the channel catfish fish collected were < 27 cm, but 71 percent were < 27 cm in 2003.

Lily Park, located just downstream of Cross Mountain Canyon, had a very different channel geomorphology from that of the two upstream sites. Its gradient was much steeper (0.2 percent versus 0.06 and 0.05 percent at Duffy and Sevens), its channel was narrower, its mean velocity was much higher and its substrate was dominated by cobble (Table II-4). Runs were swifter at Lily Park and riffle and rapid habitat types were more common, at 10 percent (Table II-5). Field crews often observed large mayfly hatches during sampling, suggesting that invertebrate productivity was also much higher than at the other two Yampa sites.

Flow and Degree-Day Correlation

Age-1 smallmouth bass in the Yampa River increased in abundance at Sevens and Lily Park in 2003 and 2004, years in which temperature units (degree-days over 12 C) were elevated the preceding years. We found a positive correlation between the number of days flow was below 200 cfs and degree-days-12C and (Anderson 2005). These data (not shown here) indicate that reduced flows not only alter habitats but also thermal regimes. In general, recruitment of age-1 smallmouth bass was less in years following cooler growing seasons (1998, 1999 and 2000) and higher when the previous years had higher degree-days. The highest abundance of age-1 smallmouth bass was in 2004; the preceding year had the warmest summer water temperatures (Anderson 2005).

Corn Lake, Colorado River

Native fish composition at Corn Lake was somewhat higher (79 percent) under pre-drought flow conditions than post- drought conditions (70 percent) (Table II-2). Flannelmouth sucker and bluehead sucker had similar percentages of approximately 36 to 38 percent in 1999, the highest flow year. Bluehead sucker percentage dropped to 28 percent in 2004, while flannelmouth sucker and roundtail chub composition was fairly consistent during the study period (Table A2-4). The percent composition of white sucker, white-hybrids and channel catfish increased during the lower flow years of 2003 and 2004. Centrarchid (sunfish) composition was similar in 1999, 2000, 2001 and 2004, but was highest in 2003, indicating better recruitment or survival during 2002.

The lower flows of 2002 and 2003 apparently did not affect the density estimates for total fish and flannelmouth sucker, since their estimates were similar across the sample period (1999 to 2004). However, the density estimates for bluehead sucker in 2004 was significantly less (alpha = 0.05) than in years before 2002 (Table A2-4). Channel catfish density was significantly higher (alpha = 0.05) in 2004 than 1999- 2001.

Flannelmouth sucker biomass was stable at Corn Lake throughout the study period (Table A2-4) and was second highest among the study sites (Table II-3). Bluehead sucker had an apparent decline in biomass in 2004, but Corn Lake was still a high biomass site for this species. Channel catfish biomass was much higher in 2004, indicating improved recruitment during the reduced flow period. Roundtail chub, carp and white sucker + hybrids biomass all appeared to have higher abundance in the years that followed reduced flow of 2002 and 2003, but the differences were not statistically significant.

Colorado River base flows are typically 800 to 1,000 cfs in the irrigation period and near 2,000 cfs in the winter. The gradient at Corn Lake was 0.16 percent and the width-depth ratio was relatively low (Table II-4). The mean width at Corn Lake was less than the mean width of the 15-Mile Reach overall. The mean velocity (0.54 m/s) was similar to Lily Park, but riffle and rapid habitats were 53 percent of the area (Table II-5).

Clifton, Colorado River

Sampling was done at Clifton in only three years: 2000, 2001 and 2003. Native fish composition at Clifton was similar to that at Corn Lake in the two years before the 2002 drought, but in 2003 native fish were less prevalent at Clifton, having dropped from 78 to 64 percent (Table II-2). Flannelmouth sucker and roundtail chub composition was stable over the four year period, but bluehead sucker composition dropped from 41 percent before 2002 to 25 percent in 2003 (Table A2-5). At 12 percent Clifton had the highest percentage of carp of any site, which may have been more the result of sewage treatment effluents than habitat availability. The percentages of white sucker + hybrids and channel catfish were higher in 2003 than in the earlier years, conforming to the Corn Lake trend. Centrarchid composition was low in 2000 and 2001 and increased in 2003 after the reduced flows in 2002.

Density estimates for flannelmouth sucker and roundtail chub were similar over the three years, indicating stability through 2003 (Table A2-5). Bluehead sucker density was lowest in 2003, whereas the channel catfish density estimate was highest in 2003.

One year of reduced flows did not appear to affect flannelmouth sucker biomass, but bluehead sucker biomass appeared reduced (Table A2-5). Channel catfish biomass was higher in 2003 than in the earlier years, indicating that recruitment could have been improved during the reduced-flow period. Roundtail chub, carp and white sucker + hybrids appeared to have increasing trends in biomass the year after reduced flows. Flannelmouth sucker and bluehead sucker density and biomass (carrying capacity) were much higher in the Colorado River than in the Yampa River (Table II-3).

Clifton had a steeper gradient at 0.2 percent (Table II-4) than did Corn Lake and the 15 Mile Reach overall. The Colorado River at Clifton was wider than at Corn Lake and along the 15-Mile Reach overall. This additional width was primarily the result of an old diversion structure about midway through the site that formed a very large upstream pool. Clifton had 22 percent more surface area per kilometer than Corn Lake, which was comprised of pool habitat. Surface area of riffle/rapid habitats per kilometer was similar for Clifton and Corn Lake, indicating these sites had similar amounts of swift current habitats. However, surface area of riffle/rapid habitat per hectare was less at Clifton, 41 percent compared to Corn Lake (53 percent) because of a wider channel at Clifton (Table II-5). The native sucker density estimates at Clifton and Corn Lake were very similar when based on fish per kilometer or fish per riffle area. The density estimates based on fish/ha were lower at Clifton, because of its larger surface area.

Escalante, Gunnison River

The Gunnison River fish community was sampled for the first time in 2003, mark and recapture sampling was done in 2004 and 2005. The Gunnison River did not experience reduced base flows during the 2002 drought because of regulated flow from upstream reservoirs (Anderson and Stewart 2006).

Escalante had the highest native fish composition of all the study sites (Table II-2). Native species (fish > 15 cm TL) composed 83 percent and 78 percent of the catch in 2004 and 2005, respectively. Bluehead sucker was the most common species at about 47 percent - the highest of all the sites. Flannelmouth sucker was common at about 18 percent. Escalante had the second highest composition of roundtail chub at 14 percent. White sucker + hybrids was the only other significant member of the community. Carp were only three percent. Channel catfish, northern pike and smallmouth bass were not collected during the Gunnison River surveys.

The productivity of juvenile native sucker was very high at Escalante relative to Delta, the other Gunnison site and relative to the Colorado and Yampa River sites.

Escalante's density estimates were lower in 2005 than in 2004 (Table A2-6); these differences were significant (alpha = 0.05) for flannelmouth and bluehead sucker but not for roundtail chub or white sucker + hybrids. We suspect that the dramatically reduced flannelmouth and bluehead sucker estimates in 2005 resulted from different catch and emigration rates between the two years because of higher flows in 2005. The highly different estimates for flannelmouth sucker between years indicated either a population crash or a strong sampling bias. We believed the flannelmouth sucker density was more stable than indicated by the estimates and considered the 2004 data more reliable. We believed a more reliable estimate of population size for bluehead sucker was obtained by the average of the 2004 and 2005 estimates. (Anderson and Stewart 2007).

Bluehead sucker and roundtail chub biomass was high at Escalante relative to sites on other rivers (Table II-3). Escalante's flannelmouth sucker biomass was intermediate to those from the Yampa and Colorado rivers sites. The biomass of white sucker + hybrids was very high at Escalante.

The Gunnison River at Escalante was much narrower than the Colorado and Yampa Rivers (Table II-4). Its moderate gradient (0.09 percent) and narrow channel provided a very low width/depth ratio during normal flow conditions. At 39 percent, riffle and rapid habitats were less prevalent at Escalante than at Delta, but deeper run habitats were much more prevalent at Escalante than at Delta or in the Yampa River (Table II-5). The relatively slower and deeper habitats appeared conducive for supporting a high proportion of juvenile fish.

Delta, Gunnison River

Native species (fish > 15 cm) comprised 64 percent and 74 percent of the catch at Delta in 2004 and 2005, ranking the site the third highest behind Escalante and Corn Lake (Table II-2). Flannelmouth sucker was the most common species at Delta in the 2003 and 2004 surveys at around 40 percent (Table A2-7). Roundtail chub were about 16 percent, nearly equal to Escalante. White sucker + hybrids and carp were more prevalent at Delta than at Escalante.

Density estimates for most species varied between 2004 and 2005, with carp the only species with density estimates not significantly (alpha = 0.05) different between years (Table A2-7). The density estimate for bluehead sucker increased from 130/ha in 2004 to 593/ha in 2005. We attribute that increase to very high recruitment of age1+ or Age2+ bluehead sucker in 2005, as well as differing emigration rates between years (more information in Anderson and Stewart 2006). Flannelmouth sucker density decreased in 2005, which we attribute to differing catch and emigration rates between years. The 2005 roundtail chub estimate for Delta was very similar to the Escalante estimate. White sucker + hybrid abundance was higher at Delta than Escalante.

The 2005 biomass estimate for bluehead sucker of 180 kg/ha (Table A2-7) at Delta was the highest of any site (Table II-3). In Table II-3 the value for bluehead sucker biomass at Delta was the average of the 2004 and 2005 estimates, because it seemed to be more accurate for indicating habitat potential (carrying capacity) at this site. In Table II-3 the value for the 2004 flannelmouth sucker biomass estimate was used, because the 2005 estimate appeared biased. Delta had the highest roundtail chub and white sucker + hybrids biomass of any site.

The mean velocity at the Delta site was 0.69 m/s, the highest of all the sites (Table II-4). The moderate gradient (0.16%), the narrow channel (42 m) and high base flows produced a site that was primarily comprised of riffle and rapid habitat types (Table II-5). Delta's habitat composition was very different from Escalante's, suggesting that habitat differences were a factor for the differing species compositions at these two locations on the Gunnison River.

Big Gypsum, Dolores River

Native fish prevalence (fish > 15 cm) varied from 87 percent to 43 percent over the years 2000, 2001, 2004 and 2005 (Table A2-8). Native fish prevalence was highest in 2001 and lowest in 2004. Roundtail chub was the most common species in 2000 (55 percent), but was considerably less common (around 25 percent) in 2001 and 2005. Flannelmouth sucker was the most common species in 2001 and 2005 (55 and 59 percent, respectively), but was rare (two percent) in 2004. Bluehead sucker composition ranged from six percent in 2001 to zero percent in 2005. Black bullhead (*Ameiurus melas*) was the most common species in 2004 at 45 percent, but was uncommon in prior years. Big Gypsum was the only site where white sucker were not collected.

Density estimates for flannelmouth sucker were significantly different (alpha = 0.05) between all four years. Roundtail chub estimates were not significantly different (alpha = 0.05) between years, except for 2000 and 2004. The number of fish caught each year (total catch) approximates catch rates per year, since three passes were the standard for each year. Field crews caught a total of 580 and 514 flannelmouth suckers in 2001 and 2005, respectively, but only 25 in 2004. There were 383 bluehead sucker in 2001, but only five and four in 2004 and 2005, respectively. Black bullhead numbers were 197 in 2004, but much fewer in prior years. Crews collected more roundtail chub, channel catfish and green sunfish in the first two years than in 2004 and 2005.

Total fish biomass was very poor at Big Gypsum (Table II-3). Big Gypsum had the lowest biomass for flannelmouth sucker and bluehead sucker, but roundtail chub biomass was higher than the Yampa River sites. Channel catfish, carp and flannelmouth sucker biomass were higher before 2002 than afterward (Table A2-8). Black bullhead biomass was highest in 2004, the year following the heavily reduced 2002 and 2003 flows.

Big Gypsum had a moderate slope of 0.15 percent and a low width-depth ratio at flows above normal at 50 cfs (Table II-4). The mean velocity of the Dolores at Big Gypsum was the lowest of the study sites. Pool habitat composed 63 percent of the site, and riffle and rapid habitats composed only three percent (Table II-5). The high percentage of pool habitat meant that fish that occupy pool habitat (roundtail chub) were more prevalent than the species that tend to inhabit runs (flannelmouth sucker) and riffle (bluehead sucker).

TABLE II-2. Species composition of fish >15 cm collected from the Yampa, Colorado, Gunnison and Dolores rivers during the pre- and post-2002 (severest drought year) periods.

Species/time period	Species composition (%) (in descending order of prevalence by site in the post-2002 period, from left to right)								
Native species	Escalante	Corn L.	Delta	Clifton	Austin	Lily Park	Big Gyp	Sevens	Duffy
Pre- 2002	*	79	*	78	*	57	73	72	13
Post- 2002	80	71	69	64	63	58	42	31	7.5
Flannelmouth sucker	Lily Park	Corn L.	Clifton	Delta	Sevens	Escalante	Austin	Duffy	Big Gyp
Pre- 2002	48	39	33	*	47	*	*	5	16
Post- 2002	52	38	33	28	26	18	18	3	2
Bluehead sucker	Escalante	Austin	Delta	Corn L.	Clifton	Lily Park	Sevens	Big Gyp	Duffy
Pre- 2002	*	*	*	36	41	9	20	2	4
Post- 2002	47	44	30	28	25	6	2	0.5	0.5
Roundtail chub	Big Gyp	Escalante	Delta	Clifton	Corn L.	Duffy	Sevens	Austin	Lily Park
Pre- 2002	55	*	*	5	4	4	5	*	0.02
Post- 2002	39	14	10	6	4.5	4	3	0.7	0.3
White sucker + hybrids	Duffy	Sevens	Austin	Delta	Escalante	Corn L.	Clifton	Lily Park	Big Gyp
Pre- 2002	72	13	*	*	*	6	4	0.02	0
Post- 2002	38	36	28	22	15	11	8	1.3	0
Carp	Clifton	Delta	Corn L.	Big Gyp	Sevens	Escalante	Lily Park	Austin	Duffy
Pre-2002	12	*	10	3	5	*	2	*	2
Post-2002	12	8	7	7	5	3	3	2	1
Channel catfish	Lily Park	Clifton	Corn L.	Big Gyp	Duffy	Sevens	Escalante	Delta	Austin
Pre-2002	40	5	5	16	4	7	*	*	*
Post-2002	27	11	8.5	5	5	4	0	0	0
Nonnative predator	Duffy	Big Gyp	Sevens	Lily Park	Clifton	Corn L.	Escalante	Delta	Austin
Pre-2002	8	5	2	0.8	1	1	*	*	*
Post-2002	44 a	26 c	23 a	9 a	4 b	3 b	0	0	0

Note: The Yampa River sites were Duffy, Sevens and Lily Park; the Colorado River sites, Clifton and Corn Lake; the Gunnison River sites, Delta and Escalante; and the Dolores River site, Big Gypsum ("Big Gyp").
Legend:
a = smallmouth bass
b = all sunfish
c = black bullhead

TABLE II-3. Biomass estimates (kg/ha) for fish >15 cm collected in the pre- and post-2002 (severest drought year) periods.

Species/time period	**Biomass (kg/ha) (in descending order by site in the post-2002 period, from left to right)**							
All species	**Corn L.**	Delta	Escalante	Clifton	Lily Park	Sevens	Duffy	Big Gyp
Pre-2002	550	*	*	522	521	164	66	41
Post-2002	700	676	567	519	240	74	21	21
Flannelmouth sucker	**Delta**	**Corn L.**	**Escalante**	**Clifton**	**Lily Park**	**Sevens**	**Duffy**	**Big Gyp**
Pre-2002	*	270	*	200	218	66	3.7	4
Post-2002	348	270	174	164	120	24	1.1	0.3
Modeled Kg/Ha @ Base Flow	310 @ 1,000 cfs	273 @ 1,000 cfs	315 @ 1,000 cfs	216 @ 1,000 cfs	103 @ 250 cfs	91 @ 250 cfs	45 @ 250 cfs	10 @ 50 cfs
Bluehead sucker	**Delta**	**Escalante**	**Corn L.**	**Clifton**	**Lily Park**	**Sevens**	**Duffy**	**Big Gyp**
Pre-2002	*	*	120	78	37	16	1.6	0.2
Post-2002	121	113	80	56	17	1	0.1	0.01
Modeled kg/ha @ Base Flow	140 @ 1,000 cfs	100 @ 1,000 cfs	118 @ 1,000 cfs	96 @ 1,000 cfs	53 @ 250 cfs	24 @ 250 cfs	29 @ 250 cfs	10 @ 50 cfs
Roundtail chub	**Delta**	**Escalante**	**Corn L.**	**Clifton**	**Big Gyp**	**Sevens**	**Lily Park**	**Duffy**
Pre-2002	*	*	9	14	2.8	5	0.2	2.6
Post-2002	40	39	17	12	1.6	1.5	0.6	0.3
White sucker + hybrids	**Delta**	**Escalante**	**Corn L.**	**Clifton**	**Duffy**	**Sevens**	**Lily Park**	**Big Gyp**
Pre-2002	*	*	21	15	40	23	0.4	0
Post-2002	85	65	32	13	10.7	10	1.1	0
Carp	**Clifton**	**Delta**	**Escalante**	**Corn L.**	**Lily Park**	**Sevens**	**Big Gyp**	**Duffy**
Pre-2002	180	*	*	100	29	28	18	7
Post-2002	165	165	142	110	32	21	13	1.6
Channel catfish	**Corn L.**	**Clifton**	**Lily Park**	**Sevens**	**Duffy**	**Big Gyp**	**Delta**	**Escalante**
Pre-2002	50	92	224	22	4.9	16	0	0
Post-2002	190	107	54	12	3.4	3	0	0
Nonnative predator	**Lily Park**	**Sevens**	**Big Gyp**	**Duffy**	**Corn L.**	**Clifton**	**Escalante**	**Delta**
Pre-2002	6.8	1.6	0.6	2.3	0.5	0.5	0	0
Post-2002	8.2 a	5 a	2.8 c	1.9 a	0.5 b	0.5 b	0	0

Note: The Yampa River sites were Duffy, Sevens and Lily Park; the Colorado River sites, Clifton and Corn Lake; the Gunnison River sites, Delta and Escalante; and the Dolores River site, Big Gypsum ("Big Gyp").
Legend:
a = smallmouth bass, b = all sunfish, c = black bullhead

Geomorphic and Habitat Analysis – All Sites

Our 2D modeling (GIS) produced two versions of habitat quantification. First, we quantified the preferred habitats of flannelmouth and bluehead sucker for use in the instream flow methodology (see the Flow Recommendations section below). Second, we also quantified the surface area of the 16 mesohabitats delineated in Table II-1 in order to estimate habitat diversity as a function was flow.

Habitat availability is primarily a function of flows and secondarily a function of channel geomorphology. When base flows are similar, differences in habitat availability are due to such geomorphic properties like slope and width. Determining the relationship between stream flows and native fish abundance requires the ability to quantify habitat availability as a function of base flows. This was performed by quantifying the prevalence of 16 mesohabitat types as a function of flow (see Habitat Appendix in the attached CD, Anderson and Stewart 2003).

Mean velocities are directly related to bed slope or gravitational forces, as indicated in Table II-4. Among sites with comparable flows, those with higher bed slopes (Delta, Clifton and Lily Park) had a higher amount of riffle and rapid habitat than did the lower gradient sites (Table II-5). The Clifton data is confuscated due to its altered channel width as a result of the diversion dam; riffle and rapid habitat area was high at Clifton when measured by station length, but reduced when measured by station area. Sites with more riffle and rapid availability had higher total fish biomass and native sucker biomass (Table II-3). The abundance of bluehead and flannelmouth sucker was strongly correlated with availability of their preferred habitats. In this study, availability of preferred habitats appeared to explain about 88 percent of bluehead sucker and 83 percent of flannelmouth sucker biomass when fish data was standardized.

As a further example base flows and slopes were fairly similar for Corn Lake, on the Colorado and at Delta, on the Gunnison. The narrower width at Delta produced a higher proportion of riffle and rapid habitats (Table II-5). The higher availability of riffle habitats at Delta explained the larger bluehead sucker biomass.

Lily Park, on the Yampa, and Clifton, on the Colorado, had similar slopes and channel widths, but their base flows were very different, suggesting that their differences in habitat and fish composition were mainly due to their different flow regimes. Lily Park's base flow was similar to the other two Yampa sites, Duffy and Sevens, but Lily Park's higher gradient and narrower width produced more riffle and rapid habitat per flow volume than at the other Yampa sites (Table II-4).

The Yampa River had a wider channel than the Colorado and Gunnison Rivers, even though the Yampa has less flow volume (Table II-4). The wider channel resulted in higher width-depth ratios and, in general, lower mean velocities on the Yampa. Typically a wider channel results in a higher composition of shallow, slow habitats, which are less suitable for large native sucker than deeper, swifter habitats.

On the Yampa, Duffy and Sevens were low gradient, low velocity and high width/depth ratio sites (Table II-4). They also had the poorest native fish productivity and among the highest incidences of hybridization with white sucker and abundance of nonnative predators (Tables II-2 and II-3). These negative interactions with nonnative species became more prevalent during the four years of drought at these sites.

When measured at similar flows, the Gunnison, Colorado and Yampa Rivers have relatively similar habitat composition. At 250 cfs (7.1 cms) riffle and rapid habitats were about six to seven percent for Delta and Escalante, about 12 percent at Clifton and Corn Lake, two percent for Sevens, six percent for Duffy and 10 percent at Lily Park (Habitat appendix in CD). Differences in riffle and rapid availability at the same discharge are due to differing slopes and widths.

The fact that the Gunnison, Colorado and Yampa Rivers have similar habitat composition at similar flows rates strongly suggests that the fish communities in these rivers would be more alike if flows were more alike.

We mapped the availability of the 16 mesohabitat types and calculated the Shannon diversity index of each one over a range of flows (see the accompanying CD appendix Haibtat – 2D modeling Figures II-1 to II-16). Stewart (2000) determined the

Shannon diversity index is appropriate for indicating habitat diversity based on the 16 meso-habitat types mapped for each study site.

Shannon diversity peaked at 1,000 cfs (28.3 cms) at Clifton and at 1,200 cfs (34.0 cms) at Corn Lake, suggesting that flows near 1,100 cfs (31.2 cms) on the Colorado River support near-optimal habitat diversity (see the CD Habitat appendix). Base flows near 1,000 cfs are common in the 15-Mile Reach and since we can infer that habitat diversity is near-optimal, we can also infer that the native fish assemblage approaches near-optimal diversity in these flow conditions.

TABLE II-4. Physical attributes measured at each study site and surface areas for a set of modeled flows.

Parameter	Gunnison R.		Colorado R.		Yampa R.			Dolores R.
	Delta	**Escalante**	**Clifton**	**Corn Lake**	**Duffy**	**Lily Park**	**Sevens**	**Big Gypsum**
Mean annual flow (cfs)	**2,564**		**2,817**		**1,546**			**284**
Length (km)	3.9	4.4	4.2	3.9	2.1	3.1	2.9	3.3
Percent slope	0.16%	0.09%	0.20%	0.16%	0.06%	0.20%	0.05%	0.15%
Typical base flow (cfs)	**1,000**	**1,000**	**1,000**	**1,000**	**250**	**250**	**250**	**50**
Mean velocity (m/s)	0.69	0.52	0.44	0.54	0.39	0.51	0.38	0.28
Mean width (m)	42	44	59	50	68	57	60	21
Mean depth (m)	0.81	1.02	0.76	0.82	0.53	0.6	0.6	0.46
Width/depth ratio	52	43	77	61	128	94	100	46
Bankfull flow (cfs)	**14,350** a		**22,000** a		[No data]	**11,000** b	**11,200** b	**2,600** b
Bankfull width (m)	76.5	74.1	133.8		[No data]	93.0	98.1	38.1
Bankfull depth (m)	2.36	2.82	2.58		[No data]	2.1	3.0	2.1
Bankfull width/depth ratio	32.4	26.2	51.8		[No data]	47.1	34.0	20.3
Flow category (cfs)	**Surface area (ha/km)**							
50						4.2	4.3	2.1
60					5.1	4.2	4.5	2.1
100	3.2	3.3	3.9	2.9	5.5	4.2	4.9	2.2
200	3.6	3.7	4.7	4.2	6.0	4.8	5.4	2.3
400	4.0	4.1	5.3	4.7	6.5	5.4	5.8	2.4
500	4.1	4.3	5.5	4.9	6.6	5.5	5.9	2.5
800	4.4	4.7	6.2	5.3		5.9	6.2	
1,000	4.6	4.9	6.5	5.3		6.0		
1,400	4.8	5.1	7.0	5.8		6.3		
2,000	5.2	5.5	7.6	6.2		6.7		

*a = Pitlick et al. (1999).
*b = Richard and Anderson (2006).

Shannon diversity peaked at 600 cfs (17.0 cms) at Delta and at 800 cfs (22.7 cms) at Escalante, suggesting flows near 700 cfs (19.8 cms) provide near-optimal habitat diversity on the Gunnison River (see the CD Habitat appendix). The Gunnison has a high base flow regime (1,000 to 1,200 cfs). Base flow over 1,000 cfs had reduced habitat diversity because of high amounts of riffle and rapid habitats (Table II-4). A dominance of riffle and rapid habitats may be detrimental to the young life stages of the native fish assemblage and small-bodied fish in general.

