Status and trends of flannelmouth sucker *Catostomus latipinnis*, bluehead sucker *Catostomus discobolus*, and roundtail chub *Gila robusta*, in the Dolores River, Colorado, and opportunities for population improvement: Phase II Report

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Executive Summary

The first purpose of this Phase II report was to summarize information that described status and trends of flannelmouth sucker *Catostomus latipinnis*, bluehead sucker *Catostomus discobolus*, and roundtail chub *Gila robusta*, in the Dolores River, Colorado, and to discuss reasons for their decline. A second purpose was to present opportunities for improvement of the native fish community. Once widespread and abundant in cool and warm water reaches of small to large streams, those species now occupy 50% or less of their range in the Colorado River Basin, including only 45-55% of their ranges in the Upper Colorado River Basin (Bezzerides and Bestgen 2002). Based on analyses of available data, including observations by local ranchers, the following conclusions were made regarding the status of three native fishes in the Dolores River. Roundtail chub is rare in upstream reaches 1 and 2 (the 31 miles of river downstream of McPhee Dam), where populations are declining or may be extirpated. In downstream reaches, roundtail chub is relatively the most abundant of any of the native fishes, but populations are small and either highly fluctuating or declining. Flannelmouth sucker is rare in upstream reaches 1-3 upstream of Disappointment Creek and present in variable abundance throughout the remainder of the study area, but declining in those reaches. Bluehead sucker is very rare in the entire study area and is declining to the point of extirpation in most reaches; it is more common in the Dolores River downstream of the San Miguel River. No study area reaches have strong populations of the three species. Based on the available data, the strength of conclusions regarding status of native fish is high. This is due in part, to the relatively large decline that has occurred and a relatively high degree of information available to describe trends in the fish populations through time.

The strength of conclusions regarding exact mechanisms for population decline (e.g., reduced base flow, lack of spills, non-native fish predation) is less certain. It seems unequivocal that reduced frequency, magnitude and duration of peak flows (spills) as well as reduced base flow had a negative effect on cold and warmwater fish communities of the Dolores River compared to pre-diversion and pre-impoundment times. Non-native fishes have also likely had negative effects on native kinds in some reaches of the Dolores River, mainly via predation on early life stages.

We presented nine potential management opportunities that may assist with improvement of the native fish community including: spill management, base flow management, sediment transport flows, habitat maintenance flows, thermal regime modification, reduce effects of introduced cold water species, reduce effects of introduced warmwater species, and supplement native fishes. Each was ranked for their potential importance (benefit) for native fishes as well as for the ease and schedule for implementation. We collectively ranked improvements to base flow, thermal management, and reductions in non-native fishes as the highest priorities, while sediment flushing flows, habitat maintenance flows, and supplementation of native fishes had lower but still important ranks. Ranks were also influenced in part, by the relative ease of implementation, as well as the level of information available to support assertions of importance.

It is important to remember that certain management actions may have synergistic effects: flow management activities may produce habitat for native fishes and at the same time, reduce abundance of deleterious non-native kinds or improve water quality conditions. Similarly, it is important to recognize that there is currently no single factor that is most responsible for native fish declines, and implementation of just a single management action is unlikely to produce the desired effect of native fish restoration.

The goal for restoration depends on the overall goal designated for native fishes in the Dolores River (which has yet to be clearly defined), with several viable options for guidelines including: restore densities, distribution, and population structure to a minimum of 90's levels; restore densities and population structure to levels apparent in other "healthy" populations such as those in other systems; identify and remediate limiting factors and prevent further declines; and keep existing small problems small, including limiting smallmouth bass and white sucker.

More information would be valuable prior to implementation of some management opportunities, so that changes can be monitored most effectively. Examples of information needed to improve native fish status include: sediment flushing studies, bed mobility studies, early life history sampling, continued monitoring of native and non-native fishes, and in-stream fish habitat monitoring including water temperature; existing habitat-flow and other studies may be useful in preliminary examination of spill potential, sediment flushing and bed mobility needs. Suggestions for funding sources to obtain this important information were provided and may be particularly relevant given the potential listing status of these species.