Shannon diversity peaked at 900 cfs (25.5 cms) at Lily Park (see CD Habitat Appendix), but was not identified at Sevens and Duffy. Base flows on the Yampa River were about 250 cfs (7.1 cms) in 'wet' years and less than 100 (2.8 cms) cfs during the drought. The low flow regime of the Yampa River lacks riffle and rapid habitats (Table II-4). Most native species can likely tolerate temporary low flow conditions by switching to alternative habitats. Nevertheless, several nonnative species were more competitive at exploiting low flow habitats on the Yampa. The low flow regime of the Yampa produced a more depauperate native fish assemblage than was observed in the rivers with higher flow rivers.

At Big Gypsum Shannon diversity peaked near 200 cfs (5.7 cms) and fell sharply at flows less than 70 cfs (2.0 cms)(CD Habitat Appendix). The Dolores River flow regime has been very low for both runoff and base flows. The interaction of both altered runoff and altered base flows has resulted in very low riffle and rapid habitat availability (Table II-5). The Dolores River native fish assemblage had poor diversity and biomass (Tables II-2 and II-3).

TABLE II-5. Mesohabitat availability per kilometer at the typical base flow for each study site.

No.	Parameter	Mean Depth (m)	Mean Velocity (m/s)	Gunnison R.		Colorado R.		Yampa R.			Dolores R.
				Delta 3.9 km	Escalante 4.4 km	Clifton 4.2 km	Corn Lake 3.9 km	Duffy 2.1 km	Lily Park 3.1 km	Sevens 2.9 km	Big Gypsum 3.3 km
	Typical base flow (cfs)			1,000	1,000	1,000	1,000	250	250	250	50
No.	Mesohabitat type			Area in hectares							
1	Wetted pool	0.01 – 0.2	< 0.15	0.17	0.17	0.21	0.08	0.19	0.17	0.27	0.34
2	Shoal pool	0.21 – 0.5	< 0.15	0.24	0.33	0.31	0.12	0.70	0.27	0.72	0.32
3	Shallow pool	0.51 – 1.0	< 0.15	0.11	0.24	0.31	0.12	0.49	0.26	0.51	0.42
4	Medi pool	1.1 – 2.0	< 0.15	0.03	0.13	0.17	0.03	0.30	0.12	0.26	0.16
5	Deep pool	> 2.0	< 0.15	0.00	0.04	0.09	0.00	0.06	0.09	0.00	0.01
6	Wetted run	0.01 – 0.2	0.15 – 0.6	0.07	0.03	0.28	0.18	0.30	0.32	0.13	0.21
7	Shoal run	0.21 – 0.5	0.15 – 0.6	0.39	0.29	0.74	0.43	2.25	1.55	1.35	0.35
8	Shallow run	0.51 – 1.0	0.15 – 0.6	0.40	0.57	0.86	0.54	1.37	1.09	1.63	0.10
9	Medi run	1.1 – 2.0	0.15 – 0.6	0.15	0.94	0.77	0.96	0.16	0.42	0.49	0.01
10	Deep run	> 2.0	0.15 – 0.6	0.04	0.22	0.11	0.08	0.00	0.07	0.00	0.00
11	Shallow riffle	≤ 0.2	0.61 – 1.5	0.01	0.00	0.13	0.06	0.04	0.08	0.01	0.03
12	Riffle	0.21 – 0.5	0.61 – 1.5	0.29	0.09	0.67	0.61	0.29	0.37	0.09	0.02
13	Medi riffle	0.51 – 1.0	0.61 – 1.5	1.61	0.85	1.17	1.41	0.01	0.05	0.02	0.00
14	Deep riffle	> 1.0	0.61 – 1.5	0.94	0.97	0.54	0.60	0.00	0.00	0.00	0.00
15	Shallow rapid	≤ 0.5	> 1.5	0.00	0.00	0.09	0.07	0.00	0.00	0.00	0.00
16	Deep rapid	> 0.5	> 1.5	0.05	0.01	0.10	0.08	0.00	0.00	0.00	0.00
				Percentage of site in pools, runs or riffles and rapids							
	Pools			12.3%	18.6%	16.7%	6.6%	28.4%	18.6%	32.3%	63.4%
	Runs			23.4%	42.2%	42.0%	40.6%	66.1%	71.1%	65.5%	33.9%
	Riffles and rapids			64.3%	39.2%	41.3%	52.8%	5.5%	10.3%	2.2%	2.7%
	Total surface area per kilometer			**4.52**	**4.88**	**6.53**	**5.37**	**6.16**	**4.87**	**5.49**	**1.98**
	Shannon diversity index			1.99	2.21	2.47	2.19	1.88	2.06	1.95	1.99

DISCUSSION

The 2D modeling effort described by Stewart and Anderson accomplished two objectives: first, determining the habitat preferences of bluehead and flannelmouth and correlating biomass estimates for the two species with habitat availability; and second, modeling native fish biomass under different flow regimes. The findings on flow and habitat relationships formed the basis of our instream

low recommendations for the four study rivers, which we present at the end of this current report.

This report has presented descriptions of native fish and hydrographs found in the Yampa, Colorado, Gunnison and Dolores rivers during and after the severe drought of 2002. The pristine native fish assemblage arose and was regulated by a natural flow regime. Flow is a "master variable" strongly correlated with many critical physical-chemical attributes of rivers, such as water temperature, channel geomorphology and habitat diversity (Poff et al. 1997). As we have seen here, changes in the natural flow regime can have significant impacts onecological integrity dependent on how flow characteristics have changed relative to natural conditions (Poff et al. 1997).

Natural flow regimes cannot be restored in these study rivers. Even efforts to mimic the natural flow regimes would have to be integrated into current water use programs and may be difficult to achieve on a consistent basis. Nevertheless, maintenance and enhancement of extant native fish are realistic goals for both fish management and flow management. The data presented here have documented the extant native fish in the four rivers and the modified stream flow regimes that supported and did not support persistence of native fish during the first half of this decade.

Colorado's original native fish assemblage in the Colorado River basin at elevations below 6,200 ft comprised about nine species. Speckled dace, (*Rhinichthys osculus)* and mottled sculpin, *(Cottus bairdi)*, are small-bodied species that were incidentally collected but not quantitatively sampled as part of this study. The endangered Colorado pikeminnow and razorback sucker were rarely collected during the study and wild bonytail, (*Gila elegans*) and humpback chub, (*Gila cypha*), were not collected. The three remaining larger bodied native species were the bluehead sucker, flannelmouth sucker and roundtail chub. These three species were the primary representatives of the native fish assemblage and the focus of our sampling efforts.

Base Flows

Originally, the four rivers had a natural snowmelt hydrograph with high spring runoff flows and a base flow period from August to April. Recent hydrographs of all four rivers, however, show alterations by human activities and unique differences across rivers. The Yampa River retains a relatively natural spring runoff flow but has lower base flows. The Colorado River in the 15-Mile Reach has moderately reduced spring flows, but retains near natural base flows. The Gunnison has highly reduced spring flows but increased base flows. The Dolores River's spring and base flows are both lower than they were originally.

We found base flow volume was the most important variable explaining differences in native fish abundance among the four rivers. The rivers with higher base flow had higher native fish biomass and composition. Habitat availability for flannelmouth and bluehead sucker maximized in the flow range of 800 to 1,200 cfs for the Gunnison, Colorado and Yampa Rivers and dropped sharply to very low levels at flows less than 300 cfs.

Habitat diversity was also related to base flow volume. As might be expected, pools and shallow runs were the typical habitats available during low flows, whereas deep and fast-current habitat types were common when base flows were high. Base flows for the Colorado River during 2000 and 2001 were 800 to 1,000 cfs (23 to 28 cms). Habitat availability and habitat diversity for flannelmouth and bluehead sucker estimated using the Shannon Diversity Index, were almost ideal in this flow range. The nearly natural base flows of the Colorado River suggest that its native fish assemblage (flannelmouth sucker, bluehead sucker and roundtail chub) may be, of the four rivers, the most representative of an unaltered base flow hydrograph.

Changes to the fish assemblage during the drought period provided empirical evidence that base flows are the most important factor maintaining the native fish assemblage. The Dolores and Yampa had severely reduced base flows for four consecutive years. Over most of the summer of 2002 flows on the Dolores River were less than two cfs (0.06 cms) (Bedrock gage) and on the Yampa flows were less than 12 cfs (0.3 cms) (Maybell gage). The Colorado River experienced one year of drastically reduced base flow, 2002 (Palisade gage). The Gunnison River did not experience reduced base flows (Delta and Uncompahgre gages).

The native fish community in the Dolores River appeared stable before the recent drought period. Valdez et al. (1992) reported no significant changes in species composition in the Dolores River between 1990-91 surveys and similar surveys made ten years earlier by the U. S. Fish and Wildlife Service (Valdez et al. 1982). The authors concluded that the ichthyofaunal community in the Dolores had remained relatively stable over that ten-year period.

The Dolores River fish community at the Big Gypsum site changed dramatically between 2000 and 2004. Among the changes were drastic declines in bluehead sucker abundance; increased abundance of black bullhead, a species associated with stagnant pool habitats; reduced biomass of roundtail chub, channel catfish and carp; and a reduction in the frequency of native fish larger than 20 cm (see the CD appendix Fish- Histograms).

The Yampa River fish assemblage also changed dramatically in 2003 and 2004 relative to pre-drought conditions in 1998 and 1999. Notable changes included very low occurrences of speckled dace, mottled sculpin and bluehead sucker (Anderson 2005); reduced total fish biomass, both native and nonnative; increased white sucker hybridization with native sucker; and increased crayfish abundance that was detrimental to native invertebrate species (P. Martinez, CDOW researcher, pers. comm.). Low flows during the drought years appeared to explain the explosion in smallmouth bass abundance and an expanding smallmouth bass population appears more problematic for reestablishing the native fish assemblage than reduced base flows (Anderson 2005).

The Colorado River in the 15-Mile Reach had one year of drastically reduced flows, 2002. Nonetheless, the native fish assemblage changed only minimally between 1999 and 2004. We detected no significant changes in flannelmouth sucker or roundtail chub biomass. The biomass of bluehead sucker, a species dependent on riffle habitat area, was slightly lower in 2004. Moderate increases in white sucker, channel catfish and centrachid abundance did occur. These data imply that one year of reduced flows is not particularly detrimental to the native fish assemblage.

Anderson (2005) has observed, however, improved reproductive success among nonnative species (white sucker, channel catfish and smallmouth bass) in the Colorado River following the low flows in 2002. On the Yampa the severity of the reductions in native fish was cumulative after consecutive years of reduced flows. These data suggest two or more consecutive years of reduced flows would have increasingly negative effects on the native fish assemblage.

The Gunnison River had the highest base flow regime and the highest native fish biomass. Because the Gunnison River did not experience low base flows during the 2000 to 2004 drought period and since the Gunnison had high native fish biomass and composition in 2003, 2004 and 2005, we assumed that this river appeared to be a base flow control site.

Nevertheless, the Gunnison native fish assemblage measured in this study differed from 1992 and 1993 data (Burdick 1995). White sucker and white sucker hybrids were 9.6 percent (n = 11,148) of all fish collected (boat electrofishing) in Reach 5 (Delta site) in 1992-93. In contrast, white sucker + hybrids made up 23.3 percent (n = 6,717) of the catch at Delta in 2004-05. White sucker + hybrids composition in Reach 4 (Escalante site) was 2.6 percent (n = 5,463) in 1992-93 and 14.8 percent (n = 8,612) in 2004-05. Flannelmouth sucker were less prevalent at Escalante and bluehead sucker were less prevalent at Delta in our surveys than in Burdick's (1995 and see our CD appendix Fish Gunnison).

Burdick (1995) compared his data to those of Valdez et al. (1982) and concluded that the native fish assemblage had not changed over the 12-year period from 1981 to 1993. The higher incidence of white sucker and white sucker hybrids in our survey appears to be a fairly recent change in the Gunnison River fish community.

Spring Runoff Flows

Water authorities often ask for spring flow recommendations when requesting instream flow recommendations. The primary goal of spring flow recommendations is to maintain channel geomorphology with flushing flows. Bankfull flow is typically identified because it is the most efficient flow for transporting sediment and maintaining the channel. Spring flows are the mechanism for flushing fines, sorting bed materials and scouring pools- all important processes for maintaining fish habitats during the base flow period. Moreover, several native fish species spawn during spring flows. Maintaining spring water temperatures and spawning habitats are therefore also considerations in making spring flow recommendations.

Spring flows appeared to be related to native fish reproductive success and recruitment in this study. There is evidence that native species recruitment improves following moderate to high spring flows in the Gunnison River (Anderson and Stewart 2006). Recruitment of nonnative species increased on the Colorado River following the low spring flow years. The importance of spring flows for maintaining a native fish assemblage appeared minor however, compared to base flows. More data should be collected to determine relationships between spring flows to native fish recruitment. Efforts to sample young of the year (YOY) in the fall would help determine correlations between spring runoff flows and year class strength.

Spring runoff flows on the Gunnison were low in 2000, 2001, 2002 and 2004. Mean daily peak flow was only 1,464 cfs (41.4 cms) in 2002 and it was 2,769 cfs (78.4 cms) in 2004. Reduced spring flows have been associated with reduced reproductive success of native species and improved reproductive success of nonnative species (Burdick 1995). The increase in white sucker may have occurred during this recent period of reduced runoff flows (Anderson and Stewart 2006). Bluehead sucker composition and abundance were lower in 2004 than in 2005 and 1992-1993. Low recruitment due to poor year class strength in 2001 and 2002 would explain the lower bluehead sucker biomass in 2004 at Delta. Spring flows were higher in 2003 and a strong 2003 year class could have recruited and increased bluehead sucker biomass in 2005.

The relative importance of high spring flows in maintaining native fish integrity was minor in the Yampa River. The Yampa had relatively high spring flows in 2000, 2001 and 2003. Any apparent increase in native fish reproductive success in those years was negated by poor YOY survival related to the severely reduced summer flows.

Spring flows in the Dolores River below McPhee dam were heavily reduced during the drought, with negative consequences to the native fish assemblage. Annual hydrographs of the Dolores before the McPhee Dam showed a high frequency of flows capable of transporting bed material (3,000 to 5,000 cfs) but very low annual base flows (two to five cfs). In the pre-McPhee period flows scoured riffles and pools nearly every year, which maintained the habitats used by native fish during the irrigation season. The pre-McPhee conditions appeared more conducive to maintaining native fish than those observed in recent years (Anderson and Stewart 2006). The lack of flushing flows for four consecutive years allowed sediment to accumulate in riffles and pools, resulting in a net loss of habitat quality that was not replaced by higher base flow releases from the reservoir.

Pitlick (1999) reported the Colorado River channel had narrowed slightly and was more or less in equilibrium with the present flow and sediment transport regimes. That study also reported that channel narrowing on the Gunnison River has been minor. A slightly downsized channel may be the natural consequence of reduced spring runoff flows. Despite higher annual flow volumes, both the Gunnison and Colorado had narrower widths than the Yampa.

Spring flows on the Yampa have been the most natural of all four rivers, which suggests that sediment transport and channel maintenance has taken place fairly regularly in recent years. Geomorphic properties of the upper Yampa, however, were the least conducive to maintaining fish habitat during periods of low flows. The Yampa River channel was wide and unstable, probably because of local land use practices. Active bank cutting was evident at the Sevens site and field crews observed that sand dune substrates enlarged at Sevens and upstream of Cross Mountain during the study period. The benefits of high spring flows for channel maintenance and native species recruitment may have been negated by active bank erosion along sections of the Yampa River.

Bed slope, stream width and the width/depth ratios of typical base flows were the geomorphic properties associated with maintenance of adult native fish habitat during the base flow periods studied. These geomorphic variables should be identified in future instream flow investigations. Determination of mean depths and mean velocities of representative riffles would also be informative. Riffles need to have a depth that allows for migration of large fish. Adequate depths and velocities of riffle habitats are also important in maintaining both fish and invertebrate habitats. Adult bluehead sucker preferred deep and fast riffles. These mesohabitats were plentiful on the Colorado and Gunnison rivers but were negligible on the Yampa (< 200 cfs) and Dolores (< 60 cfs). Poor invertebrate productivity due to inadequate riffle quality and quantity is likely the most direct cause of the poor total fish productivity on the Yampa and Dolores.

An overly wide channel is counter productive for maintenance of adult native fish habitats during low flow periods. Discharge (Q) equals width x mean depth x mean velocity. Fish select habitats based on depths and velocities. A narrower channel means that either depths or velocities are increased – both are positive attributes for adult native fish habitat. A relatively wider river will require relatively higher flows to attain equivalent habitat availability. The Yampa River was wider than the Colorado and Gunnison, but had relatively lower base flows. The 2D modeling indicated that 400 cfs (11.3 cms) would be needed at Sevens and Duffy (Yampa River) to yield a similar amount of bluehead sucker habitat as the 250 cfs (7.1 cms) at Corn Lake on the Colorado River yields (Anderson and Stewart 2003).

Maintaining the relatively natural runoff flows in the Yampa River appears to be more critical in the lower Yampa. Bestgen et al. (1998) reported that moderate to high runoff flows played an important role in the reproductive success for endangered Colorado pikeminnow in Dinosaur Canyon. Recovering endangered species has been a higher priority for native fish management and maximizing pikeminnow spawning potential is an important recovery objective. Nevertheless, the lesson of the Yampa River is that a holistic approach for the native fish assemblage would be to prioritize adequate base flows over high spring flows.

Nonnative Species

Competition, predation and hybridization by nonnative species are other factors that can potentially affect native fish biomass and diversity independently of habitat availability. As a rule, most of the successful nonnative species are detrimental and are well adapted to survive drought and inhabit low- to mild- velocity habitats. Species native to the Colorado River Basin have adapted to regular and often extreme flooding events each spring. Many tend to spawn during the runoff period and all except the chub species utilize moderate- to swift- velocity habitats.

The site with the largest nonnative fish component was Duffy on the Yampa River. Even in 1998 and 1999 pure native sucker were rare at this site because of previous hybridization with white sucker. In fact, native sucker were so rare at Duffy that the site was unsuitable for studying native fish habitat use (Anderson and Stewart 2003). Moreover, Duffy and the river reach from Maybell to Hayden had a very large population of nonnative predators. Impacts of northern pike predation included a near elimination of all forage-sized (12 to 40 cm) fish from the site (see the CD, appendix Fish-histograms). In the Yampa the nonnative white sucker may have gained superiority over the native sucker because of better predation avoidance adaptations instead of more efficient exploitation of available habitats.

The negative impacts of nonnative species interactions at Duffy have superseded the impacts of flow regimes in configuring the native fish assemblage. Once predation has reduced the native fish assemblage, little additional pressure is necessary to keep natives suppressed. A return to pre-drought flows is therefore not likely to restore the native fish assemblage of the upper Yampa without concurrent reductions in predator impacts. Nevertheless, the flow management at Duffy should not be ignored because of these nonnative fish pressures. Instream flows are critical for maintaining habitat diversity. Habitat diversity is simplified at flows less than 300 cfs. Low flows and habitat simplification could mean that the hybridization and predation impacts were unavoidable.

Unlike Duffy, the Sevens site on the Yampa had a high native fish component prior to the drought period. Anderson (2005) speculated that flannelmouth sucker abundance was high and stable at Sevens because of recruitment of fish from spawning sites near Cross Mountain Canyon or the Little Snake River confluence. Flannelmouth sucker abundance did not decrease until the third consecutive year of reduced flows. White sucker and smallmouth bass numbers also increased in the third year of the drought. Sevens appears to be an example of reduced flows precipitating an altered native fish assemblage.

White sucker may be better than native sucker at avoiding predation by smallmouth bass. If smallmouth bass persist in the Yampa, white sucker and hybrids may completely replace native sucker upstream of Maybell because of these differences in predatory impacts. During a period of higher flows in the late 1990s, smallmouth bass were uncommon in the Yampa and were not expected to be a threat given flows and thermal conditions of that period (Nesler 1995). During the 2000-2005 flow regimes, however, smallmouth bass proliferated throughout the river and their dominance will likely continue as long as base flows and temperatures are suitable for their reproduction.

Channel catfish and carp were other nonnative species commonly collected in the four rivers we studied. Neither species appeared to be a serious threat to flannelmouth sucker, bluehead sucker and roundtail chub populations. Not enough data were available, however, to indicate wheather channel catfish and carp have been a threat for endangered species, such as Colorado pikeminnow and razorback sucker.

Field crews found no nonnative predators in the Gunnison River during the study period. Burdick (1995) attributed the lack of channel catfish to the Redlands Diversion dam, a physical block to their upstream migration. Redlands Dam has been an efficient method for controlling certain nonnative species. Low-head weirs appear to have potential for controlling undesirable nonnative species in other rivers.

Species Accounts

Bluehead Sucker

Data on bluehead sucker provide the most information for justifying instream flows needed to maintain the native fish assemblage. The bluehead sucker is a relatively large-bodied fish with a strong association for “medi-riffle” habitat (Anderson and Stewart 2003, Byers et al. 2001 and Rees and Miller 2001; see CD Reports appendix). Sampling for this study confirmed a strong relationship between increased medi-riffle habitat and increased bluehead sucker biomass.

Bluehead sucker biomass was highest on the Gunnison River. The 15-Mile Reach and near Parachute on the Colorado River (Osmundson 1999, Anderson 1997) were other sites with high bluehead sucker biomass, high base flows and high availability of riffle habitat. Bluehead sucker biomass was extremely low at Duffy and Sevens (Yampa River) and Big Gypsum (Dolores River) where optimal habitat availability was lacking.

The primary objective of most cross-section methodologies is to maintain the quality of riffles (Nehring 1979). Riffles are the most vulnerable habitat to dewatering, yet they are the most important habitat for invertebrate productivity. When riffle habitats are maintained, there should be sufficient habitats for perpetuating carrying capacity (biomass) and composition for all members of the native fish assemblage (Nehring 1979).

Bluehead sucker abundance is a very good indicator of riffle habitat availability. Riffle habitat availability appeared nearly optimal on the Colorado River. Bluehead sucker were about 36 percent of all fish collected and about 17 percent of the total biomass at Corn Lake on the Colorado. At Lily Park on the Yampa, where base flows were lower, bluehead sucker were only nine percent of the catch and about seven percent of the biomass. These differences between the two rivers were most likely due to differences in base flow volume, since slopes and widths were similar at these sites. An instream flow for the 15-Mile Reach (Colorado River) and

Lily Park (Yampa River) would be the same when based on a standardized methodology that relied on riffle habitat availability. Flow recommendations for these two rivers should differ only if native fish management objectives or water availability are notably different.

The reproductive success of bluehead sucker may be related to spring runoff flows. The senior author observed spawning bluehead sucker in mid May near the mouth of Dominguez Creek. In low flow years ova and larvae survival may be poor because of more efficient predation. Spring flows were higher in 2003 on the Gunnison River than in the other years studied and there appeared to be a strong 2003 year class of bluehead sucker (Anderson and Stewart 2006, CD). Bluehead sucker biomass on the Colorado and Yampa rivers was relatively stable in years of normal spring runoff and base flows, but bluehead sucker biomass dropped after years of reduced runoff flows.

Hybridization with white sucker is a potential problem for bluehead sucker. The Yampa had the most extreme problem of white sucker hybridization. During the drought medi-riffle habitat was lacking on the Yampa and pure bluehead sucker became rare. Bluehead sucker - white sucker hybridization may prohibit recovery of pure bluehead sucker in the upper Yampa River even if riffle habitat can be restored. The Gunnison River had the next highest hybridization rates; but medi-riffle habitat was abundant on the Gunnison and pure bluehead sucker biomass was very high. The Colorado River had high bluehead sucker biomass and only a small white sucker and hybridization component in the 15-Mile Reach. The Dolores had the lowest bluehead sucker population, but this river did not have white sucker.

Bluehead sucker should be the primary indicator species for biologically-based instream flow recommendations. Bluehead sucker abundance is directly related to the availability and quality of riffle habitats. Riffles are important habitats for speckled dace and aquatic invertebrates. Optimal bluehead sucker habitat availability occurred when riffles were about 30 to 50 percent of the surface area.

Flannelmouth Sucker

Flannelmouth sucker is another good indicator species for flow and habitat relationships. Stewart and Anderson (2003) identified significant correlations between habitat area and flannelmouth sucker biomass.

Flannelmouth sucker was the most common native fish collected during this study. It was the most common species at the Lily Park, Corn Lake, Clifton, Delta, Sevens and Escalante sites, composing about 47, 41, 38, 41, 40 and 31 percent of total biomass at each site, respectively. The relatively high abundance of flannelmouth sucker resulted from the high availability of preferred habitat. In fact, the only sites where flannelmouth sucker was not the most common species were those in which their optimal habitat had been reduced because of either very low or very high base flows. In the low flow rivers (Dolores & Yampa < 200 cfs), pools and shallow runs were the dominant habitat and flannelmouth habitat was lacking. At high base flows, the Gunnison >1200 and the Colorado >2000, riffles and rapids were dominate habitats and flannelmouth habitat is reduced.

Flannelmouth sucker occupy 'deep semi-swift runs', which is typically the most plentiful main channel habitat (Anderson and Stewart 2003-CD, Byers et al. 2001-CD, Rees and Miller 2001-CD). Flannelmouth sucker should be the highest biomass species in the community because of its large body size (up to 60 cm). The species also inhabits the most prevalent habitat type in normal flow conditions.

Flannelmouth sucker were present over a wide range of base flows. A general observation was that higher flow rivers had a higher compliment of larger sized fish. Flannelmouth sucker over 45 cm were common in the Gunnison and Colorado Rivers. In the low-flow Dolores River, flannelmouth sucker were typically less than 20 cm. Flannelmouth sucker size and discharge were intermediate at Lily Park on the Yampa River. Achieving a large size allows individuals to exploit swifter habitats and also avoid predation.

Flannelmouth sucker appear capable of tolerating periods of reduced flows better than bluehead sucker because of their different habitat requirements. Possibly due to a higher degree of overlapping habitat and spawning periods, flannelmouth sucker appeared more susceptible to hybridization with white sucker (WS x FMS).

Hybridization with white sucker is a very serious threat to flannelmouth sucker on the Yampa River.

Low base flows, habitat overlap and predation pressure are selection forces for high hybridization rates there. Flannelmouth x white sucker hybrids are common on the Gunnison River as well, where base flows have been very high. Reduced peak flows may be associated with the increased white sucker abundance on the Gunnison. White sucker numbers were low in the 15-Mile Reach on the Colorado River and the species was absent in the Dolores River. The Dolores River is an example of a persisting flannelmouth sucker population under conditions of long term flow reductions, but a threat of white sucker hybridization would likely imperil this species under these flow conditions.

Flannelmouth sucker is an important species for biologically justifying instream flow recommendations to maintain the native fish assemblage. Flannelmouth sucker is the most common native fish. An adequate flow regime would support an abundant flannelmouth sucker population that includes both juveniles and large fish (>45 cm). An abundant flannelmouth sucker population with a normal size distribution is a very good indication that habitat diversity is being maintained for all members of the native fish assemblage.

Roundtail Chub

Roundtail chub abundance was not a good indicator for justifying instream flows. Roundtail chub are a multi-habitat species. During the day they occupied deep pools and at night they frequented runs and riffles, presumably for feeding (Byers et al. 2001 and Rees and Miller 2001; see the CD appendix). Roundtail chub appeared more concentrated in scour or eddy pools in areas with higher channel complexity. Boat electrofishing is not as efficient in deep pools and roundtail chub numbers could have been underestimated in some surveys. Turbidity, which decreases light penetration during the day, also appeared to influence the catch rates of roundtail chub. In some surveys, however, the roundtail chub catch rates improved during turbid conditions.

Roundtail chub were not a good indicator species for instream flow needs for two reasons: their habitat preferences and their status as predators. Roundtail chub prefer deep pools habitats, which are the least vulnerable habitats to dewatering. Pool habitats increase proportionately with decreasing flow due to reduced velocities, so pool habitat availability tends to maximize at lower discharges. The fact that roundtail chub are a predator species means their biomass potential is more likely dependent on prey availability (which is riffle associated) than on pool habitat availability. Attempts to correlate roundtail chub biomass to pool area did not result in significant correlations (Anderson and Stewart 2003).

In general roundtail chub were highly resistant to flow reductions, but they were vulnerable to predation. Roundtail chub biomass was highest in the Gunnison River, probably because this river did not have nonnative predators and because its high riffle content made it biologically productive. Among the four rivers studied, the Gunnison was unique in its lack of nonnative predators, which make it a very good location for testing relationships of habitat and biomass.

The river with the highest percentage composition of roundtail chub was the Dolores. The Dolores was the lowest flow river and had a very high relative availability of shallow pool habitats. Roundtail chub in the Dolores were small (10-20 cm), indicating a relationship between small body size and the quality of available habitats. Roundtail chub achieved a total length up to 45 cm in the high volume Gunnison and Colorado Rivers. Reduced body size and decreased age of maturity are apparent adaptations to long-term low flow conditions.

Roundtail chub abundance during the drought was more related to predation impacts than habitat availability. Roundtail chub were uncommon at both Duffy and Sevens on the Yampa River. Predation impacts likely increase during drought periods. In times of low flows, predator avoidance would be more difficult because prey and predators are confined to the remaining habitats.

Roundtail chub were very rare at Lily Park on the Yampa even though suitable habitat was available. The lack of roundtail chub at Lily Park indicates no local spawning and a complete lack of larvae drifting down from upstream spawning sites. Channel catfish were extremely abundant at Lily Park, however and may have been responsible for the lack of roundtail chub recruitment. There was evidence of a catfish annual migration through Lily

Park (Anderson 2004) and therefore the Lily Park catfish population could have been even larger than estimated.

Roundtail chub were relatively common in the Colorado River. The species' percent composition and biomass in the 15-Mile Reach were similar to upstream at Parachute (Anderson 1997). The 15-Mile Reach had a large channel catfish population, whereas catfish were rare at Parachute. This suggests channel catfish were not a negative impact for roundtail chub in the 15-Mile Reach.

Roundtail chub abundance and habitat was not very informative in making recommendations for instream flows. Roundtail chub should be a common species at almost any range of flows. If juvenile fish are abundant but adult fish are missing (as in the Dolores River), adult habitat is insufficient. On the other hand, if large adults are present but juveniles are missing (as at Duffy and Sevens on the Yampa), predation is likely the cause. If no roundtail chub are present (as at Lily Park on the Yampa), lack of recruitment is the suspected cause. The presence of all sizes of roundtail chub (5 to 45 cm) is good evidence that habitat diversity is adequate and predation by nonnative fish is minimal (as in the Colorado and Gunnison Rivers).

Endangered Species

> ..[A] holistic approach to endangered fish management is essential and the species (or life stages) selected for study should reflect the environmental constraints on the population as a whole. –Rose and Hann (1989)

Colorado Pikeminnow

Colorado pikeminnow is not a suitable species for determining instream flows for the same reasons given for roundtail chub. During the day Colorado pikeminnow primarily frequent deep pools (eddies). Again, pools are the least vulnerable habitats to dewatering. At night Colorado pikeminnow are predators and occupy multiple habitats (Modde et al. 1999). Correlations between habitat and Colorado pikeminnow biomass would not be possible to determine, because appropriate data are rarely collected. The very low abundance of Colorado pikeminnow and other endangered fish is likely caused by factors other than lack of adult fish habitat on the Colorado 15-Mile Reach.

Rose and Hann (1989) believed the lack of base flow habitats were likely not the primary limiting factor for Colorado pikeminnow in the Colorado River. As they explained "Formulating stream flow recommendations for adults is meaningless if channel stability, spawning, larval transport, exotic competition and/or other factors are limiting to the population." Nevertheless, formulating holistic instream flow recommendations with the goal of sustaining the native fish assemblage is an ecological imperative.

Using radio telemetry, Modde et al. (1999) and Osmundson et al. (1995) described Colorado pikeminnow habitat use in the Colorado and Yampa Rivers. With a modified inflection point methodology, Modde et al. (1999) identified 93 cfs (2.6 cms) as the minimum instream flow for the Yampa River. Osmundson et al. (1995), using a videography method, recommended an instream flow of 1,243 cfs (35.2 cms) for the 15-Mile Reach of the Colorado. Although both recommendations were intended to protect adult Colorado pikeminnow habitat, they demonstrate that different methodologies may yield widely different results.

The traditional approach for biologically justifying instream flow recommendations is to use an analysis methodology that integrates the needs of the native fish assemblage. Holistic instream flows should be compatible with endangered fish recovery goals. Adult Colorado pikeminnow habitat in the Colorado, Gunnison and Yampa River does not appear to be limited nor does it appear appropriate to use pool habitat to justify an instream flow. Recommendations for spawning flows, larval drift flows and wet year flows are outside the normal definition of an instream flow (base flow period) and recommendations that address specific biological concerns need to be based on an identified limiting factor.

The other three endangered species in the upper Colorado River Basin - **razorback sucker, humpback chub and bonytail** - are also not good indicator species for recommending instream flow. These species are currently very rare and making base flow recommendations for maintaining their adult habitats will not likely correct factors that are currently limiting their abundance.

White Sucker

White sucker is a species that is detrimental to the native fish assemblage. Identification of white sucker habitat preference was not an objective of this project, but in general, pure white sucker were collected primarily from low velocity habitats such as pools, backwaters and slow deep runs. White sucker x flannelmouth hybrids achieved a large body size (40-50 cm) and occupied faster run habitats than pure white sucker. White sucker x bluehead sucker hybrids achieved a large body size and were common in swift habitats. Both hybrids were able to inhabit areas used by the native parent. White sucker and hybrids were able to occupy a wide range of pool and run habitat types.

We did observe an apparent longitudinal trend in white sucker composition, with higher relative abundance at upstream sites. On the Colorado River white sucker and hybrids were 22 percent of the total catch at Rifle, 12 percent at Parachute and six percent in the 15-Mile Reach, decreasing in a downstream direction. On the Yampa River white sucker and hybrids were 72 percent at Duffy, 13 percent at Sevens and less than one percent at Lily Park and white sucker are rare further downstream in Dinosaur Canyon (Mark Fuller U.S. Fish and Wildlife Service, personal comm.). On the Gunnison River white sucker were 28 percent at Austin, 22 percent at Delta and 15 percent at Escalante. A longitudinal distribution suggests that cooler temperatures tend to benefit this species. We also observed, however, that white sucker and hybrids increased in prevalence at Sevens (Yampa River), the Gunnison River and the 15-Mile Reach during the drought period, a time of reduced runoff flows and presumably warmer water temperatures.

White sucker and hybrid recruitment appeared to increase relative to native sucker following the low spring runoff flow years in the Gunnison and Colorado Rivers. Perhaps native sucker recruitment was poor in low runoff years. White sucker and hybrids have been able to persist under regimes of both low and high base flows. The white sucker and hybrids are species (taxa) well adapted to thrive over a wide variety of flow conditions including both the ‘dry’ and ‘wet’ hydrographs. White sucker has demonstrated it can persist in western Colorado rivers regardless of flows or flow alterations.

Nonnative Predators

Northern Pike

Northern pike have been able to maintain a large population in the Yampa River over a wide range of flow conditions. The species appeared to prefer main channel pools during the base flow and winter periods (Nesler 1995). The preference for pool habitats would explain how northern pike have been able to persist through the prolonged drought period on the Yampa.

Nesler (1995) found no relationship between northern pike abundance and spring runoff magnitude. Suitable spawning habitat is very abundant in the Yampa River upstream of Craig. The large northern pike population is maintained by recruitment of fish from off-channel ponds, sloughs and upstream reservoirs (Nesler 1995). In the Colorado, Gunnison and Dolores rivers lack of suitable spawning habitat appears to explain the low numbers of northern pike collected.

Smallmouth Bass

Smallmouth bass was the only species with a strong positive change in abundance during the drought on the Yampa River. Nesler (1995) described suitable smallmouth bass habitat as low-current velocity habitat with instream or shoreline cover and limited boulder-gravel substrates inundated year-round for cover and feeding. These habitats are plentiful in the Little Yampa Canyon reach and are not diminished by drought conditions.

Recruitment of age-1+ smallmouth bass appeared negatively related to the magnitude of spring runoff flows on the Yampa. Large numbers of YOY but small numbers of age1+ smallmouth bass were collected at Duffy on the Yampa in 1998, 1999 and 2000. This finding indicated poor YOY overwinter survival. During the drought age-1+ recruitment increased. Drought years tend to have higher thermal units and a longer growing season that results in bigger YOY smallmouth bass. Bigger YOY have better overwinter survival and much higher recruitment rates after their first winter season. A warmer and lengthier growing season in the other western Colorado rivers might also result in greater recruitment of smallmouth bass in those rivers.

Channel Catfish

Channel catfish had high density populations in Lily Park (Yampa River) and in the Colorado River. Nesler (1995) summarized the preferred habitat of adult channel catfish from several authors. Channel catfish preferred deep pool habitat (Aadland et al 1991) and usually select slow current velocities and preferred cover (Peters et al. 1992). Sampling during this study took channel catfish from backwaters and deep pools, but collected the majority from run habitats with gentle to moderate velocities. As many as 20 to 60 channel catfish were collected from certain run habitats (usually < 1m depth and < 0.5 m/s) in Lily Park and 15-Mile Reach surveys. Collection of large numbers of channel catfish in certain glides suggests that the catfish (30-50 cm) may have been foraging in schools.

The high-density channel catfish population at Lily Park (Yampa River) was maintained by recruitment of juveniles from downstream (Nesler 1995). We observed the same process at work in the current project at Lily Park and the 15-Mile Reach (Colorado River). In general, adult catfish migrate downstream to spawn (temperature related). The smallest channel catfish collected at Lily Park and the 15-Mile Reach prior to 2002 was about 30 cm. In 2003 YOY and channel catfish less than 20 cm were collected at Lily Park, which indicated spawning sites were further upstream during low flow years (Anderson 2004-CD). Spawning sites during normal base flow conditions were likely further downstream because water temperatures take longer to warm in high flow years.

Downstream migration to spawning sites makes channel catfish vulnerable to removal by trapping efforts. The Gunnison River did not have channel catfish or other nonnative predator species. As noted earlier, the Redlands Diversion Dam appears to be an effective block to upstream migration. Anderson (1997) did not collect channel catfish upstream of the Government Highline Diversion Dam on the Colorado River. Again, strategically located low-head diversion dams or weirs may offer an effective technique for controlling or reducing channel catfish from upstream reaches.

Supplemental Data

Colorado River

A common assumption concerning stream flow is that habitat availability increases with increasing flows. Our 2D modeling effort projected that habitat availability for flannelmouth and bluehead sucker would rapidly increase with increasing flow from zero to about 600 cfs in the 15-Mile Reach of the Colorado River. Flannelmouth and bluehead sucker habitat would be near maximum at flows of 800 to 1,200 cfs, but habitat would not increase substantially at flows above 1,400 cfs. The shape of the 15-Mile Reach (Figure II-18) habitat-flow relationship was also similar to the Gunnison and Yampa Rivers (Figures II-19 and II-20).

We suggest that the 2D modeling habitat-flow relationship that project bluehead and flannelmouth sucker habitat does not substantially increase with flows over 1,400 cfs, can be confirmed from field observations in different sections of the Colorado River.

The 15-Mile Reach is located below 2 major diversion structures that reduce flows during the April to November irrigation season. The upper diversion structure is called the Government Highline Diversion Dam or simply known as the Roller Dam and is located in Debeque Canyon about 20 km upstream of the 15-Mile Reach.

Pitlick and Cress (2000) found that the Colorado River near Una Bridge and the town of Parachute had similar bed slopes and bankfull widths to those of the 15-Mile Reach. Similar channel geomorphology for the 15-Mile Reach and Parachute indicates the main difference in habitat potential for these two areas is their respective base flow regimes.

The Colorado River upstream of the roller dam has had a much higher base flow regime than the 15-Mile Reach. Flows recorded at the Cameo gage on the Colorado River were rarely less than 1,800 cfs between 1993 and 1996. Flows recorded at the Palisade gage were about 1,200 cfs less than those at the Cameo gage during the irrigation season.

Anderson (1997) sampled the Colorado River near Parachute for fish in 1994, 1995 and 1996 using similar electrofishing and population estimation techniques as those used for the 15-Mile Reach in this report (1999 to 2004). The biomass estimates for

Parachute for flannelmouth sucker and bluehead sucker averaged 187 and 94 kg/ha, respectively. Flannelmouth sucker and bluehead sucker biomass in the 15-Mile Reach averaged 235 and 100 kg/ha, respectively. These data indicate a similar flannelmouth and bluehead sucker biomass for Parachute and the 15-Mile Reach.

The composition of flannelmouth and bluehead sucker at Parachute was 38 percent and 36 percent of all fish, respectively (Anderson 1997). In the 15-Mile Reach (this study) flannelmouth sucker were 36 percent and bluehead sucker, 38 percent. These data indicate that the Parachute reach has a native sucker and roundtail chub population size that is nearly equivalent to that in the 15-Mile Reach. Similar native fish biomass at Parachute and the 15-Mile Reach suggests that habitat availability was not different between the two locations. Similar native sucker biomass at Parachute and the 15-Mile Reach confirmed that flows above 1,800 cfs did not increase bluehead sucker or flannelmouth biomass in the Colorado River.

These field observations confirmed our 2D model projections that stream flows above 1,400 cfs would not result in greater availability of habitat for flannelmouth and bluehead sucker in the Colorado River. The geomorphic and fish data also indicate that habitat modeling done in the 15-Mile Reach is also applicable to the Colorado River upstream of the Roller Dam.

Fish population surveys by the U. S. Fish and Wildlife Service (USFWS) in the 15-Mile Reach and the river upstream of the Roller Dam conform to those reported by Anderson (1997). Osmundson (1999) reported higher flannelmouth and bluehead sucker catch rates in the 15-Mile Reach than at Parachute. The USFWS data indicate that the 15-Mile Reach is more productive for native fish than upstream of the Roller Dam, where base flows were higher.

Two factors could be an influence for greater native fish biomass in the 15-Mile reach than in the upstream reaches. First, the 15-Mile Reach is located near the confluence of the Gunnison River and native fish from the Gunnison River could supplement recruitment in the 15-Mile Reach. Second, the sewage treatment facilities located near Clifton could be adding to the general productivity of the 15-Mile Reach. Nevertheless, habitat availability for native sucker was modeled to be higher at flows typically associated with the 15-Mile Reach.

Yampa River

Native fish have not persisted in the upper Yampa River except at Lily Park. Lily Park was a very short river section located between the confluence of the Little Snake River and Cross Mountain Canyon. The slope was steeper and the river narrower than at the other two Yampa sites and thus Lily Park was not representative of the river upstream of Cross Mountain.

Lily Park was the only Yampa site sampled where pure flannelmouth sucker and bluehead sucker were common, because of the lack of white sucker at Lily Park. White sucker have been only rarely collected in Dinosaur Canyon and therefore hybridization is not a problem in the lower Yampa River (Mark Fuller USFWS Vernal, personal comm.)

Perhaps one of the more insidious impacts of the drought is a recent explosion in the crayfish community in the Duffy site by 2003 (Anderson 2005). Martinez (2006) estimated that the current biomass and production of crayfish exceeds the fish population. The nonnative virile crayfish (*Orconectes virilis*), appears to have increased during the recent drought. This change has implications for fish productivity. Although fish species that prey on crayfish (such as smallmouth bass and channel catfish) may benefit (Martinez 2006), suckers and chub may be in competition with crayfish for invertebrate forage, which could explain concurrent reductions in sucker biomass.

Gunnison River

Native fish have persisted in the reduced spring flow and increased base flow regime of the Gunnison River. High base flow regimes were not detrimental to native species and did not inhibit white sucker reproduction and recruitment. The cooler water temperature associated with high base flow regimes may be beneficial for white sucker. Increased water temperatures in the lower Gunnison River could have a negative impact on white sucker, but more data are needed on white sucker temperature preferences. In contrast, increased water temperatures could benefit species like smallmouth bass.

Reduced spring runoff flows in the Gunnison River could be detrimental to endangered fish such as Colorado pikeminnow and razorback sucker, since their spawn is associated with the spring runoff. Flow recommendations concerning the magnitude, duration and timing of peak flows are typically made for geomorphic purposes. Geomorphic processes are important for maintaining preferred habitats during the low flow period, but base flows are high in the Gunnison. Spring flow recommendations to ensure that geomorphic functions and processes remain intact need to be crafted in context with the existing base flow regimen. Spring flow recommendations are clearly desirable if reproduction or recruitment of endangered or other native fish is affected in poor runoff years. It appeared that bluehead sucker had improved recruitment during normal (> 4,000 cfs) runoff years on the Gunnison.

Dolores River

The fish data on the Dolores River demonstrate that roundtail chub and flannelmouth sucker can survive and adjust to low-flow conditions over the long term, albeit in very low abundance. Bluehead sucker, however, only barely survived the recent drought and further surveys are needed immediately to establish the status of this species.

The Dolores River has been heavily diverted since 1886 (Vandas et al. 1990). The small size of flannelmouth sucker, bluehead sucker and roundtail chub at Big Gypsum may be adaptations by the native fish to the existing habitat conditions. Endangered Colorado pikeminnow and razorback sucker have not been observed in the Dolores River above Gateway or in other low-flow rivers.

The lack of runoff flows in the Dolores River has had geomorphic consequences. Large sedimentation deposits had accumulated at Big Gypsum in 2004. The large spring runoff of 2005 then scoured these deposition sites. Although there was evidence of roundtail chub and flannelmouth sucker recruitment even during years of low spring runoff, there was no evidence of bluehead sucker recruitment in 2004 or 2005.

CONCLUSIONS

Based on the data reported here, we have found that maintaining adequate base flows is the highest priority for sustaining a thriving native fish community, especially when negative impacts of nonnative fish introductions intensify. Native fish abundance (density and biomass) was much greater in the high base flow Colorado and Gunnison rivers than in the Yampa and Dolores rivers. Our habitat modeling determined that most extant native fish (bluehead sucker, flannelmouth sucker, speckled dace and roundtail chub) prefer habitats with moderate to swiftly flowing currents. Even roundtail chub, which occupies pool habitats during the day, had its highest biomass in the Gunnison River where they occupied eddy pools. Availability of preferred habitat was directly and significantly related to base flow volume.

The Yampa River, with its low base flows, had lower native fish abundance than the Colorado River and abundance decreased in years following a long term drought. Low base flows were associated with low native fish biomass, low availability of native fish habitats and the lack of riffle habitat suitable for invertebrate production.

We found no overt trend in native fish abundance varying with the magnitude or volume of runoff flows, making runoff flows secondary in importance for maintaining native species (flannelmouth sucker, bluehead sucker and roundtail chub). The Colorado River had moderately reduced runoff flows but a near native base flow. The Gunnison River had heavily reduced runoff flows and greatly increased based flows. The Yampa River retains a relatively natural spring runoff but has low base flows. The Dolores River has low runoff and base flows relative to natural conditions.

Increased abundance in nonnative species was usually associated with declines in the native species assemblage. The impacts of nonnative species were high to moderate in all study rivers. Channel catfish and carp were the most common nonnative species (fish > 15 cm TL) in the Colorado River, but these species did not have substantial habitat overlap with the extant native species during normal base flows. Channel catfish and carp were also the most common nonnative fish at Big Gypsum in the Dolores River, but we consider these impacts on native species to have been secondary to the impacts of low flows. White sucker and carp were the most common nonnative fish in the Gunnison River. White sucker is a high-impact species because of hybridization with native sucker. Smallmouth bass is another species with high negative impacts on native fish. The Yampa River had very high abundance of both white sucker and smallmouth bass at Seven and Duffy. Channel catfish and smallmouth bass were abundant at Lily Park.

Among different species habitats, we found that bluehead sucker habitat was the most indicative for the habitat needs of the native fish assemblage overall. An abundant bluehead sucker population, composing about 25 percent of adult fish (> 15 cm) and about 15 percent of the total biomass, indicated that medi-riffle habitat was common. The availability of medi-riffle habitat was also associated with peaking habitat diversity, based on the Shannon diversity index.

We validated the assumption that flows suitable for adult bluehead sucker are also suitable for adult flannelmouth sucker using the 2D habitat analysis. Flannelmouth sucker were usually the most common native species collected. When bluehead sucker habitat and numbers were adequate, flannelmouth sucker habitat and numbers were high.

We confirmed the assumption that flows suitable for adult bluehead sucker are also suitable for speckled dace by electrofishing under a wide range of base flow regimes. Speckled dace occupy shallower riffles than do adult bluehead sucker. In rivers where bluehead sucker were common, speckled dace were also common to abundant (the Colorado and Gunnison Rivers). In the Dolores Rivers bluehead sucker were rare but speckled dace were common but in the Yampa River both bluehead sucker and speckled dace were rare.

We also used electrofishing surveys to confirm the assumption that flows suitable for adult bluehead sucker are also suitable for adult roundtail chub. Roundtail chub were common in the high base flow rivers (Gunnison and Colorado) and persisted in low abundance in low base flow rivers (Dolores and Yampa). Roundtail chub were vulnerable to predation and predation impacts appeared heightened during low flow periods. On the Yampa River low base flows may have exacerbated predation impacts on roundtail chub.

The assumption that flows suitable for adult bluehead sucker are also suitable for spawning and YOY life stages of the native fish assemblage also appears valid. High numbers of juvenile native fish were collected in the 15-Mile Reach on the Colorado and at Escalante on the Gunnison, whereas low numbers were collected at Lily Park where bluehead sucker habitat was poor.

We also examined the assumption that flows suitable for adult bluehead sucker are also suitable for endangered adult Colorado pikeminnow and adult razorback sucker. Although these two endangered fish were rarely collected during the study, most of those found occupied habitats that were similar to roundtail chub and flannelmouth sucker habitats. It does not seem reasonable the adult Colorado pikeminnow and razorback sucker would require habitats or flows that are outliers to the natural flow regime. Thus, maintaining of bluehead sucker abundance by maintaining medi-riffle habitats will likely ensure the persistence of the habitat types required by all adult native fish.

For the Colorado, Yampa and Gunnison rivers the 2D modeling analysis indicated adequate bluehead sucker habitat in the flow range of 600 to 1,200 cfs. Base flows in this range appear to be sufficient to maintain bluehead sucker abundance and reduce some of the nonnative fish problems identified with low base flows.