A few considerations were apparent for the Scientific and Water User Panel through the A Way Forward Project as efforts proceed to improve native fish status in the Dolores River. One was recognition that the system is complex and unlike many other regulated river systems because prevailing hydrology exhibits relatively low peaks *and* low base flows. Each opportunity for improvement has inherent complexities and costs that need to be considered carefully, and many factors affecting native fishes interact, but uncertainty should not equate to lack of action; in the absence of better information restoration of the natural flow and water temperature regime should provide a fallback when no information exists. We also recognize the need to reverse trends in native fish abundance, but at the same time, recognize the need to "do no harm", such that certain factors that may negatively affect native fishes are not made worse. Finally, release of higher magnitude and warmer base flows, release of spills that are well-timed, thermally compatible, and capable of flushing fines, creating a much-reduced predator/competitor environment, and monitoring of changes to understand most effective strategies and adapt accordingly are areas which we feel will provide the most benefit for native fishes in the Dolores River system.

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INTRODUCTION

In the Colorado River Basin of the American Southwest, distribution and abundance of large-bodied, main-stem, native fishes has declined significantly as a result of habitat modifications and negative effects of introduced, non-native fishes. At least seven large-bodied fishes were historically widespread and inhabited main-stem reaches of the Colorado River and tributaries. Humpback chub *Gila cypha*, bonytail *Gila elegans*, Colorado pikeminnow *Ptychocheilus lucius*, and razorback sucker *Xyrauchen texanus* have suffered population declines and are listed as endangered by the U. S. Fish and Wildlife Service, Department of Interior.

Declines of three other large-bodied species, roundtail chub *Gila robusta*, flannelmouth sucker *Catostomus latipinnis*, and bluehead sucker *Catostomus discobolus*, (collectively the "three species") are also extensive throughout the basin. An exhaustive review of available literature and collection records suggested distribution and abundance of those species has declined in many localities (Bezzerides and Bestgen 2002). One of those places where the three species have declined in historical distribution and abundance is the middle Dolores River, Colorado, from near the town of Dolores downstream to the confluence with the San Miguel River. There, reduced streamflows from out-of-basin water diversions, which began in 1886, initially reduced populations of the three species (Holden and Stalnaker 1971). Beginning in 1985 with the closure of McPhee Dam and filling of McPhee Reservoir, additional streamflow alterations have occurred, a coldwater trout fishery was established, and several other introduced warmwater fishes have successfully established. However, the overall status of the fish community in that reach is uncertain, and available information regarding potential mechanisms for decline, has not been summarized.

Because of the need to better manage the middle Dolores River downstream of McPhee Dam for the protection of native fishes, the LOWER DOLORES PLAN WORKING GROUP-LEGISLATIVE COMMITTEE contracted with the authors of this study to independently summarize information to describe the status of the native fish community in the study area. This project was entitled "**Native Fish Synthesis and Identification of Management Possibilities to Protect 3 Species"**, and is relevant to the Dolores River "A Way Forward" program. Main objectives of Phase I of this project were as follows:

- Describe status of the three species in the Colorado River Basin
- Describe status of the three species in the Dolores River between McPhee Dam and the confluence of the San Miguel River

- Describe potential reasons for population changes in the Dolores River
- Describe preliminary management options and opportunities for improvement of the Dolores River fish community

That status information, which described distribution, abundance, and trends of the native fishes and preliminary opportunities for improvement, was summarized and presented orally by each scientist to the Dolores River group in April 2011. Those presentations were formalized as Phase I reports and represent the opinions of the individual scientists without the influence of the others; those reports are placed as appendices to this report (beginning on page 57, Bestgen 2011, Budy and Salant 2011, Miller 2011).