The 2D modeling analysis also validated the relationship between flow and habitat availability. Several other factors are associated with low base flows. Variations in flow also affect water temperature, cover, migration barriers and species interactions such as predation and hybridization. In general these associated factors are less detrimental in higher flow rivers, because native fish are well adapted to exploit swift habitats. During low-flow conditions multiple factors act against the native fish assemblage, because habitats and resources are more limiting. For example, 2002 was the lowest flow year on the Yampa River and appeared to be the year that initiated the wide scale losses in the native fish assemblage upstream of Cross Mountain.

Summary Statements

- Minimum base flows are needed to maintain the existing native fish communities of the Colorado, Gunnison, Yampa and Dolores rivers.
- Base flows are necessary for maintaining adult habitats and invertebrate forage availability.
- Base flows that were too low appeared to exacerbate interaction with nonnative fish, namely, predation and hybridization.
- Smallmouth bass increased on the Yampa River during the drought period.
- Runoff flows were not correlated with native fish abundance.
- For community persistence base flows should therefore be a higher priority over runoff flows.
- Spring runoff flows may be important for reproductive success of certain native species.
- In the short term the reduced spring runoff flow may have less negative impacts on native fish than reduced base flows.
- Bluehead sucker abundance is a very good indicator of riffle habitat availability.
- Bluehead sucker reproductive success may be related to spring runoff flows.
- White sucker have had severe negative impacts on native sucker.
- Bluehead sucker should be the primary indicator species for biologically based instream flow recommendations.

- Flannelmouth sucker appeared capable of tolerating periods of reduced flows better than bluehead sucker, because of basic differences in habitat requirements between the two species.

- Roundtail chub was not a good indicator species for making instream flow recommendations because of its habitat use and predatory foraging behavior.

- Roundtail chub were highly resistant to flow reductions, but vulnerable to predation by nonnative species (northern pike and smallmouth bass).

- Colorado pikeminnow is not a good indicator species for instream flow recommendations because of its habitat use and predatory foraging behavior.

- The abundance of white sucker increased in an upstream direction in the Colorado, Gunnison and Yampa Rivers.

- The abundance of white sucker may be related to water temperatures.

- Channel catfish were not collected in the Gunnison, which indicated the Redlands Diversion Dam has blocked their migration.

- Low head dams may be an effective method for controling channel catfish.

- One of the more insidious impacts of the drought has been the recent explosion in crayfish at the Duffy site on the Yampa River.

We employed 2D modeling to develop habitat suitability criteria for two native sucker species: flannelmouth and bluehead sucker. Our methods and results appeared in Anderson and Stewart (2003) and this report. The analysis yielded significant correlations between habitat availability and flannelmouth and bluehead sucker biomass. The relationship between discharge and projected biomass (optimal habitat) was the primary tool for making biologically based instream flow recommendations. The inflection point of the biomass-to-discharge relationship determined the recommended instream flow.

Yampa River

Flow and Habitat Relationships

The inflection point of the discharge-to-biomass relationship for bluehead sucker at Lily Park and Sevens was at 600 cfs, an inflection point could not be determined for Duffy (Figure II-5). The analysis modeled Duffy flows to 600 cfs and Sevens flows to 880 cfs. The biomass curves for bluehead sucker at Duffy and Sevens were very similar at flows less than 600 cfs. When the 2D modeling was contracted in 2001, we believed that 600 cfs would be a reasonable upper limit for the flow simulations, because that limit was well above the usual base flow regime of about 250 cfs and a previous instream flow study recommended 93 cfs for the instream flow (Modde et al. 1999). Our modeling added simulations up to 2,000 cfs in 2004 for Lily Park, but additional simulations were not run for Duffy and Sevens.

Bluehead sucker biomass maximized at flows near 1,400 cfs at Lily Park. A flow of 600 cfs provided about 80 percent of maximum bluehead sucker biomass at Lily Park and at Sevens (Figure II-6). A flow of 800 cfs is necessary to provide 85 percent of maximum bluehead sucker biomass at Lily

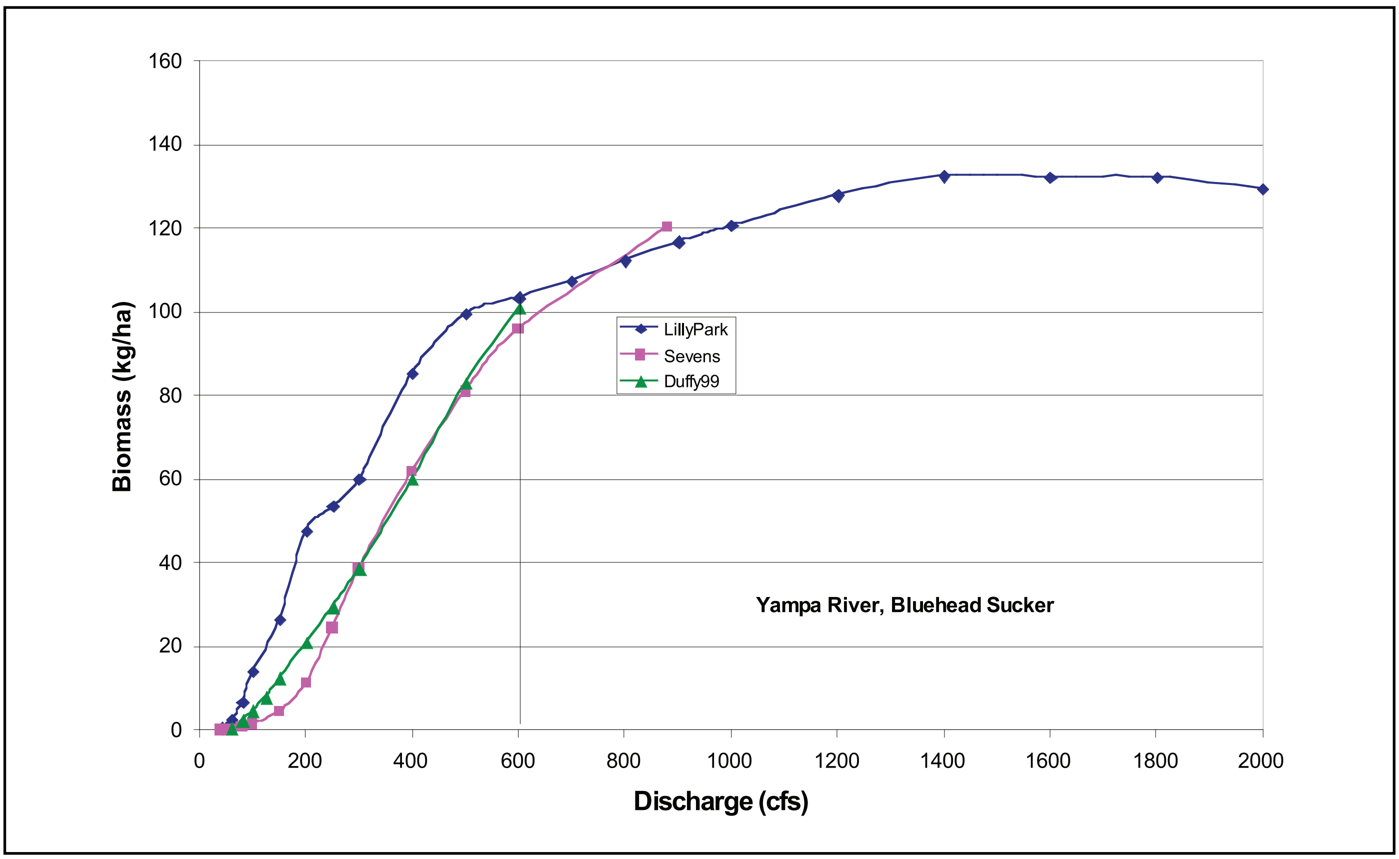

FIGURE II-5. Modeled biomass (kg/ha) of bluehead sucker as a function of discharge, Duffy, Sevens and Lily Park, Yampa River.

Park. The typical base flows of 250 cfs provided about 20 percent of maximum at Sevens and 40 percent of maximum at Lily Park. Flows of 100 cfs provided only 1 percent of the maximum bluehead sucker biomass at Sevens and 14 percent at Lily Park.

The bluehead sucker biomass curve (Figure II-5) was consistent with our sampling data. Bluehead sucker biomass was higher at Lily Park than at Sevens and Duffy in the flow range below 250 cfs (Table II-2). Lily Park and Corn Lake on the Colorado River (Figure II-9) had similar bluehead sucker biomass projection curves of about 120 kg/ha at 1,000 cfs. These curves indicate that Lily Park and Corn Lake would have similar bluehead sucker biomass given similar base flow regimes. Lily Park (at 250 cfs) had about 30 percent of the bluehead sucker biomass of Corn Lake (at 1000 cfs) (Table II-2).

For flannelmouth sucker the discharge-to-biomass inflection point at Lily Park was at 700 cfs (Figure II-7). The Duffy and Sevens inflection points were likely higher than the highest simulated flow. Flannelmouth sucker biomass peaked at 1,400 cfs at Lily Park. The modeling shows a steep decline in biomass at flows less than 600 cfs. Modeled base flows of near 250 cfs yielded a flannelmouth sucker biomass of about 100 kg/ha at Lily Park and Sevens. At 150 cfs modeled biomass was only 15 kg/ha at Sevens and 5 kg/ha at Duffy.

Discharge at 700 cfs (the inflection point flow for Lily Park) provided about 78 percent of the maximum modeled flannelmouth sucker biomass (Figure II-8). Base flows of 700 cfs or higher have not been available for the Yampa River. Typical base flows have been about 250 cfs during the winter but much less in the irrigation period. Both the measured and the modeled biomass of flannelmouth sucker were substantially lower under a base flow regime below 150 cfs.

Base Flow Recommendation

Based on the 2D modeling results above, our instream flow recommendation for the Yampa River from the Little Snake River confluence upstream to the town of Craig is 650 cfs. The 650 cfs

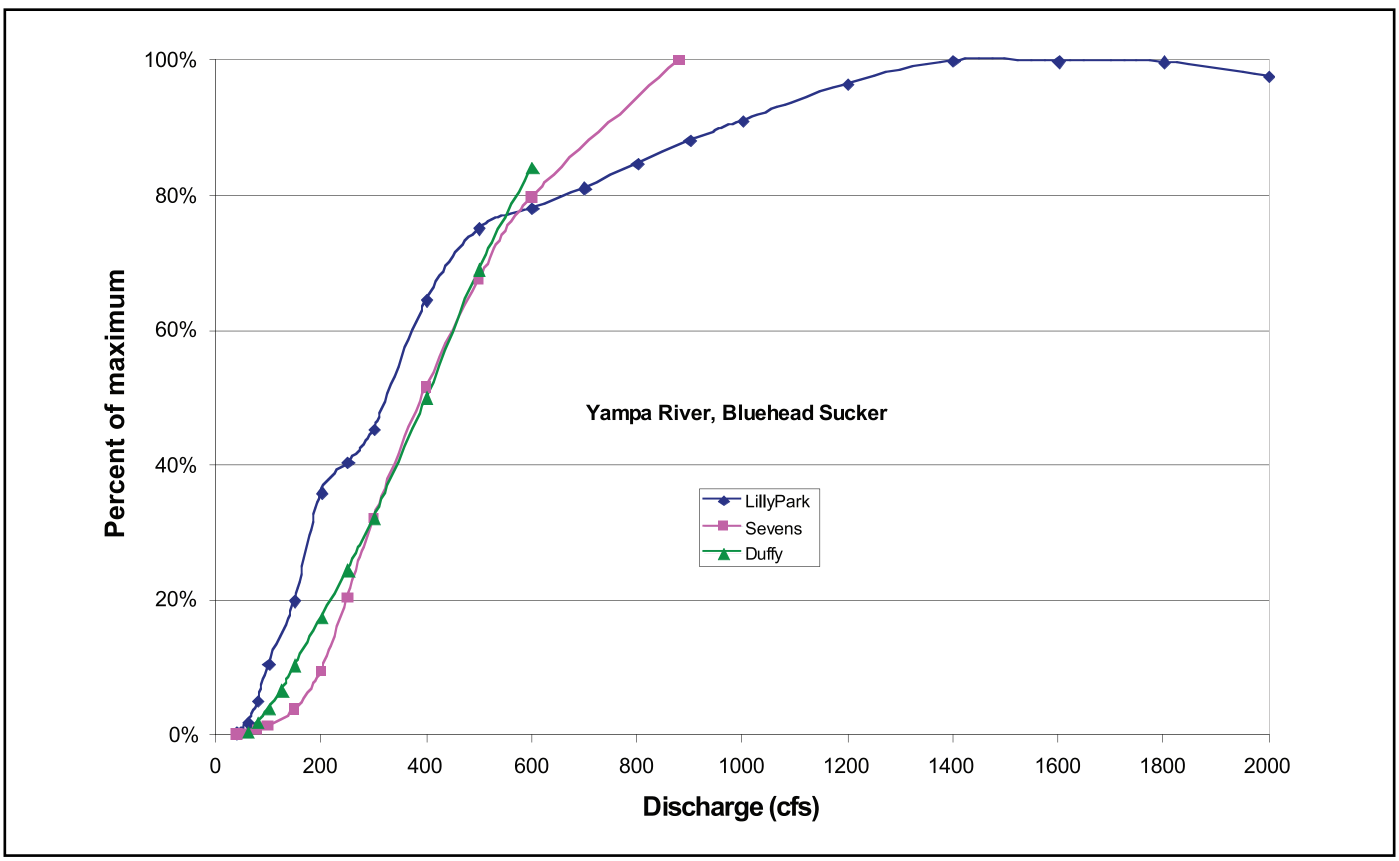

FIGURE II-6. Percent of modeled maximum biomass (kg/ha) of bluehead sucker as a function of discharge at Duffy, Sevens and Lily Park, Yampa River.

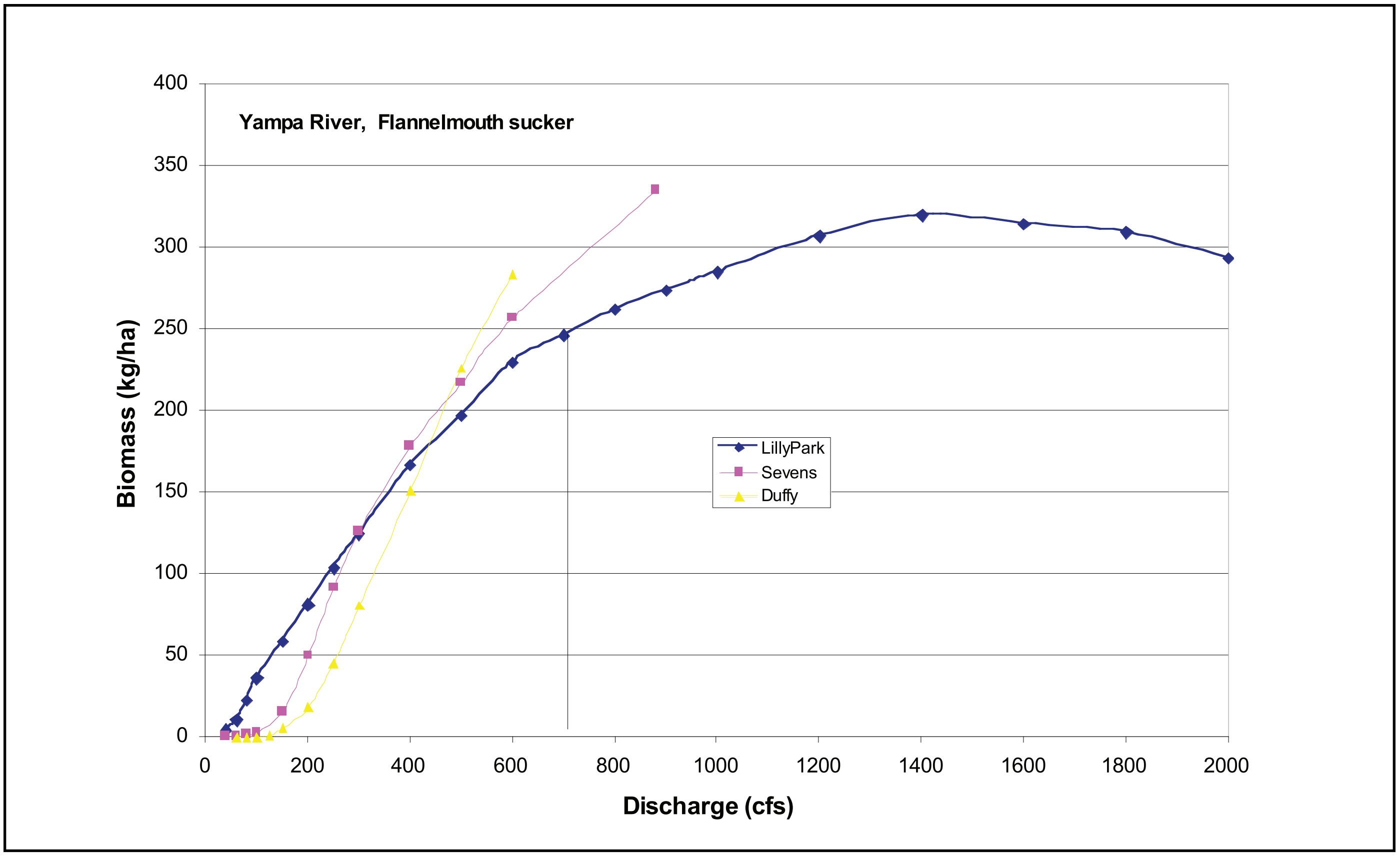

FIGURE II-7. Modeled biomass (kg/ha) of flannelmouth sucker as a function of discharge at Duffy, Sevens and Lily Park, Yampa River.

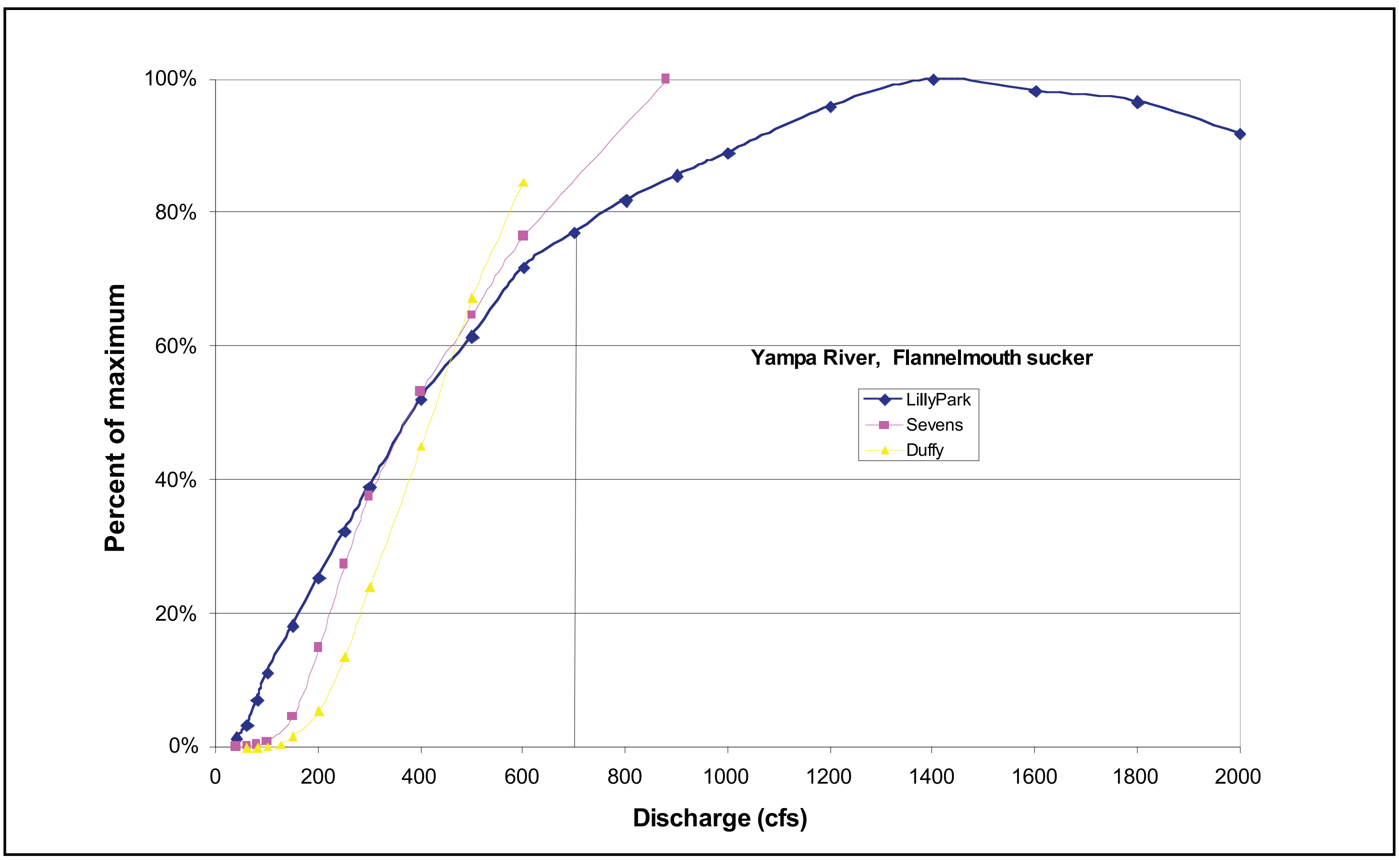

FIGURE II-8. Percent of maximum modeled biomass (kg/ha)of flannelmouth sucker as a function of discharge at Duffy, Sevens and Lily Park, Yampa River.

recommendation is the average of the inflection points for the curves representing bluehead and flannelmouth sucker biomass as a function of discharge. Nevertheless, the 650 cfs recommendation is not realistic for the Yampa because of the lack of available water. We make the 650 cfs recommendation as a formality, since it is necessary to maintain consistency when using an instream flow methodology.

Population sampling in the Yampa River has documented that the post-1999 base flow regimes were not adequate to sustain the native fish assemblage. The base flow regime before 1999 was more conducive to sustaining native fish abundance and species. Prior to 1999 typical summer/fall base flows were near 250 to 300 cfs with minimum flow of at least 200 cfs. The fish data suggests that a reasonable minimum flow recommendation is at least 200 cfs.

Spring and Channel Maintenance Flow Recommendations

We did not formulate spring flow recommendations as part of this analysis. Maintaining high spring flows appears to be important for native fish management in the lower Yampa River (Dinosaur Canyon), however, and for mitigating altered flows from the Green River. Bestgen et al. (1998) concluded that moderate spring flows produce the largest Colorado pikeminnow YOY numbers. Maintaining high spring flows in the Yampa upstream of Cross Mountain Canyon has not been associated with maintenance of the native fish assemblage in that river reach. In fact, bank instability appears to be a problem in the upper Yampa River (Richard and Anderson 2006) and high spring flows may be exacerbating bank erosion.

Bankfull flows are directly related to sediment transport and therefore channel maintenance. Channel maintenance flows are necessary to maintain channel geomorphology and habitats used by fish during base flow periods. Andrews (1980) determined bankfull flow to be about 9,000 cfs for the Yampa River near the Maybell gage. Richard and Anderson (2006) identified bankfull flow of 11,100 cfs for Sevens and Lily Park. Flows exceeding 9,000 cfs have occurred in four of the seven years from 1998 to 2004 and flow exceeding 11,100 cfs occurred in only one of those years (Figure A1-1). The Yampa River has had a higher frequency of bankfull flows than the Colorado and Gunnison rivers in recent years. The magnitude, duration and frequency of spring runoff flows do not appear to be a primary limiting factor for the native fish assemblage in the upper reaches of the Yampa River.

At flow less than 500 cfs, the geomorphology of the Yampa River was poor for maintaining fish habitat. A much narrower channel (akin to the Dolores River at Big Gypsum) would be required to provide substantial native sucker habitat in the range of 200 to 250 cfs. Base flows substantially higher then 250 cfs do not currently appear to be a possibility for the Yampa River. Bank stabilization or channel narrowing efforts designed to improve native fish habitat are not highly feasible. Elimination of undesirable nonnative species (smallmouth bass, northern pike, channel catfish and white sucker) would be effective for restoring native fish and some removal efforts are currently under way as part of the Upper Colorado River Recovery Program.

Colorado River

Flow and Habitat Relationships

The inflection point of the discharge-to-biomass relationship for bluehead sucker on the Colorado River was 600 cfs at Clifton and 700 cfs at Corn Lake (Figure II-9). Modeled bluehead sucker biomass peaked at a discharge of 1,000 cfs at Corn Lake and 1,200 cfs at Clifton. The modeled biomass did not increase at flows over 1,200 cfs. Sampled bluehead sucker biomass was not higher in sections of the Colorado River with flows over 1,400 cfs (see the Supplemental Data for Each River section above). Modeled biomass at both sites declined rapidly as flows decrease below 500 cfs (Figure II-9).