Phase II of the project was designed to take the summaries of fish status in the study area (Phase I reports) and then formalize the presentation of opportunities for improvement for the fish community; main topic areas include spill management, base flow and fish pool management, each of which include aspects of thermal regime management, and reduction of effects of non-native fishes. Nine specific opportunities were presented orally in early June 2011 to the Dolores group and represent a synthesis of information by the scientists involved.

Thus, the main purposes of this Phase II report are to 1) briefly summarize information that describes status and trends of flannelmouth sucker, bluehead sucker, and roundtail chub, in the Dolores River, Colorado, and 2), present opportunities for management changes to the physical or biotic environment that may improve the native fish community. This report will draw heavily on the Phase I reports (Appendices I-III) to justify and describe opportunities for improvement of the status of native fishes.

STUDY AREA

The Dolores River rises in southwestern Colorado, flows in a northwesterly direction, and is tributary to the Colorado River in southeastern Utah (see study area maps in appendices 1-3). We mainly considered the section of the Dolores River from downstream of McPhee Dam downstream to the San Miguel River, which is divided into six reaches. We note however, that rarely was detailed information available that would allow “reach-specific” conclusions or recommendations. We considered the general areas upstream and downstream of the San Miguel River for purposes of discussion of the historical fish community and opportunities for re-invasion of upstream reaches. The San Miguel River is the only permanent and large tributary of the Dolores River and is important because of its unregulated nature and potential to assist with restoration of native fishes in the Dolores River.

Methods

To prepare Phase I reports, we read widely from the available literature, and analyzed existing data that was provided by the Dolores River group. We borrowed extensively from the literature and analyses, particularly the fish data and reports prepared and provided by the Colorado Division of Wildlife, and the hydrologic analyses prepared by the Dolores Water Conservancy District. We also borrowed extensively from existing research that is presently being conducted in the Upper Colorado River Basin, as part of our own research and monitoring on the three species as well as that of others. As the reader studies Phase I reports, much overlap may be noted. This is because each report was prepared independently so that analyses and conclusions are not affected by opinions of the other scientists. Significantly, the main findings of each scientist were quite similar, no major differences of opinion regarding fish status were evident, and the strength of conclusions made from existing data was high.

To prepare Phase II findings, we prepared and distributed final Phase I reports, assimilated post-April-meeting feedback, conducted new research on opportunities for improvement, reviewed and discussed the benefits and drawbacks of those opportunities during numerous email and conference call exchanges, and had a final review of findings prior to an oral presentation in early June 2011. Similar to the Phase II oral presentation, this report presents project objectives (Introduction), a brief description of the three species status in the Colorado River Basin, a brief description of the three species status in the Dolores River, opportunities for improvement of the native fish community, a table that ranks the relative importance of the benefits for each of the opportunities, and some concluding summary and discussion. Similar to Phase I findings, there was also a high level of agreement among scientists for the relative importance of the opportunities for improvement for the native fishes. Rankings of relative importance were conducted independently by each scientist and were then summarized; differences among ranks are discussed.

To assist the reader, the presentation of opportunities for improvement follow the same general outline as for the oral presentation as below:

- Opportunity (e.g., spill management)
  Action,
  Benefit,
  Method (s),
  Schedule and Effectiveness,
  Issues and Uncertainties.

For each specific opportunity (e.g., spill management, nine in all), an action is described and reasons are given as to why it may be needed. The Action is followed by: a Benefits section that describes what aspects of the fishes life history the Action may improve; Methods to accomplish the stated action; when (Schedule) such an Action could be implemented given institutional constraints and information needs, and Issues and Uncertainties regarding each opportunity that may result from implementation of said Action.

The reader should also understand that some opportunities (e.g., thermal management of flows) can be achieved with different means (spill timing, different release levels from the reservoir, or both) so some redundancy in the discussion should be expected. Prior to discussion of the opportunities for improvement of native fish status, we will also describe some basic life history needs of the three species including: reproduction/spawning/movement; embryo and larvae development and growth; juvenile-recruit survival; and adult abundance, survival, condition. This basic information, some of which was excerpted from the extensive summary of Bezzerides and Bestgen (2002), will allow the reader to better link the opportunities for improvement to the specific life history needs of the species, which should increase the level of understanding regarding why each action should improve the status of native fishes in the study area. Throughout we will discuss additional information needs that may assist with an adaptive management process.