At Corn Lake a flow of 700 cfs (inflection point) maintained about 90 percent of the modeled maximum biomass of bluehead sucker (Figure II-10). At Clifton the inflection point flow of 600 cfs maintained 73 percent of the maximum and 800 cfs maintained 85 percent of the maximum. These differences between Corn Lake and Clifton are an artifact of their different channel widths. Corn Lake and Clifton had similar optimal habitat area and

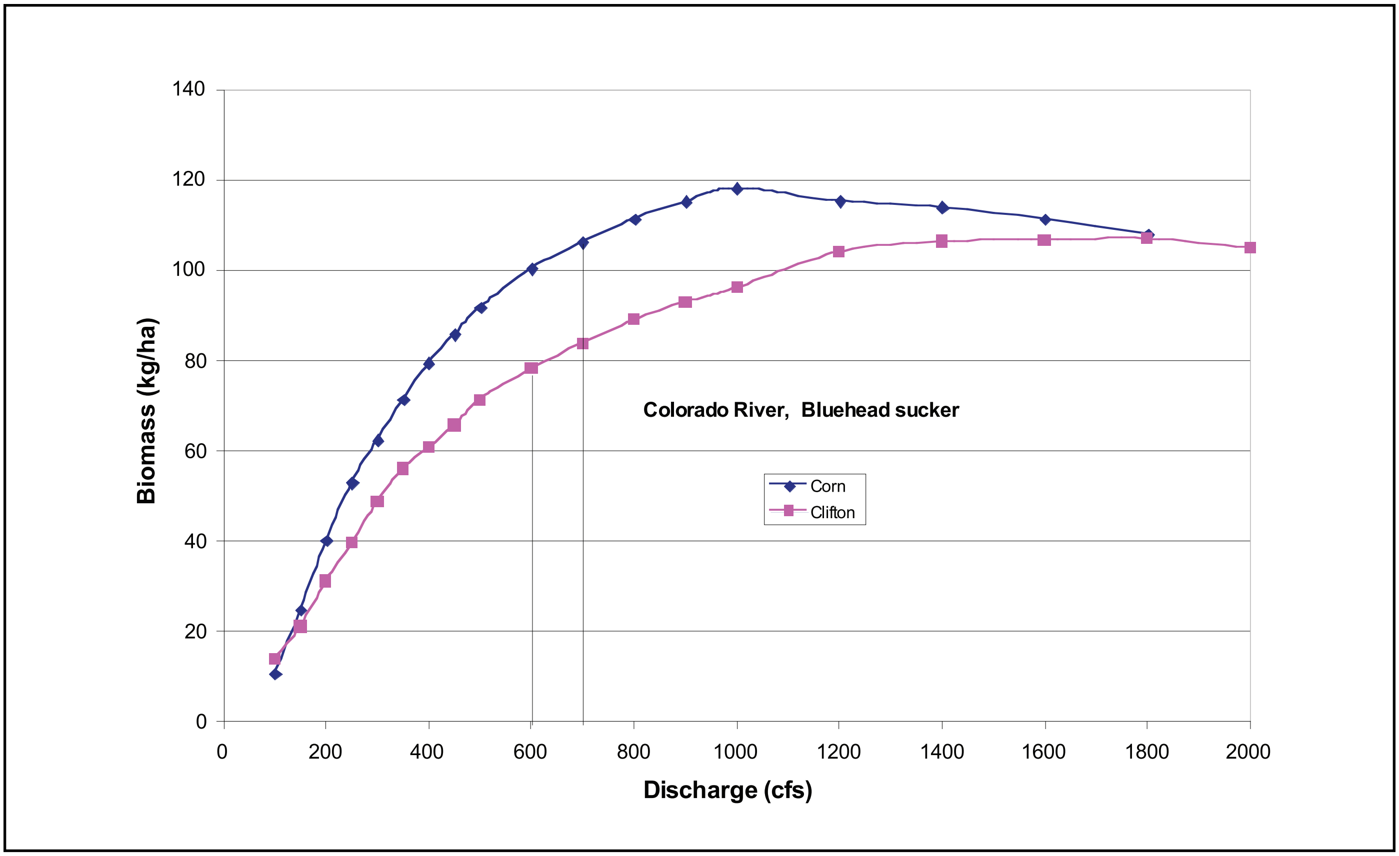

FIGURE II-9. Modeled biomass (kg/ha) of bluehead sucker as a function of discharge at Corn Lake and Clifton, Colorado River.

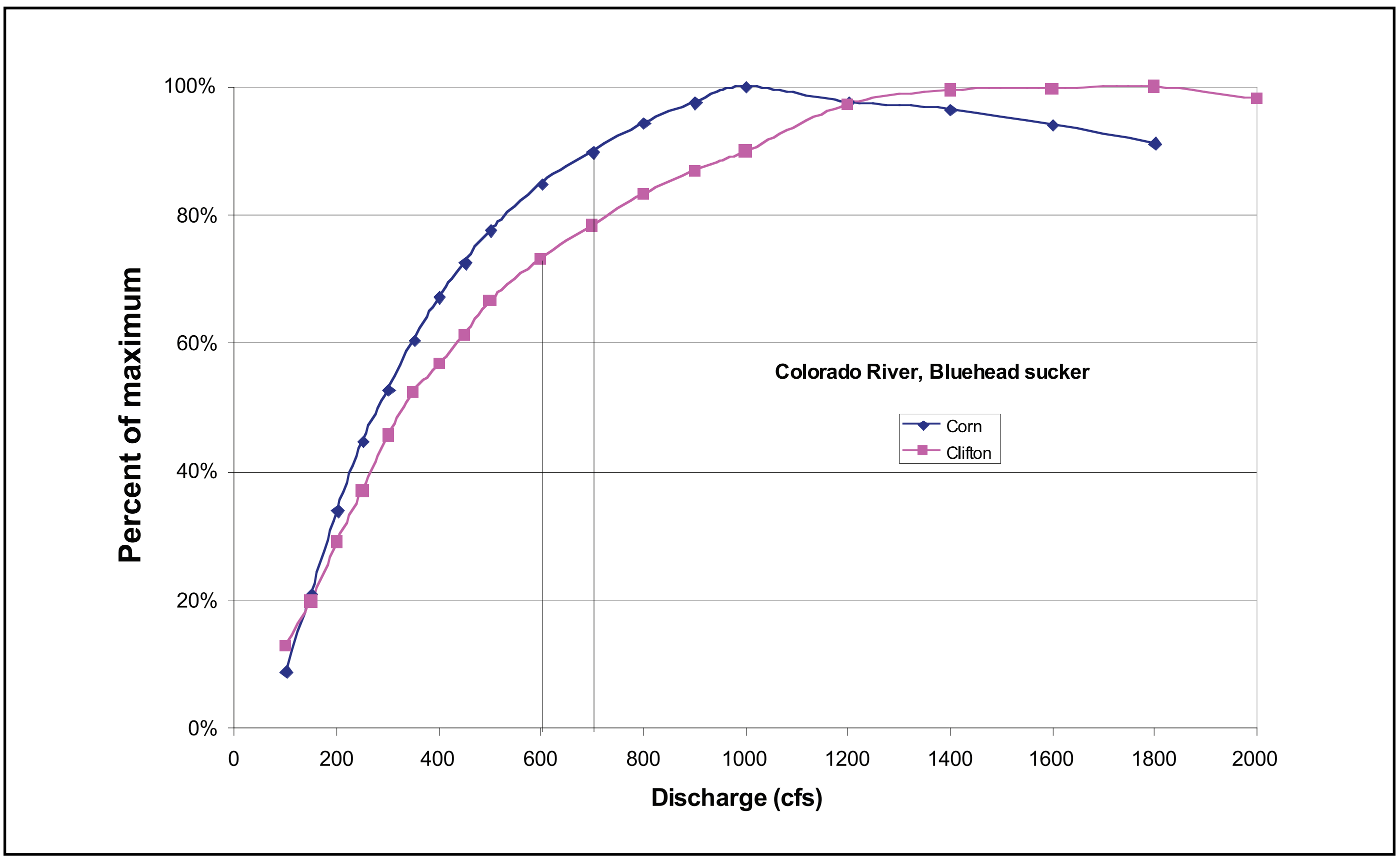

FIGURE II-10. Percent of modeled maximum biomass (kg/ha) of bluehead sucker as a function of discharge at Corn Lake and Clifton, Colorado River.

biomass estimates per distance (km) but not for surface area. Clifton had a wider channel and a larger surface area, so its biomass (kg/ha) was lower than Corn Lake's. The average width of Corn Lake and Clifton was close to the mean width of the 15-Mile Reach overall. Thus, the average of the Corn Lake and Clifton biomass curves is probably the best representation for the reach.

For the flannelmouth sucker in the Colorado the inflection points for the biomass curve were 600 cfs at Corn Lake and 800 cfs at Clifton (Figure II-11). Modeled maximum biomass of flannelmouth was at about 1,000 cfs. Flows above 1,000 cfs did not increase modeled flannelmouth sucker biomass in the 15-Mile Reach (Figure II-12). Sampled flannelmouth sucker biomass was not higher in sections of the Colorado River with higher base flow regimes (see the Supplemental Data section above). Modeled flannelmouth sucker biomass declined sharply as flows declined below 500 cfs.

The inflection point flow of 600 cfs for flannelmouoth sucker at Corn Lake maintained about 85 percent of the modeled maximum biomass (Figure II-12). The 800 cfs inflection point at Clifton maintained about 94 percent of the modeled maximum. Modeled flows of 400 cfs maintained about 60 to 70 percent of the flannelmouth sucker biomass at both sites.

Base Flow Recommendation

Based on the 2D modeling results above, our instream flow recommendation for the 15-Mile Reach of the Colorado River is 700 cfs.

The 700 cfs recommendation was the bluehead sucker inflection point at Corn Lake and the average of the flannelmouth sucker inflection points for the two sites. Typical base flows in the 15-Mile Reach have ranged from 800 cfs to 1,200 cfs. This suggests that the bluehead sucker and flannelmouth sucker biomass estimates made in this flow regime also represent the maximum biomass of these sites. The 700 cfs flow maintained 85 percent of the modeled maximum bluehead sucker biomass and 89 percent of the maximum flannelmouth sucker biomass. Maintenance of 85 percent of the maximum value appears adequate for ensuring the long-term survival of native fish in the 15-Mile Reach.

Base flows in the range of 800 cfs to 1,200 cfs appear to be representative of the natural flow regime (Pitlick 1999). Flows of 800 to 1,000 cfs also have a high habitat diversity rating (Shannon index). The fish surveys in 1999, 2000 and 2001 were in the flow range of 800 to 1,200 cfs. Large numbers of age-1+ native fish were collected at flows of 800 cfs and above (see the CD Appendix –Fish- Histograms). The fish sampling confirmed that a flow of 700 cfs would maintain adequate nursery habitats for native fish species. Typically, fry and nursery habitats availability are expected to be maximized at a lower base flow than that needed for adult fish habitat, since juveniles occupy shallower and lower velocity habitats.

Spring and Channel Maintenance Flow Recommendations

The 2D modeling did not include spring or channel maintenance flow recommendations since there is little promise of relating peak flows or recurrence of bankfull flows with biologically based metrics. Bankfull flows are directly related to sediment transport and therefore channel maintenance. Channel maintenance flows maintain channel geomorphology, which is the template for habitat availability during base flow periods.

Pitlick (1999) identified bankfull flow to be 22,000 cfs for the 15-Mile Reach of the Colorado River. Bankfull flows have not been achieved since 1997 (eight years). In 2002 the mean daily peak flow was 2,780 cfs; in 2004 it was 5,510 cfs. Although the fish collections showed higher recruitment of nonnative fish in years of low peak flows, overt problems with channel morphology or sedimentation were not observed during our fish or habitat surveys in the years of low spring flows.

Recommendations for the magnitude, frequency and duration of spring runoff flows have low potential for implementation and spring flows have been driven almost entirely by snow-pack conditions. As noted earlier, we have concluded that base flows should be a higher priority than spring flows. For these reasons it seems more appropriate to focus on maintaining adequate base flows. Adequate base flows are maintained in the 15-Mile Reach with flows of 700 to 1,200 cfs. Base flows do not need to be in excess of 1,200 cfs. Flows that exceed 1,200

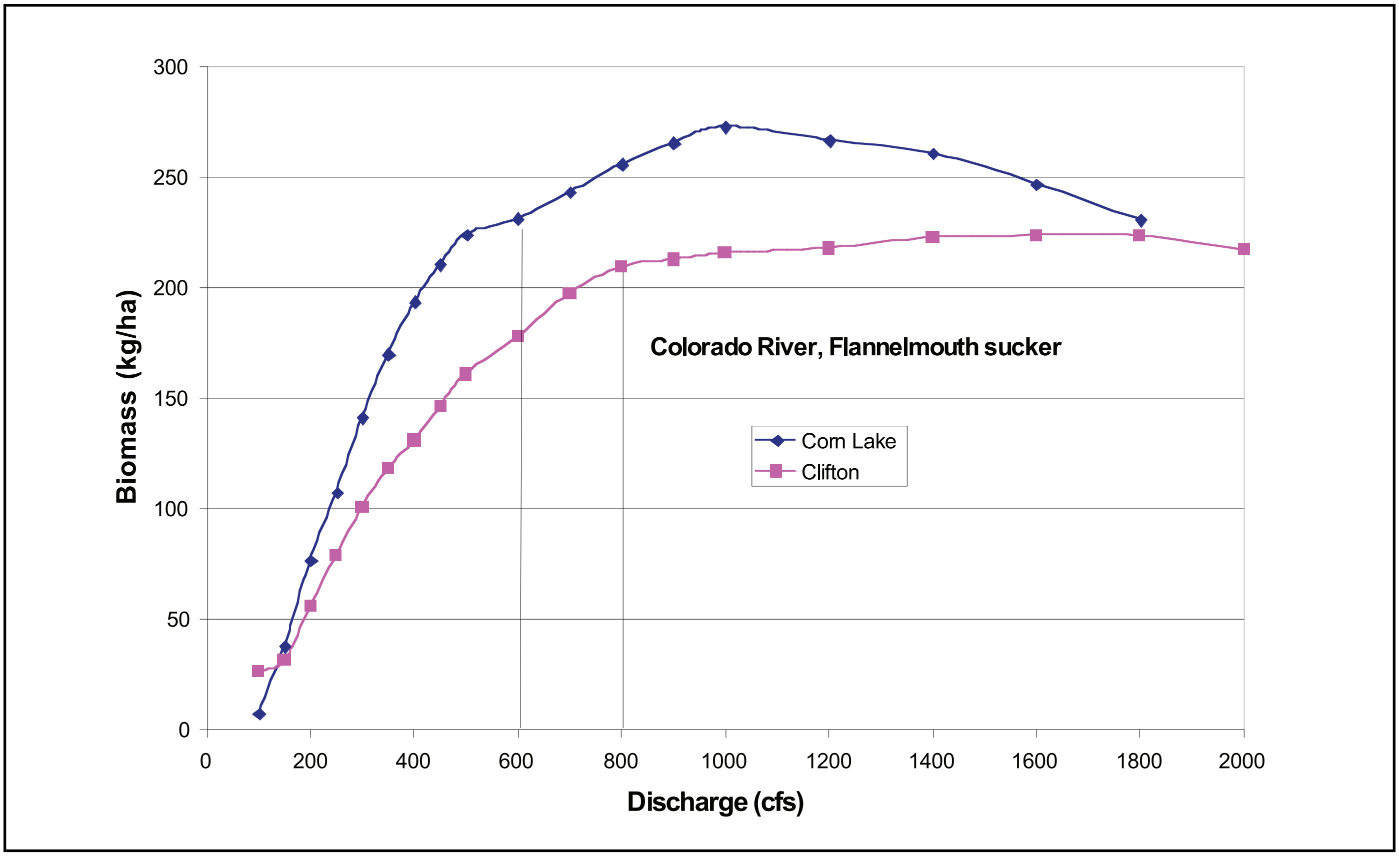

FIGURE II-11. Modeled biomass (kg/ha) of flannelmouth sucker as a function of discharge at Corn Lake and Clifton, Colorado River.

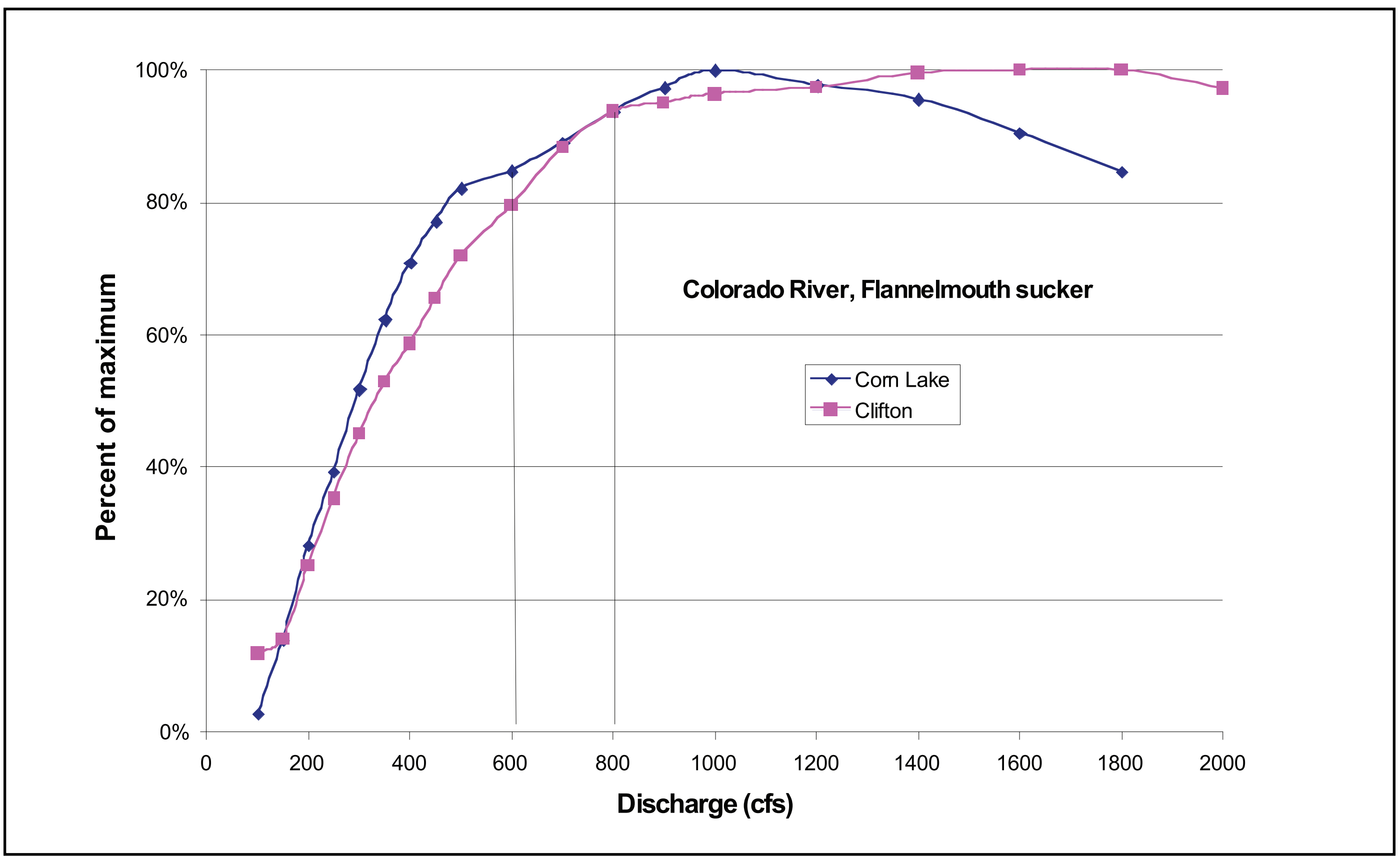

FIGURE II-12. Percentage of modeled maximum biomass (kg/ha) of flannelmouth sucker as a function of discharge at Corn Lake and Clifton, Colorado River.

cfs during the base flow period should be stored for a spring release.

Our spring flow recommendation is to maintain the current 15 year median peak of about 13,000 cfs. We also recommended that biological sampling be conducted to determine relationships between spring flows and biological processes such as reproductive success of native and nonnative fish species. A biological data base is necessary to determine the habitat suitability indices associated with spring flows and, in turn, to model the optimal conditions associated with spring flow regimes.

Gunnison River

Flow and Habitat Relationships

The inflection points of discharge-to-biomass relationships curves for bluehead sucker at both Delta and Escalante were at 600 cfs (Figure II-13). Bluehead sucker biomass peaked at about 1,000 cfs at both study sites on the Gunnison. Flows over 1,200 cfs resulted in decreasing habitat. The curves for both Delta and Escalante dropped sharply as base flows decreased below 400 cfs (Figure II-13).

Maximum bluehead sucker biomass was modeled at flows near 1,000 cfs at both Delta and Escalante. About 95 percent of maximum remained at 700 cfs and 91 percent of maximum remained at 600 cfs (Figure II-14). These findings suggests that base flows of 600 cfs are sufficient for perpetuation of existing bluehead sucker biomass.

For flannelmouth sucker the inflection points for the discharge-to-biomass curve was at 600 cfs at Delta and Escalante (Figure II-15). Flannelmouth sucker projected biomass peaked between 600 to 800 cfs at Delta and between 1,000 to 1,400 cfs at Escalante. The flannelmouth sucker curves indicated reduced abundance when flows exceed 1,000 cfs at Delta and 1,400 cfs at Escalante. Modeled flannelmouth sucker abundance dropped sharply when flows are less than 400 cfs (Figure II-15).

The projected maximum flannelmouth sucker biomass peaked near 800 cfs at Delta and 1,200 cfs at Escalante (Figure II-16). At 600 cfs about 98 percent of maximum biomass was retained at Delta and 87 percent persisted at Escalante. This modeling

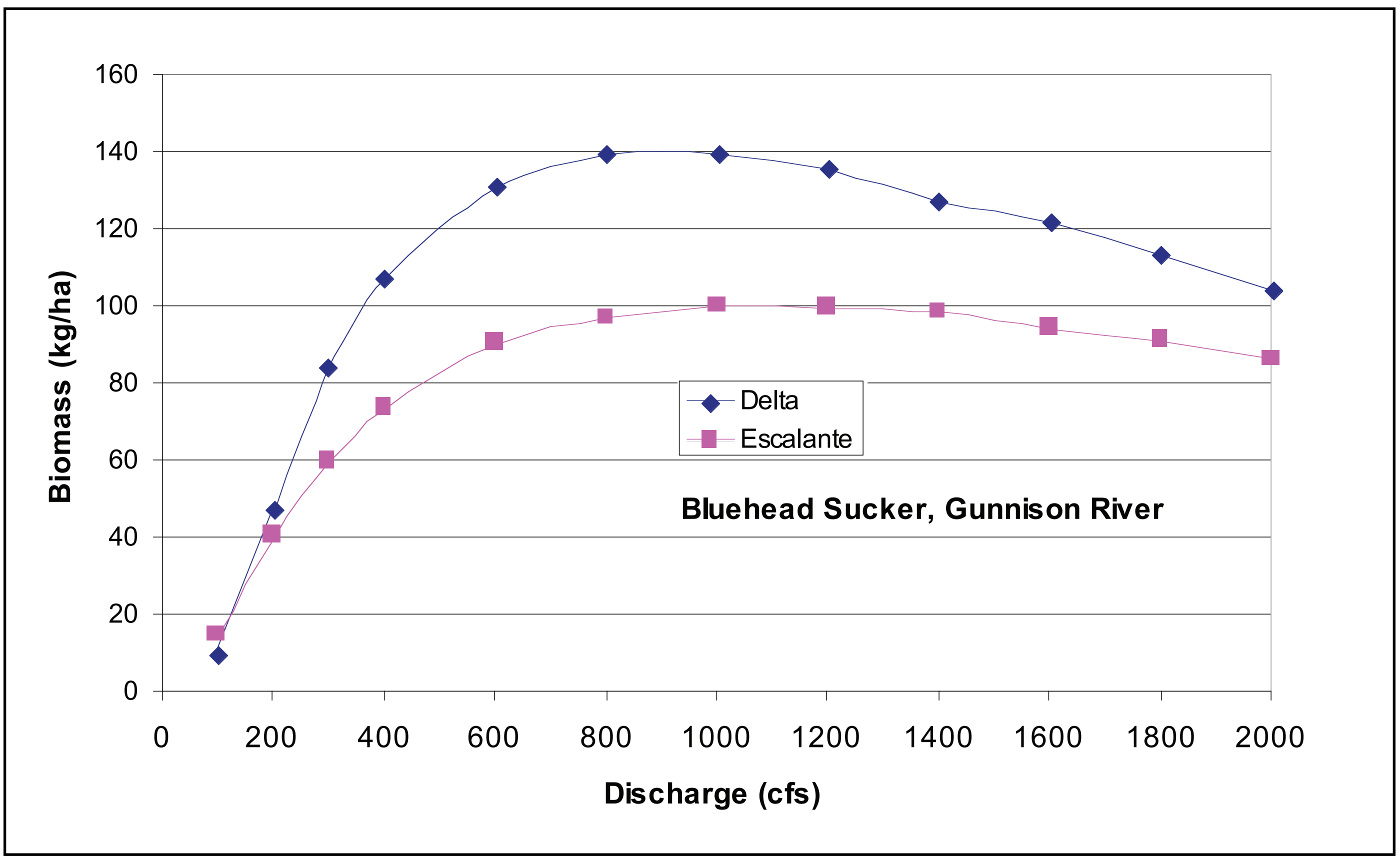

FIGURE II-13. Modeled biomass (kg/ha) of bluehead sucker as a function of dischargeat Delta and Escalante, Gunnison River.

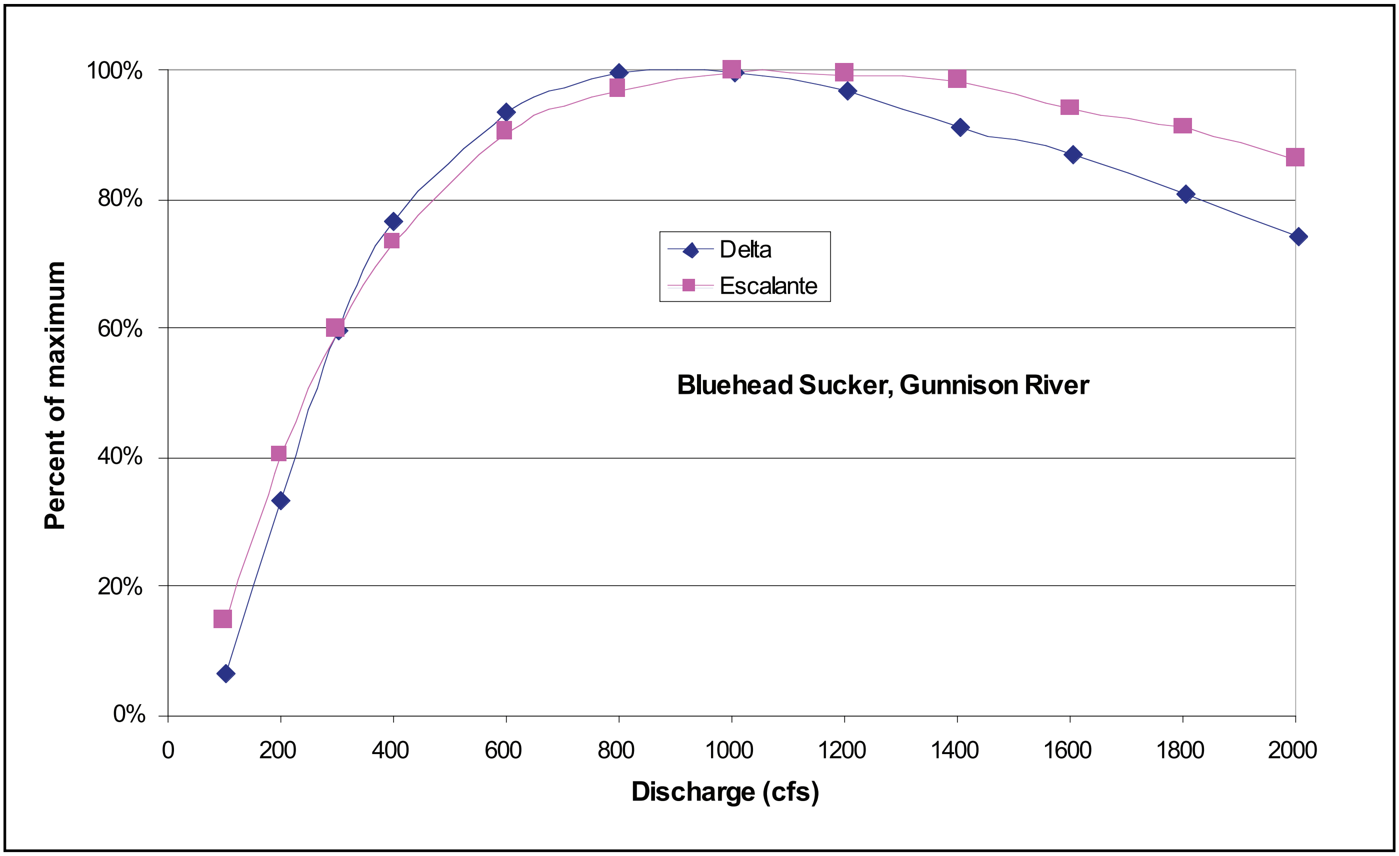

FIGURE II-14. Percentage of modeled maximum biomass (kg/ha) of bluehead sucker as a function of discharge at Delta and Escalante, Gunnison River.

identified that a 600 cfs base flow regime is sufficient to maintain existing flannelmouth sucker biomass.

Base Flow Recommendation

Based on the 2D modeling results above, our instream flow recommendation for the Gunnison River from its Colorado River confluence upstream to the town of Delta is 600 cfs.

The recommendations of 600 cfs represents the inflection points for bluehead and flannelmouth sucker biomass as a function of discharge at both study sites on the Gunnison. The 2D modeling indicated that about 90 percent of the projected maximum bluehead and flannelmouth sucker biomass would be maintained at 600 cfs.

The 600 cfs recommendation is supported by the Shannon habitat diversity values, which were highest at flows of 600 to 800 cfs. The maximum Shannon diversity suggests that the habitat types required by other species and by younger life stages of native species would also be available at a 600 cfs base flow (Anderson and Stewart 2006).

The fish surveys in 2004 and 2005 empirically determined that fry and juvenile native fish were common at the base flows in those years, 900 to 1,200 cfs. Typically, fry and nursery habitat availability are expected to maximize at lower base flows than those maximizing adult fish, because juveniles prefer shallow low-velocity habitats.

Spring and Channel Maintenance Flow Recommendations

Again, the 2D modeling did not include developing a spring or channel maintenance flow because there is little promise of relating peak flows or recurrence of bankfull flows with biologically based metrics. Bankfull flows are directly related to sediment transport and therefore channel maintenance. Channel maintenance flows are necessary to maintain channel geomorphology and habitats used by fish during base flow periods.

Pitlick (1999) identified bankfull flow on the Gunnison River to be 14,500 cfs, but flows have not

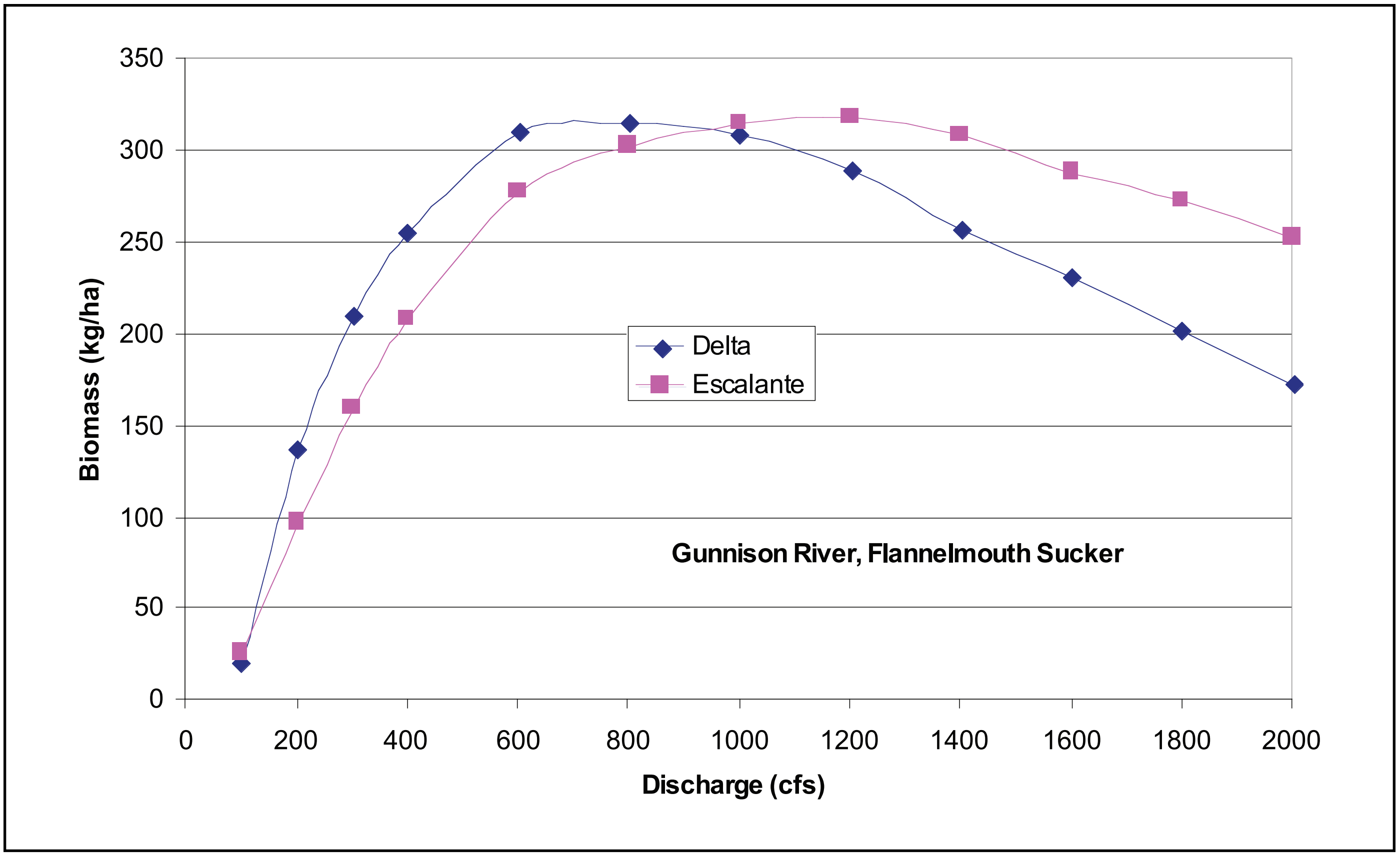

FIGURE II-15. Modeled biomass (kg/ha) of flannelmouth sucker as a function of discharge at Delta and Escalante, Gunnison River.

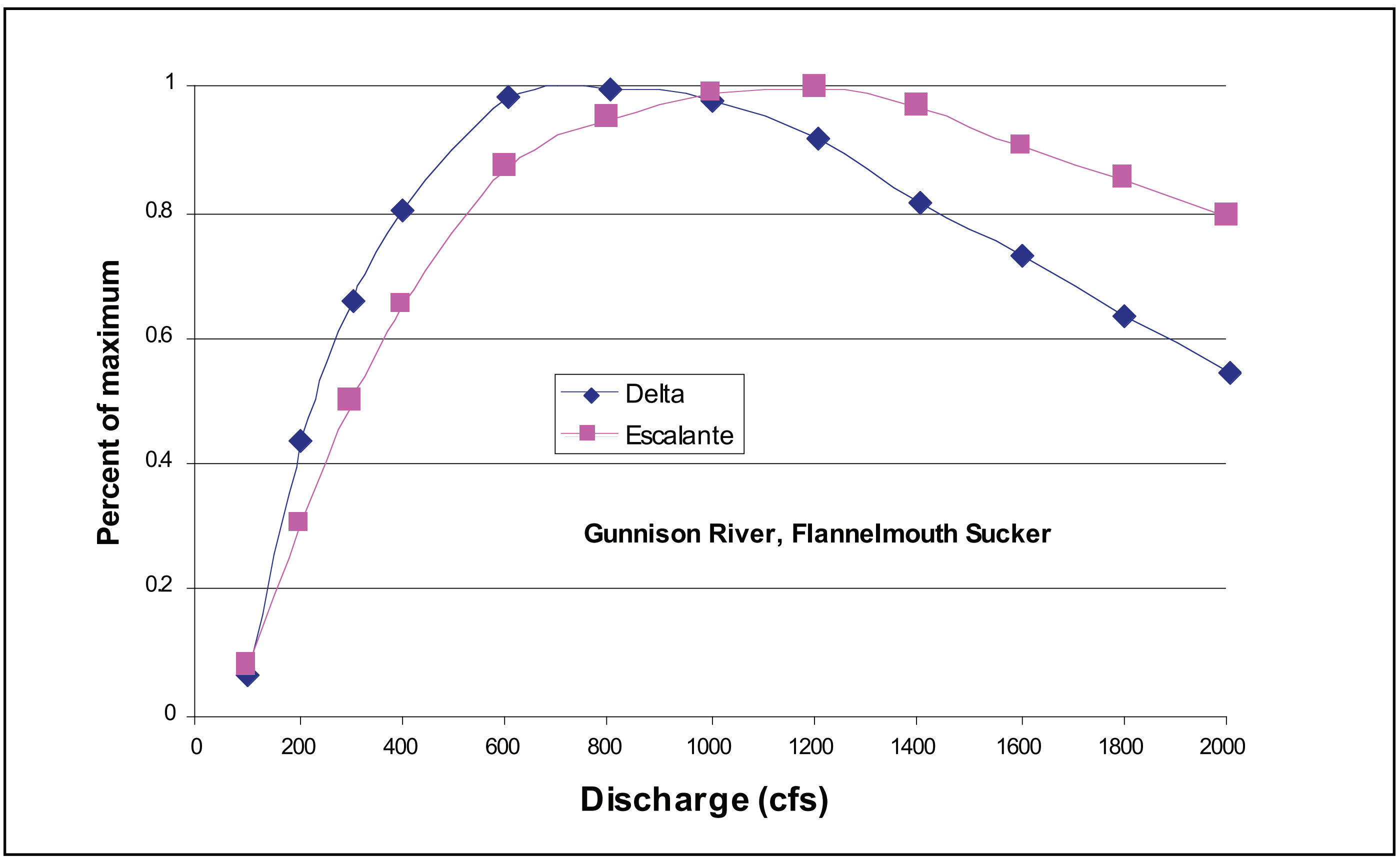

FIGURE II-16. Percentage of modeled maximum biomass (kg/ha) of flannelmouth sucker as a function of dischargeat Delta and Escalante, Gunnison River.

been that high since 1995. In 2002 the mean daily peak was flow was 1,464 cfs, in 2004 it was 2,769 cfs. Reduced reproductive success for native species is a potential negative consequence in years with low runoff flows. Two or more consecutive years of low spring flows could negatively impact native sucker biomass. The lack of flushing flows in 2002 and 2004 did not appear to result in negative impacts to channel geomorphology. Field crews did not notice excessive sedimentation or channel deterioration during the 2003, 2004 and 2005 fish and habitat surveys.

Since 1965 the mean annual peak on the Gunnison has been about 6,000 cfs. If 6,000 cfs has been functional for sediment transport equilibrium in the last 40 years, it should continue to be functional in the future. Base flows have been quite high since 1965 (1,000 to 1,200 cfs), however, these flows are certainly capable of transporting fine sediment from riffles and runs. Spring runoff or flushing flows may need to be higher than 6,000 cfs to maintain current sediment transport rates if the base flow regime drops to 600 cfs or less.

Our recommendation is to strive to maintain an average peak of 6,000 cfs for a spring peak flow. Sediment transport studies are necessary to determine accurate sediment transport rates under the current hydrograph and potentially altered hydrographs.

Dolores River

Flow and Habitat Relationships

At Big Gypsum the discharge-to-biomass inflection point for bluehead sucker was 300 cfs (Figure II-17). Bluehead sucker biomass was still increasing at the highest modeled flow of 500 cfs. Modeled bluehead sucker biomass fell sharply as flows decreased below 100 cfs.

The modeled maximum for bluehead sucker biomass was at the highest modeled flow of 500 cfs (Figure II-18). About 85 percent of maximum biomass was available at 300 cfs and 68 percent of maximum biomass remained at 200 cfs. Outlet flows from McPhee Dam normally range from 25 to 60 cfs. Only one percent of the bluehead sucker

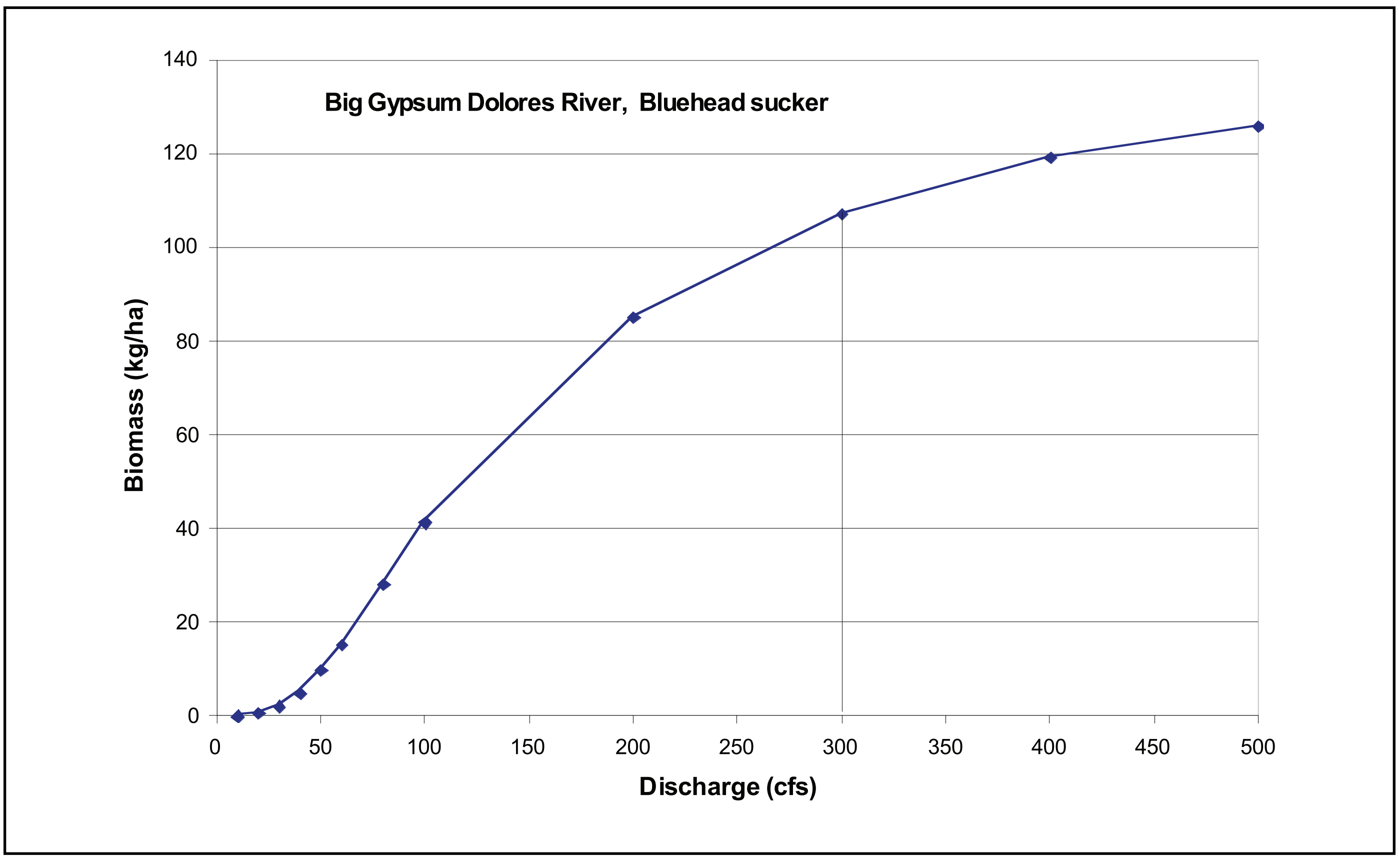

FIGURE II-17. Modeled biomass (kg/ha) of bluehead sucker as a function of discharge at Big Gypsum, Dolores River.

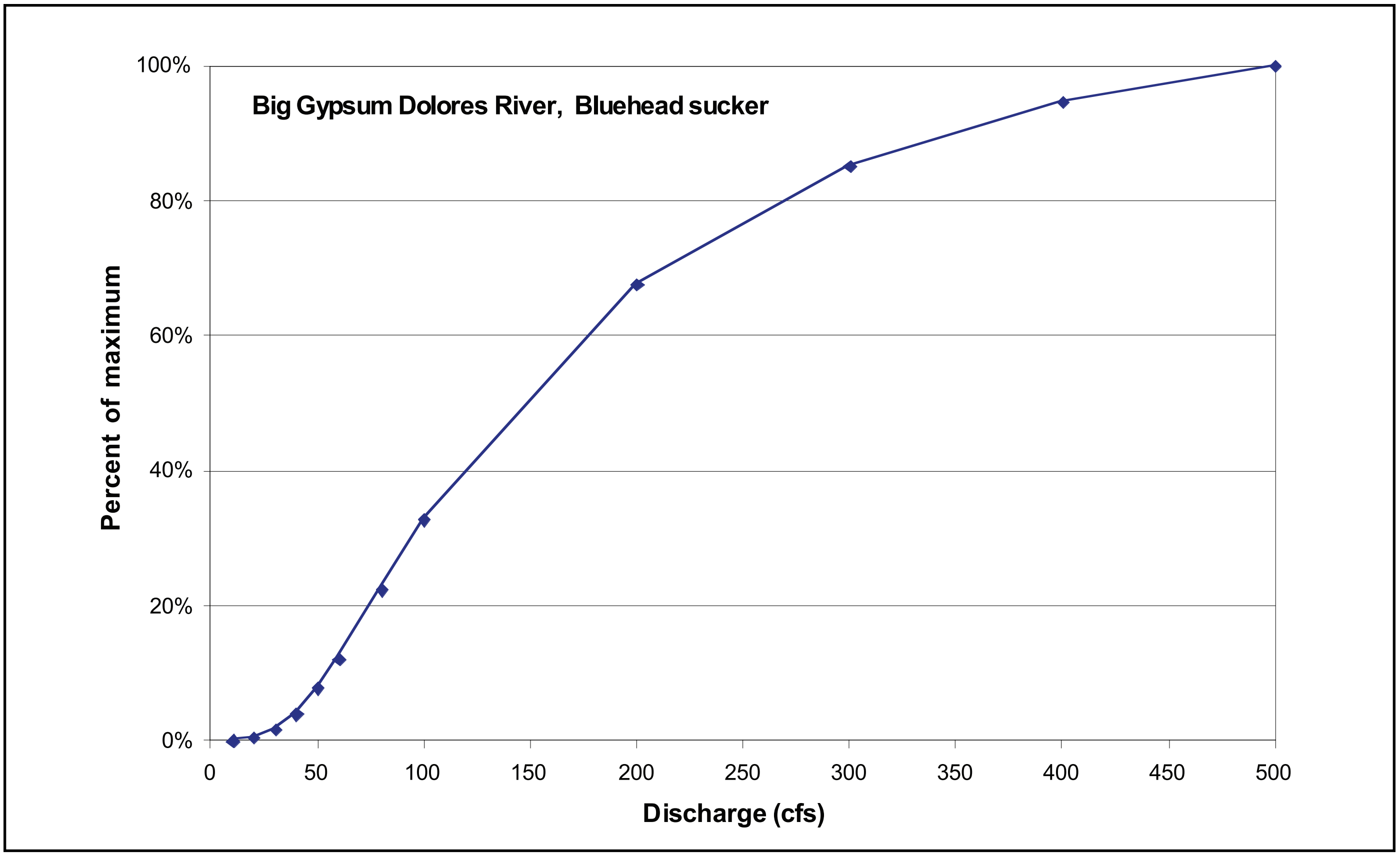

FIGURE II-18. Percentage of modeled maximum biomass (kg/ha) of bluehead sucker as a function of discharge at Big Gypsum, Dolores River.

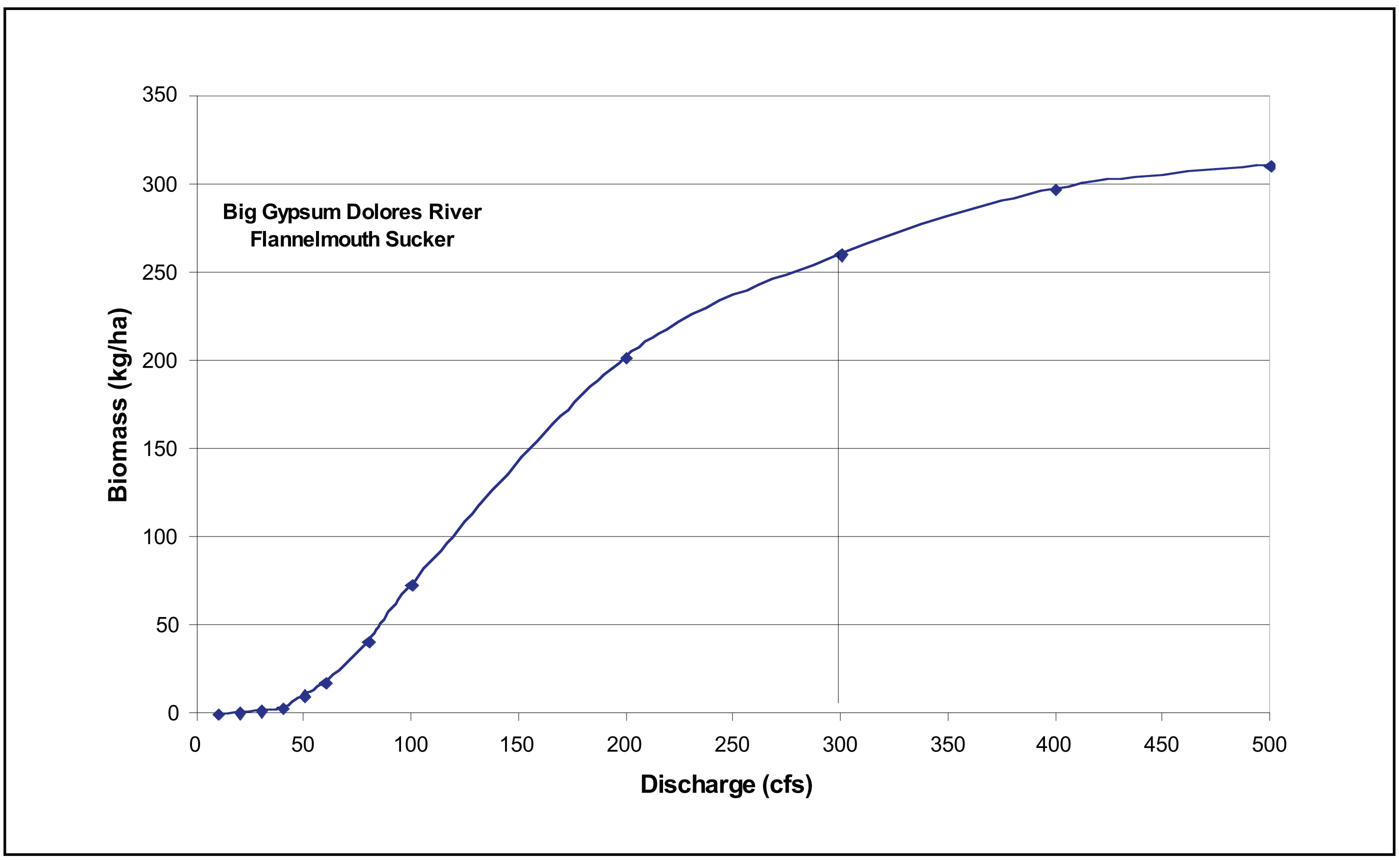

FIGURE II-19. Modeled biomass (kg/ha) of flannelmouth sucker as a function of discharge at Big Gypsum, Dolores River.

biomass maximum remained at 25 cfs and 12 percent remained at 60 cfs. Measured bluehead sucker biomass at Big Gypsum was very poor in all sample years, but it was extremely low in years after 2002, the severest year of the drought.

The inflection point for the flannelmouth sucker biomass curve was at 300 cfs (Figure II-19). The projected maximum biomass for flannelmouth was at the highest modeled flow of 500 cfs. Projected flannelmouth sucker biomass dropped sharply when flows fell below 100 cfs.

The modeled maximum biomass for flannelmouth sucker peaked at 500 cfs at Big Gypsum. At 300 cfs about 85 percent of maximum biomass was retained (Figure II-20). The modeling indicated that flannelmouth sucker habitat is severely limited at base flows less than 60 cfs at Big Gypsum. The electrofishing surveys found that flannelmouth sucker biomass was in fact very poor in all years of the survey.

Base Flow Recommendation

Based on the 2D modeling results above, our instream flow recommendation for the Dolores River from the San Miguel confluence upstream to the Disappointment Creek confluence is 300 cfs.

The recommendation is not a possibility for an instream flow downstream of McPhee dam because of historic diversions and current water availability. Current releases from McPhee reservoir are consistent with its operational plans and constraints. The habitat modeling indicates that flows near 300 cfs are required to produce a native fish assemblage biomass comparable in biomass to those currently occupying the Colorado River in the 15-Mile Reach and the Gunnison River between Delta and Whitewater. (The Colorado and Gunnison are rivers that appear to be most representative of naturally occurring standing stocks of native sucker.) The 2D modeling effort clearly identifies low flows as the

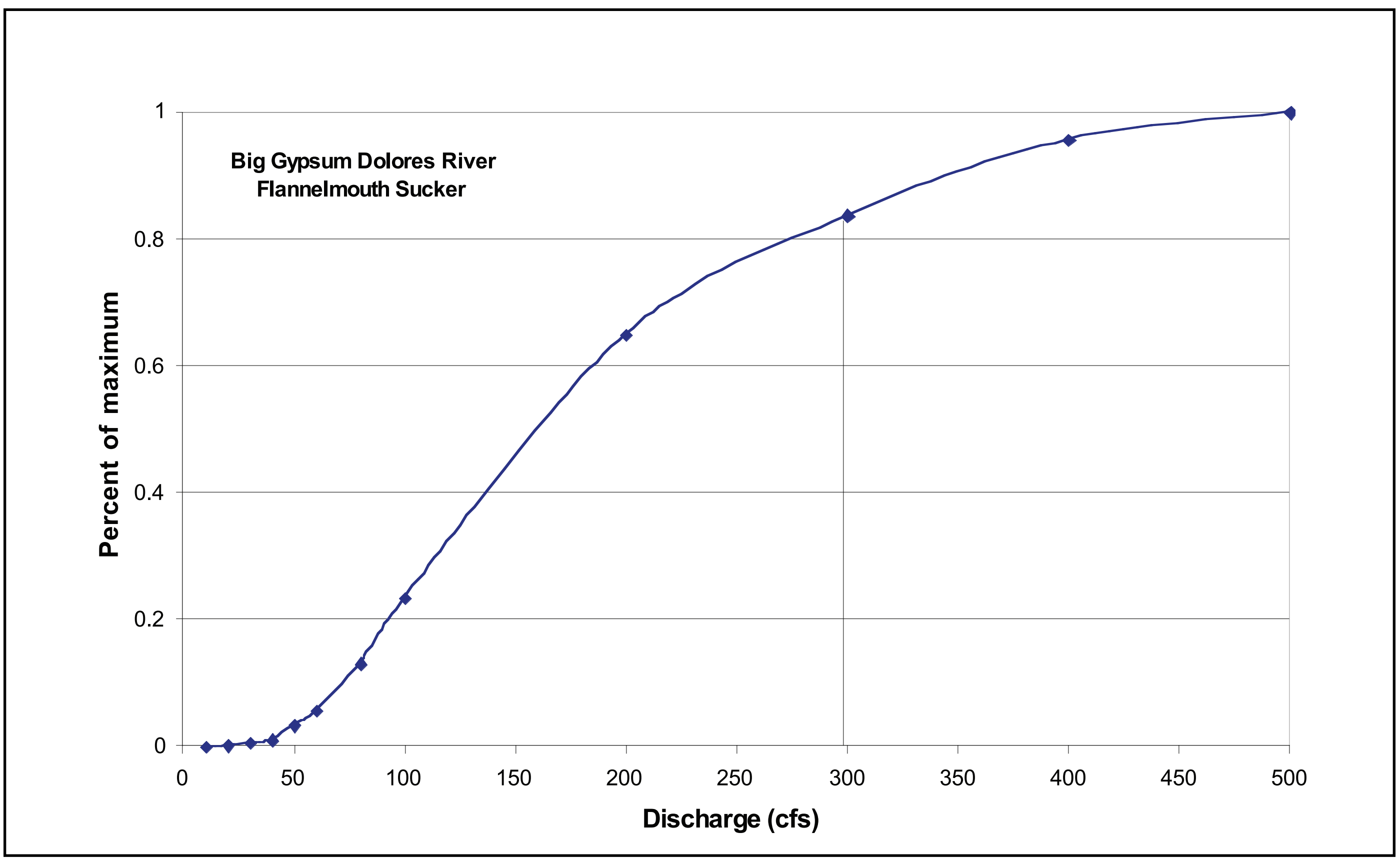

FIGURE II-20. Percentage of modeled maximum biomass (kg/ha) of flannelmouth sucker as a function of discharge at Big Gypsum, Dolores River.

cause for a nearly complete lack of adult native sucker at Big Gypsum in recent years.

The reason the 2D instream flow methodology did not produce a reasonable instream flow recommendation for the Dolores River has to do with several underlying factors. The 300 cfs recommendation is based on channel geomorphology and not current water availability. The model identified the instream flow based on habitat criteria for adult bluehead and flannelmouth sucker, which occupy the deeper and swifter habitats. In addition, the 2D model simulations were conducted only up to 500 cfs, which was not high enough to capture the range of flows where the curve peaked. Flow simulations up to a 1,000 cfs appear necessary to capture the full bluehead and flannelmouth sucker biomass potential for the Dolores River.

Moreover, the analysis modeled only one site on the Dolores River. Additional data on fish and habitat upstream of Disappointment Creek would have provided useful information. In general, the reach upstream of Disappointment Creek has a steeper gradient and does not have a sedimentation problem. A steeper gradient and clean cobble substrates were geomorphic factors that improved habitat and biomass at Lily Park relative to upstream Yampa River sites. On the Dolores these geomorphic factors would also result in higher invertebrate and fish productivity upstream of Disappointment Creek relative to Big Gypsum, under similar flows.

Two approaches would provide an instream flow recommendation that is based on current water use practices. One is to rerun the 2D model and using habitat criteria for juvenile bluehead and flannelmouth sucker. The fish surveys at Big Gypsum (2000 to 2005) found that juvenile-sized native sucker far outnumbered adult fish. Juvenile bluehead and flannelmouth sucker (12- 23 cm) prefer habitats with lower depth and velocity ranges than those preferred by adults and use of juvenile criteria would produce a lower inflection point that the adult criteria did in the results presented above. This approach would makes sense if the native fish management objective is to provide long-term habitat suitable for sustaining small or stunted native fish.

The second approach would be to base the instream flow recommendation on long- term fish sampling data. Before 2000 adult flannelmouth and bluehead sucker were commonly collected in the Dolores from McPhee dam to Dove Creek (Nehring, DOW unpublished data), but very few adult native sucker have been collected from this reach after 2002. Clearly, Dolores River flows at the Bedrock gage in 2002, 2003 and 2004 were inadequate for sustaining the native fish assemblage. Native fish were more plentiful from 1986 to 1999, however, which suggests that river flows during that period were adequate.

Our analysis of fish and habitat data from the recent drought period raises a major concern in the management of flow for ecological or native fish objectives. The “fish pool” (reservoir water reserved for downstream releases) is not a fixed amount of water but varies depending on the water yield each year. The fish pool is a fixed quantity in years when there is a ‘spill’, but in years without spills (when the entire runoff is stored or diverted), the fish pool can be much lower that usual. This was the case on the Dolores in 2002 and 2003. This practice is poor flow management for sustaining native fish and the ‘shared shortage’ policy appears to have had severe negative consequences for native fish abundance during 2002 and 2003.

Even in spill years the downstream releases on the Dolores appear to be only minimal for providing native fish habitat. Native fish evolved under a snowmelt-driven hydrograph. Spring flows have several geomorphic processes (Richard and Anderson 2006). In years when McPhee Reservoir fully captures all the spring flows, base need to be as high as normal or higher to mitigate the consequences of lost runoff flows. The Dolores River Dialogue (2006B) estimated that no spill years have a frequency of about 45 percent.

The minimum flow necessary to sustain a modest flannelmouth and bluehead sucker biomass during spill years appears to be in the range of 50 to 60 cfs. The minimum flow necessary during “no spill” years may need to be higher than 60 cfs. At 60 cfs about 61 percent of the habitat at Big Gypsum is in pool, 34 percent in run and only five percent in riffles (see the CD appendix- 2D Modeling, Figure II-11). At 80 cfs about 50 percent is pool, 42 percent is run and eight percent is riffles. At Big Gypsum a base flow of 80 cfs is necessary to achieve a 50:50 pool-to-run/riffle ratio.

In summary, based on habitat features identified at Big Gypsum, we recommend an instream flow of 60 cfs is recommended for years with spills and an 80 cfs flow for years without spills.

Spring and Channel Maintenance Flow Recommendations

Bankfull flows are directly related to sediment transport and channel maintenance. Channel maintenance flows are necessary to maintain channel geomorphology and habitats fish require during base flow periods. Richard and Anderson (2006) determined that bankfull flows at the Big Gypsum site were 2,600 cfs. Excessive sedimentation and channel encroachment was obvious during the 2004 fish surveys and highly detrimental to maintaining native fish.

The Big Gypsum site is located downstream of Disappointment Creek, which is a major source of sediment (Richard and Anderson 2006). Upstream of Disappointment Creek the Dolores does not appear to have severe sedimentation problems. Spring flows of 2,000 cfs for a period of seven days at a frequency of every other year would likely maintain channel configuration (Vandas et al. 1990). Observations made during our study are supportive of a spring instream flow recommendation of 2,000 cfs at a frequency of every other year.

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LITERATURE CITED

Aadland, L. P., C. M. Cook, M. T. Negus, H. G. Drewes and C. S. Anderson. 1991. Microhabitat preferences of selected stream fishes and a community-oriented approach to instream flow assessments. Investigational Report No. 406. Minnesota Division of Fish and Wildlife, St. Paul. 142 pp.

Anderson*, R. M. 2005. Riverine fish-flow investigations: Quantification of impacts of the 2002 drought on native fish population in the Yampa and Colorado Rivers. Annual Progress Report to Colorado Division of Wildlife, F-289-R. Fort Collins, CO 89pp.

Anderson, R.M. 2004, Riverine Fish-Flow Investigations: Quantification of impacts of the 2002 drought on native fish populations in the Yampa and Colorado rivers. Annual Progress Report to Colorado Division of Wildlife, F-289-R7. Fort Collins, CO 96pp.

Anderson, R. M. 1997. An evalulation of fish community structure and habitat potential for Colorado squawfish and razorback sucker in the unoccupied reach (Palisade to Rifle) of the Colorado River, 1993 -1995. Colorado River Recovery Implementation Program Project No. 18. Colorado Division of Wildlife Federal Aid Project SE-3. Fort Collins, Co.

Anderson*, R. M. and G. Stewart. 2006. Riverine fish-flow investigations: Quantification of habitat availability and instream flows on the Gunnison River and impacts of long term drought on native fish populations in the Dolores River. Annual Progress Report to Colorado Division of Wildlife, F-289-R. Fort Collins, CO 89pp.

Anderson*, R. M. and G. Stewart. 2003. Riverine fish-flow investigations: Using 2D modeling to determine relationship between flow and habitat availability for warn-water riverine fish in Colorado. Annual Progress Report to Colorado Division of Wildlife, F-289-R. Fort Collins, CO 106pp.

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

Annear, T., I. Chisholm, H. Beecher, A. Locke, P Aarrestad, N. Burkhart, C. Coomer, C. Estes, J. Hunt, R. Jacobson, G. Jobsis, J. Kauffman, J. Marshall, K. Mayes, C. Stalnaker and R. Wentworth. 2002. Instream Flows for Riverine Resource Stewardship. Instream Flow Council, Cheyenne, WY. (see www.instreamflowcouncil.org)

Bain, M. R., J. T. Finn. And H. E. Booke. 1988. Stream flow regulation and fish community structure. Ecology 69(2):382-392.

Bestgen. R. R., R. T. Muth and M. A. Trammell. 1998. Downstream transport of Colorado squawfish larvae in the Green River drainage: temporal and spatial variation in abundance and relationships with juvenile recruitment. Final report to the Recovery Program for Endangered Fishes in the Upper Colorado River, Project Number 32. Larval Fish Lab, Colorado State University, Fort Collins.

Burdick, B.. D.. 1995. Ichthyofaunal studies of the Gunnison River, Colorado, 1992 - 1994. Final Report prepared for the Recovery Implementation Program for Endangered Fishes in the Upper Colorado River Basin. U.S. Fish and Wildlife Service, Grand Junction, Colorado. 66 pp.

Byers*, D.W., C. Sodergren, J. M. Bundy and K. Bestgen. Habitat use and movement of bluehead sucker, flannelmouth sucker and roundtail chub in the Colorado River. Contribution 121, Larval Fish Laboratory, Dept. of Fishery and Wildlife, CSU, Fort Collins Co.

Chapman, D. G. 1954. The estimation of biological populations. Annals. Mathematical Statistics 25:1-15.

Courtenay, W. R. and P. B. Moyle. 1992. Crimes against Biodiversity: The lasting legacy of fish introductions. Trans. N. A. Wildlife & Nat. Res. Conference No. 57. Vol. 57:365-372.

Dolores River Dialogue (DRD) Hydrology Report (draft). 2006a. DRD Report, Cortez CO 61 pg. (David Graf CDOW editor, Grand Junction).

Dolores River Dialogue (DRD) Correlation Report (draft). 2006b. DRD Report, Cortez CO 61 pg.

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

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

Martinez, P. J. 2006. Westslope Warmwater Fisheries. Federal Aid in Fish and Wildlife Restoration Project F-325-r Progress Report. Colorado Division of Wildlife, Fort Collins, 121 pages.

McAda, C.W. 2003. Flow recommendations to benefit endangered fishes in the Colorado and Gunnison Rivers. Recovery Program Project Number 54. Final Report July 2003. U. S. Fish and Wildlife Service, Grand Junction CO.

Modde, T., W. J. Miller, R M. Anderson and D. Irving. 1999. Determination of habitat availability, habitat use and flow needs of endangered fishes in the Yampa River between August and September. Final Report to the Recovery Program for Endangered Fishes in the Upper Colorado River. U. S. Fish and Wildlife Service, Denver CO. 134 pp.

Modde, T. and G. Smith. 1995. Flow recommendations for endangered fishes in the Yampa River. Final Report to the Recovery Program for Endangered Fishes in the Upper Colorado River, U. S. Fish and Wildlife Service, Denver, CO. 44 pp.

Nehring, R. B. 1979. Evaluation of instream flow methods and determination of water quantity needs for stream in the state of Colorado. Report to the U.S. Department of interior, U.S. Fish and Wildlife Service. Colorado Division of Wildlife Final Report, Fort Collins, CO.

Nesler, T. P. 1995. Interactions between endangered fishes and introduced gamefishes in the Yampa River, Colorado , 1987-1991. Colorado River Recovery Implementation Program Project No. 91-29. Colorado Division of Wildlife Federal Aid Project SE-3, Fort Collins, CO.

Osmundson, D. B. 1999. Longitudinal variation in fish community structure and water temperature in the upper Colorado River. Final Report. U. S. Fish and Wildlife Service, Grand Junction, Colorado.

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

Peters, E, J., R. S. Holland and B. C. Chapman. 1992. Studies of the channel catfish in the lower Platte River, Nebraska. Final Report, Federal Aid Project F-78-R. Nebraska Game and Parks Commission, Lincoln, 198 pp.

Pitlick, J., M. Van Steeter, B. Barkett, R. Cress and M. Franseen. 1999. Geomorphology and hydrology of the Colorado and Gunnison rivers and implications for habitats used by endangered fishes. Final Report to the Recovery Program for Endangered Fishes in the Upper Colorado River, Project Number 44, Department of Geography, University of Colorado, Boulder.

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

Poff, N. L.. J. D. Allan, M. B. Bain, J. R. Karr, K. L. Prestegaard, B. D. Richter, R. E. Sparks and J. C. Stromberg. 1997. The Natural Flow Regime, *A paradigm for river conservation and restoration*. BioScience Vol. 47 No. 11.

Rees*. D. E. and W. J. Miller. 2001. Habitat selection and movement of native fish in the Colorado River, Colorado. Miller Ecological Consultants, Inc. Fort Collins, CO.

Richard G. A. and R. M. Anderson. 2006. Channel-forming discharge on the Dolores River and Yampa River, Colorado. Colorado Division of Wildlife Technical Report #80, Fort Collins, CO.

Rose, K. L. and D. R. Hann. 1989. Consolidated instream flow report habitat modeling on the Green River using the physical habitat simulation system. Final Report. U. S. Fish and Wildlife Service, Grand Junction, CO.

Scoppettone, G. G. 1993. Interactions between Native and Nonnative fishes of the Upper Muddy River, Nevada. Transactions of the American Fisheries Society: 122:599-608.

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

Stewart* G., R. M. Anderson and E. Wohl. 2005. Two-Dimensional modeling of habitat suitability as a function of discharge on two Colorado Rivers. River Research and Applications: 21:1061-1074.

Stewart* G. and R. M. Anderson, 2005. Two-Dimensional modeling of habitat suitability as a function of discharge on two Colorado Rivers. River Research and Applications (In press).

Travnichek, V. H., M. B. Bain and J. J. Maceina. 1995. Recovery of a warmwater fish assemblage after the initiation of a minimum-flow release downstream from a hydroelectric Dam. Transactions of the American Fisheries Society: 124:836-844.

Tyus H. M. and C. A. Karp. 1989. Habitat use and streamflow needs of rare and endangered fishes, Yampa River, Colorado, U. S. Fish and Wildlife Service, Biological Report 89 (14).

Valdez, R. A., P. G. Mangan, M. McInerny and R. P. Smith. 1982. Tributary Report: Fishery Investigations of the Gunnison and Dolores Rivers. Pages 321-365 in W. H. Miller et al., editors. Colorado River Fishery Project, Final Report; Part Two, Field Studies. U. S. Fish and Wildlife Service and Bureau of Reclamation. Salt Lake City Utah. .

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

Vandas, S., Whittaker, D., Murphy, D., Prichard, D., MacDonnell, L., Shelby, B., Muller, D., Fogg, J.\ and Van Havern, B., 1990. Dolores River Instream Flow Assessment, Project Report. US Department of the Interior, Bureau of Land Management.

Author* = citation.pdf is included provide in CD in Appendix - Report-Project F-288.

APPENDIX ONE

Site Hydrographs

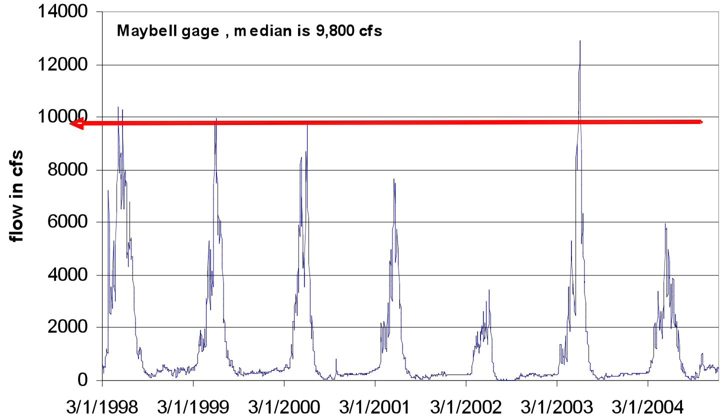

Figure A1-1. Yampa River hydrograph (Maybell gage), 1998–2004.

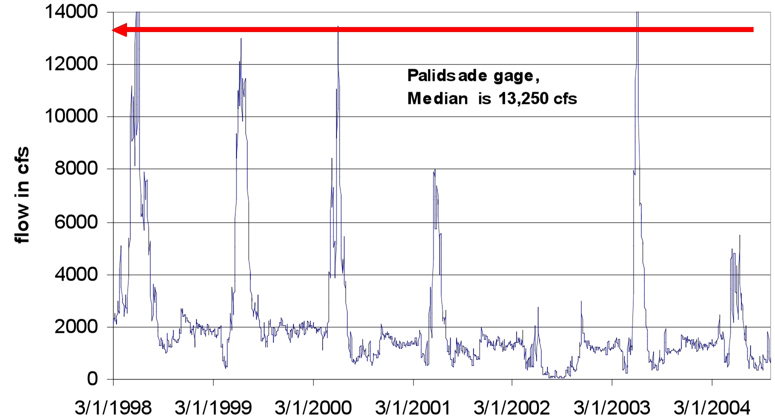

Figure A1-2. Colorado River hydrograph (Palisade gage), 1998–2004.

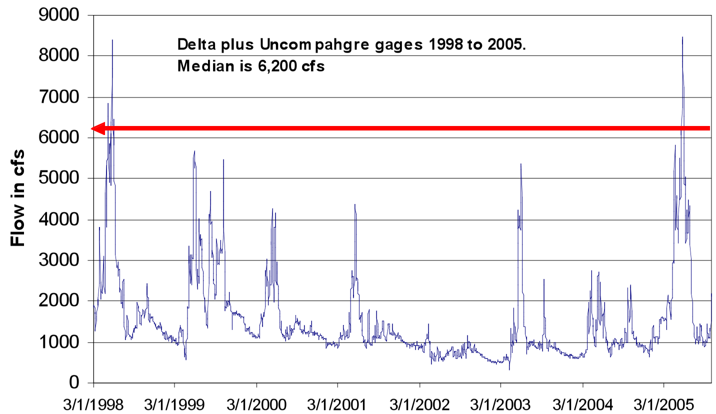

Figure A1-3. Gunnison River hydrograph (Delta plus Uncompahgre gages), 1998–2005.

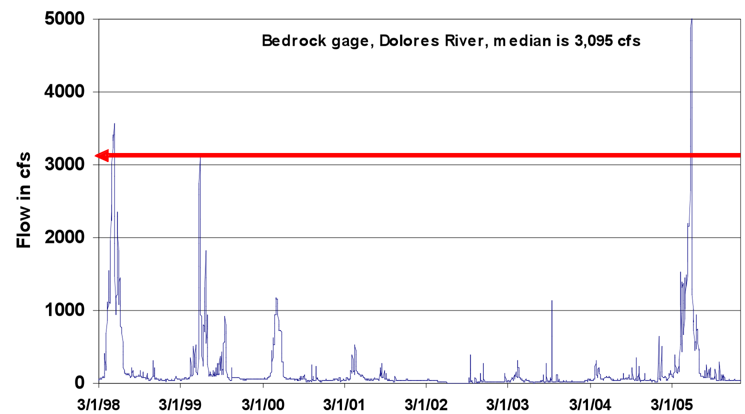

Figure A1-4. Dolores River hydrograph (Bedrock gage), 1998–2005.

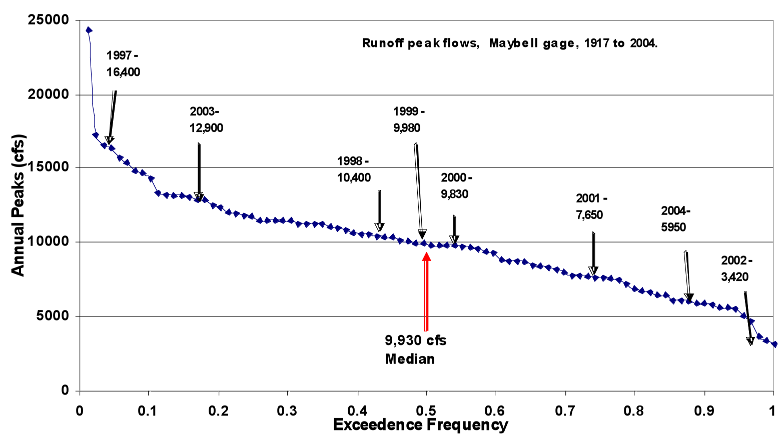

Figure A1-5. Yampa River annual peak flows (Maybell gage) 1997–2004.

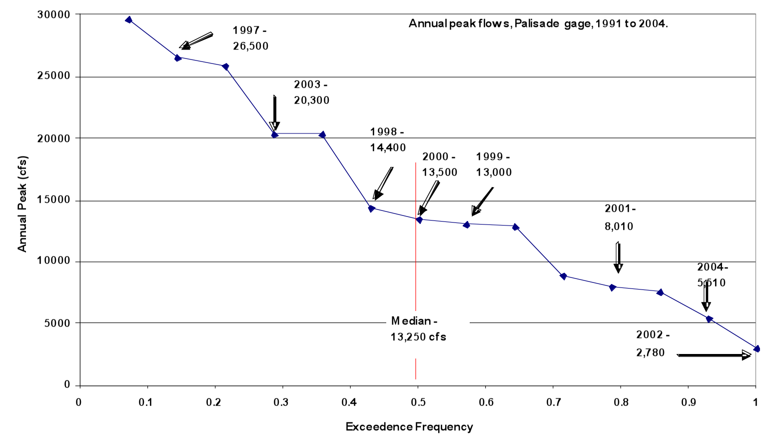

Figure A1-6. Colorado River annual peak flows (Palisade gage), 1997–2004.

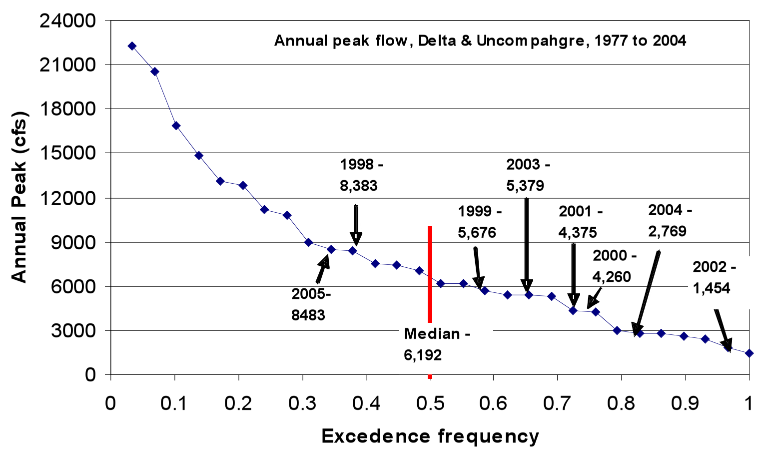

Figure A1-7. Gunnison River annual peak flows (Delta plus Uncompahgre gages), 1998–2005.

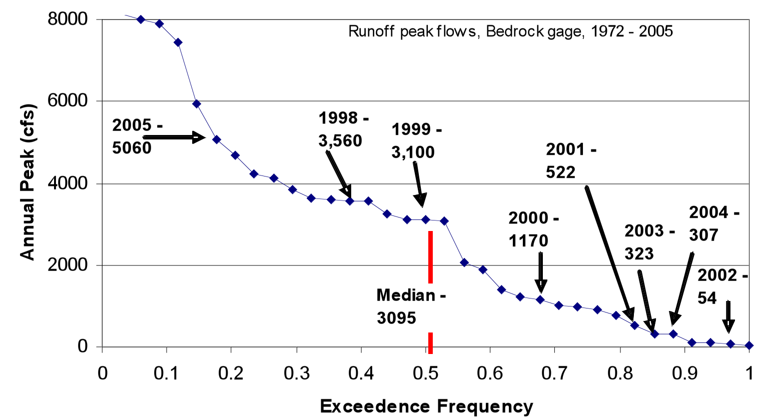

Figure A1-8. Dolores River annual peak flows (Bedrock gage), 1998–2005.

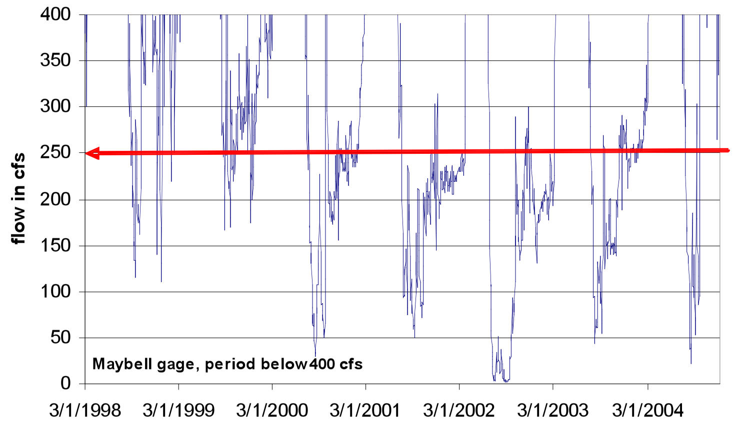

Figure A1-9. **Yampa River below 400 cfs (Maybell gage), 1998–2004.**

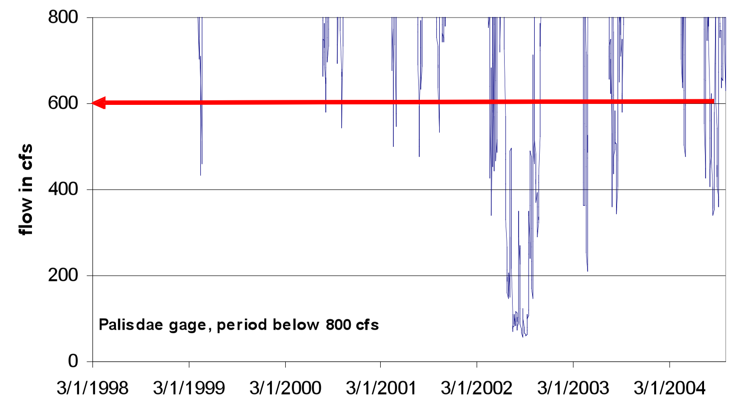

Figure A1-10. **Colorado River below 800 cfs (Palisade gage), 1998–2004.**

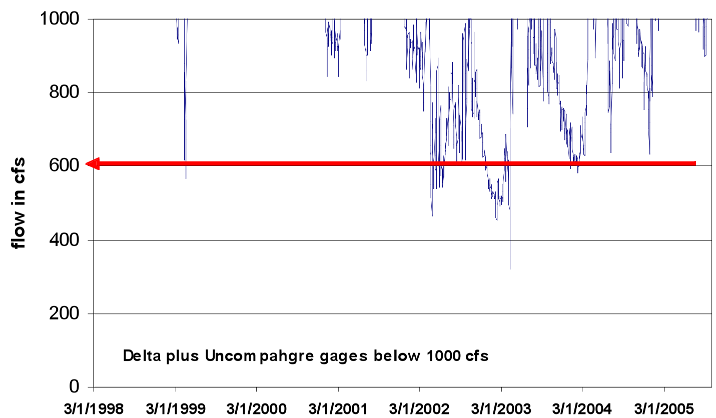

Figure A1-11. **Gunnison River below 1,000 cfs (Delta plus Uncompahgre gages), 1998–2005.**

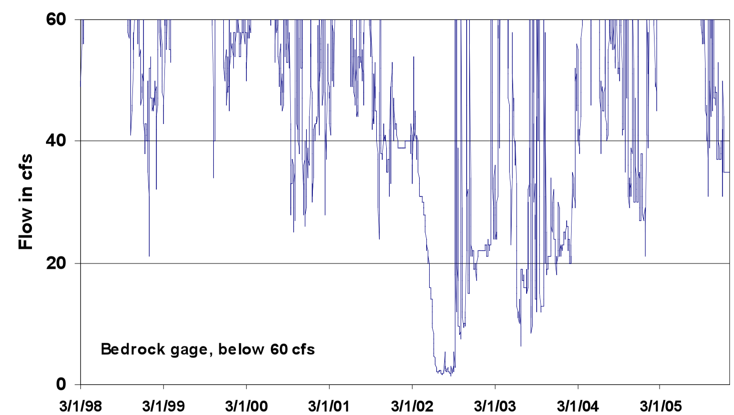

Figure A1-12. **Dolores River below 60 cfs (Bedrock gage), 1998–2005.**

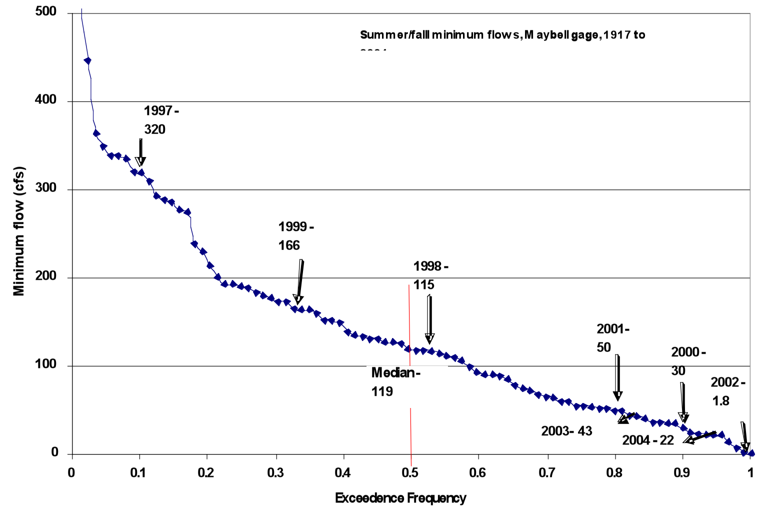

Figure A1-13. Yampa River summer/fall minimum flows (Maybell gage), 1997–2004.

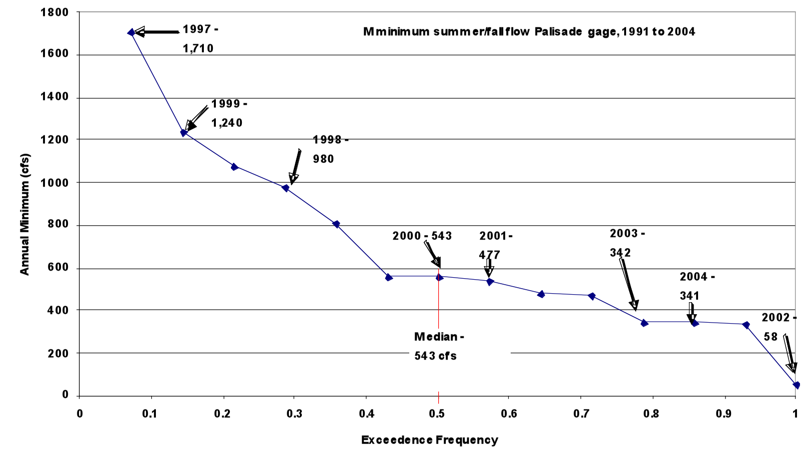

Figure A1-14. Colorado River summer/fall minimum flows (Palisade gage), 1997–2004.

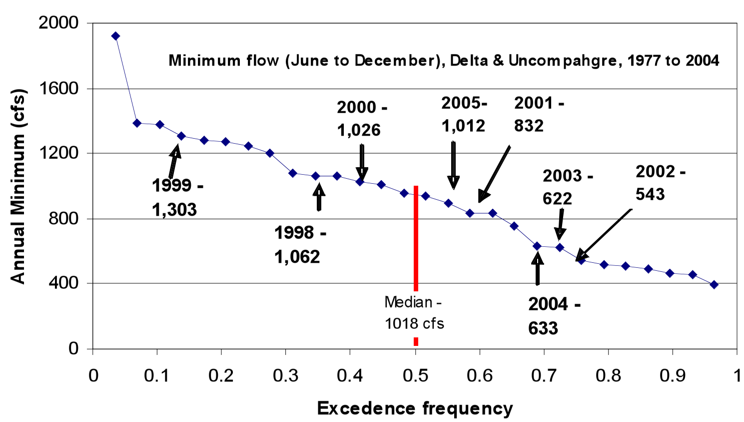

Figure A1-15. Gunnison River summer/fall minimum flows (Delta plus Uncompahgre gages), 1998–2005.

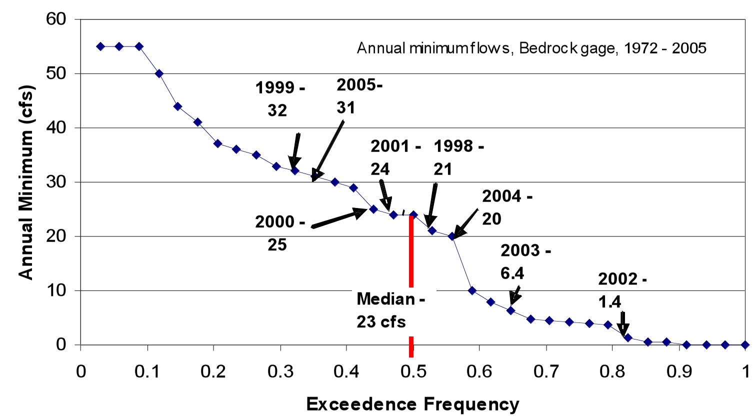

Figure A1-16. Dolores River summer/fall minimum flows (Bedrock gage), 1998–2005.

APPENDIX TWO

Fish Data
Annual Species Composition, Density and Biomass Estmates for Each Study Site

Table A2-1. Species composition, density and biomass estimates for Duffy, Yampa River, 1998–2004.

Year	Flannelmouth sucker	Bluehead sucker	Roundtail chub	Colorado pikeminnow	White sucker. + hybrids	Channel catfish	Carp	Smallmouth bass	Northern pike	Total
	Species composition (percentage of all fish collected)									**n**
1998	6	4	4	1.6	71	3	2	6	3	1,375
1999	5	7	3	0.9	72	4	1.5	6	2	1,213
2000	5	4	4	0.8	72	3	0.8	10	0.9	1,294
2001	2	4	3	0.6	50	4	2	33	1.1	856
2003	4	1	2	0	66	4	0.3	18	0.7	584
2004	3	0.5	5	0.5	38	6	1	44	1.6	428
	Density (number per hectare)									**n/ha**
1998	4.0	3.6	1.3	2.8	39.2	2.6	1.8	5.0	2.5	62.9
1999	2.4	3.7	0.9	2.9	39.4	5.5	1.5	6.3	3	65.6
2000	1.8	4.0	0.6	1.8	33.0	2.3	0.5	6.7	0.6	51.5
2001	0.7	2.7	0.5	2.6	29.7	3.9	1.3	27.1	1	69.4
2003	0.9	0.5	0	1.1	20.8	3	0.2	13.0	0.5	40.0
2004	1.0	0.1	0.1	1.4	11.2	1.8	0.3	11.9	0.5	28.4
	Biomass (kilograms per hectare)									**kg/ha**
1998	4.7	1.8	2.5	2.5	39.9	4.3	7.3	1.9	1.5	66.5
1999	2.7	1.3	2.7	1.6	39.7	6.5	6.1	2.6	2.8	65.9
2000	2.2	2.2	1.6	0.9	35	3.3	2.8	2.3	0.7	51
2001	0.8	1.5	2.2	0.7	26.9	4.1	6.1	4.8	0.2	47.4
2003	1.1	0.2	1.1	0	12.7	3.9	1.5	1.9	0.3	22.6
2004	1.2	0.1	0.3	1.2	10.7	3.4	1.7	1.9	0.0	20.6

Table A2-2. Species composition, density and biomass estimates for Sevens, Yampa River, 1998–2004.

Year	Flannelmouth sucker	Bluehead sucker	Roundtail chub	White Sucker + hybrids	Channel catfish	Carp	Smallmouth bass	Northern pike	Total
	Species composition (percentage of all fish collected)								**n**
1998	48	23	5	11	7	4	1.0	1.3	1,391
1999	46	18	4	15	7	5	2.5	1.8	1,040
2000	50	22	4	17	2	4	0.5	0.2	807
2001	53	13	3	16	5	4	5	0.3	676
2003	36	2	4	36	3	4	13	0.4	832
2004	26	2	2	36	6	5	23	0.3	731
	Density (number per hectare)								**n/ha**
1998	63.2	42.8	10.6	30.4	14.8	9.1	2.4	3.6	179.4
1999	60.5	36.9	6.0	29.2	19.8	12.6	5.6	4.6	179.1
2000	47.4	46.9	6.4	16.7	2.0	4.1	0.5	0.3	122.1
2001	42.3	17.9	3.7	20.8	7.5	5.6	5.8	0.4	104.7
2003	30.6	1.6	3.5	77.8	9.5	10.5	32.8	1.0	173.1
2004	19.0	2.4	1.5	20.3	6.4	6.9	24.5	0.2	82.5
	Biomass (kilograms per hectare)								**kg/ha**
1998	66.1	17.2	6.3	22.9	21.5	25.4	1.2	1.4	162.2
1999	66.1	14.5	3.9	23.2	22.4	30.8	1.9	2.6	165.4
2000	50.0	14.8	3.9	14.4	3.2	11.6	0.2	0.4	98.4
2001	39.2	5.0	2.0	12.3	10.2	17.0	0.9	0.8	87.5
2003	35.4	0.6	1.8	24.6	14.7	28.0	5.3	0.4	110.7
2004	24.1	1.0	1.1	10.0	11.8	20.5	4.7	0.5	73.5

Table A2-3. Species composition, density and biomass estimates for Lily Park, Yampa River, 2000–2004.

Year	Flannelmouth sucker	Bluehead sucker	Roundtail chub	Colorado pikeminnow	White sucker + hybrids	Channel catfish	Carp	Smallmouth bass	Northern pike	Total
	Species composition (percentage of all fish collected)									n
2000	48	9	0.02	0.1	0.3	40	2	0.8	0.2	4,058
2001	68	7	0.03	0.03	0.2	18	2	5	0.2	2,989
2003	55	8	0	0.1	0.6	28	3	5	0.1	2,159
2004	52	6	0.3	0.5	1.3	27	3	9	0.1	2,244
	Density (number per hectare)									n/ha
2000	347.5	96.8	0.4	0.4	0.9	513.3	26	10.6	2.6	1,001.5
2001	277.5	54.8	0.3	0.3	0.3	137.3	16.8	39	1.4	528.9
2003	250.5	57.1	0	0	4	275.6	33.1	51.5	1.4	680
2004	208.3	47.1	3.6	2.3	2.2	193.2	24.6	57.7	1.0	547.2
	Biomass (kilograms per hectare)									kg/ha
2000	218.4	37.2	0.2	0.6	0.4	224.2	29.1	6.8	3.8	521.1
2001	143.3	19.8	0.01	0.7	0.2	61.7	21.5	8.0	2.8	253
2003	122.4	18.9	0	0	2.5	64	38.2	7.2	2.6	256.8
2004	120.3	17.1	0.6	5.6	1.1	53.9	31.7	8.2	1.7	240.3

Table A2-4. Species composition, density and biomass estimates for Corn Lake, Colorado River, 1999–2004.

Year	Flannelmouth sucker	Bluehead sucker	Roundtail chub	Colorado pikeminnow	White sucker + hybrids	Channel catfish	Carp	Sunfish (all species)	Bullhead	Total
	Species composition (percentage of all fish collected)									**n**
1999	38	35	3	0.1	6	4	11	0.9	1.3	3,499
2000	31	36	4	0.04	4	6	14	1.5	0.6	2,784
2001	40	37	3	0.03	6	5	7	1.2	1.3	3,667
2003	32	31	5	0.02	10	7	12	2.7	0.7	4,279
2004	38	28	5	0.03	11	9	7	1.4	0.6	3,888
	Density (number per hectare)									**n/ha**
1999	311	313	30.9		48.3	36.9	88.6			843
2000	215	232	56.9		23.1	54.1	99.0			691
2001	369	258	29.2		105	74.4	49.5			857
2003	379	234			95.0	78.3	147			967
2004	304	163	59.3		74.7	271	73.6			781
	Biomass (kilograms per hectare)									**kg/ha**
1999	253	160	9	1.4	20	34	112			590
2000	165	99	11	1.6	8	41	136			463
2001	284	121	7	0.6	23	31	32			548
2003	299	103	38	1.0	31	70	170			711
2004	267	80	17	1.0	32	192	109			697

Table A2-5. Species composition, density and biomass estimates for Clifton, Colorado River, 2000–2003.

Year	Flannelmouth sucker	Bluehead sucker	Roundtail chub	Colorado pikeminnow	White sucker + hybrids	Channel catfish	Carp	Sunfish (all species)	Bullhead	Total
	Species composition (percentage of all fish collected)									n
2000	33	41	5.1	0.03	3.7	5.1	12	1.2	0.2	3,276
2001	42	27	5.9	0.09	4.1	5.7	14	1.1	0.4	4,485
2003	33	25	6.0	0.1	8.0	10.5	12	4.0	1.0	3,558
	Density (number per hectare)									n/ha
2000	296	187	63	0.4	45	86	92			617
2001	271	201	59	0.3	33	85	144			789
2003	252	157	53	0	46	138	129			718
	Biomass (kilograms per hectare)									kg/ha
2000	190	67	13	0.6	14	87	81			454
2001	171	79	14	0.7	10	66	183			524
2003	192	65	14	0	16	125	193			605

Table A2-6. Species composition, density and biomass estimates for Escalante, Gunnison River, 2003–2005.

Year	Flannelmouth sucker	Bluehead sucker	Roundtail chub	Colorado pikeminnow	White sucker + hybrids	Channel catfish	Carp	Sunfish (all species)	Bullhead	Total
	Species composition (percentage of all fish collected)									**n**
2003	28.7	41.8	12.5		9.6		6.2			1,475
2004	20.4	48.5	13.4	0.1	12.9		3.0			4,381
2005	16.0	45.9	15.3		17.1		3.0			3,575
	Density (number per hectare)									**n/ha**
2003										
2004	267	502	303		149		75.2			1,119
2005	201	358	260		132		38.3			894
	Biomass (kilograms per hectare)									**kg/ha**
2003										
2004	174	136	40.0		65.3		142			567
2005	115	90.5	37.1		64.9		75.6			384

Table A2-7. Species composition, density and biomass estimates for Delta, Gunnison River, 2003–2005.

Year	Flannelmouth sucker	Bluehead sucker	Roundtail chub	Colorado pikeminnow	White sucker + hybrids	Channel catfish	Carp	Sunfish (all species)	*Bullhead*	Total
	Species composition (percentage of all fish collected)									**n**
2003	41.2	22.7	6.2		22.7		6.5			1,622
2004	40.1	20.1	3.7	0.3	24.5		9.7			2,773
2005	16.3	40.5	16.1		19.0		6.0			3,439
	Density (number per hectare)									**n/ha**
2003										
2004	367	130	25.0		153		94.4			739
2005	258	593	268		212		86.9			1,496
	Biomass (kilograms per hectare)									**kg/ha**
2003										
2004	348	61.8	8.1		80.0		179			674
2005	213	180	40.0		90.4		150			677

Table A2-8. Species composition, density and biomass estimates for Big Gypsum, Dolores River, 2000–2005.

Year	Flannelmouth sucker	Bluehead sucker	Roundtail chub	Colorado pikeminnow	White sucker + hybrids	Channel catfish	Carp	Sunfish (all species)	Bullhead	Total
	Species composition (percentage of all fish collected)									n
2000	15.7	2.2	54.7			16.7	3.4	2.0	5.0	503
2001	55.0	6.2	25.8			9.1	2.0	1.4	0.5	562
2004	2.4	1.2	39.5			5.2	7.1	0	44.5	420
2005	59.1	0	24.8			5.0	1.4	0.2	9.5	484
	Density (number per hectare)									n/ha
2000	20.0	1.6	53.3			40.7	8.7		8.1	119.7
2001	76	6.5	43.9			31.2	3.2		0.9	154.3
2004	3.2	1.0	34.6			8.7	8.3		61.1	115.5
2005	150	0	78.4			28.8	2.9		16.1	283.8
	Biomass (kilograms per hectare)									kg/ha
2000	4.2	0.2	3.0			16.3	17.5		0.6	41.9
2001	3.2	0.6	2.4			10.3	2.6		0.1	19.2
2004	0.4	0.1	1.6			3.2	14.2		2.8	22.3
2005	6.6	0	5.2			10.9	4.4		0.9	27.9