FISH LIFE HISTORY NEEDS

Prior to reproduction, adult life stages of the three species are known to undergo some level of movement to find suitable spawning habitat. This typically occurs in late spring (sucker species) when flow levels are rising or at their peak or early summer (roundtail chub) when flow levels are declining. During relatively high peak flows, stream substrate is disturbed and moved, which flushes fine sediments and algae from rocks and spaces between rocks. Thus, spawning during or just after peak flows ensures that clean cobble substrate is available for egg deposition and development. Eggs are typically deposited over gravel-cobble substrate and they attach (eggs are adhesive) to substrate particles in spaces between the rocks. That environment allows flow through interstitial spaces in substrate and carries oxygenated water to developing embryos. Flannelmouth sucker spawns earliest of the three species during just pre-peak to post-peak flow, and at water temperatures of 10-18°C. Bluehead sucker spawns slightly later, during peak or post-peak periods, at water temperatures of 14-20°C. Roundtail chub spawns the latest of the three species, typically as streamflows have declined from peak levels to nearly base flow and at water temperatures of 16-22°C.

Embryo and larvae development and growth then occurs during periods with relatively stable or declining flow and increasing water temperatures. Eggs development is temperature dependent; sucker eggs may take up to three weeks to hatch at water temperatures of 10°C, and then may not emerge from spawning substrate for an additional 7-14 days. Roundtail chub eggs will hatch in as little as 5-7 days at water temperatures of 18°C, and emerge within about 7 days.

When larvae emerge, they drift downstream until they encounter low or zero velocity habitat, which usually occurs near the stream margin in pools or backwaters. That habitat also supports early life stages of chironomid larvae, which are a primary food item for all three species, and growth rates are also enhanced by relatively warm water temperatures. Reduced competition for food and space and low levels of predators, especially non-native fishes, also enhance their survival and growth.

Juvenile life stages of the three species begin to show more specialized habitat use and different diets. Bluehead suckers occupy the swiftest riffle-run habitat, flannelmouth suckers mostly run and pool habitat, and chubs mostly pool and backwater habitat. Clean, hard substrate in each habitat type supports the highest food abundance; the three species (others as well) are typically rare as juveniles and adults in reaches that have predominantly sand or silt substrate. Bluehead suckers are scrapers of algae and invertebrates and often restricted to riffle habitat, flannelmouth suckers also obtain food items from the substrate, and roundtail chubs are highly omnivorous. High food abundance and warm water enhance their growth, and once achieved, relatively large body size limits their susceptibility to non-native predators. Low abundance of non-native predators promotes high survival and successful recruitment classes or cohorts of juvenile life stages.

Habitat and dietary needs of adults are similar to those of juveniles. Adults also require relatively deep overwinter habitat, including lower velocity pools and runs. Deep overwinter habitat is especially important in stream with low base flows, because many reaches that support these species have surface ice in winter. The need for hard and clean spawning substrate has already been discussed. Adults of bluehead sucker (> about 250 mm total length) and flannelmouth sucker (> than about 350 mm total length) are typically large enough to escape predation by all but the largest non-native predators, but adult life stages of roundtail chub (e.g., 200 mm total length) may be susceptible to predation by large smallmouth bass *Micropterus dolomieu*. Historically, all three species were susceptible to predation by native Colorado pikeminnow *Ptychocheilus lucius*.

RESULTS AND DISCUSSION

Colorado River distribution and status.--Flannelmouth sucker, bluehead sucker, and roundtail chub are cypriniform fishes native to the Colorado River Basin. While once widespread and abundant in cool and warm water reaches of small to large streams, those species now occupy 50% or less of their range in the Colorado River Basin, including only 45-55% of their ranges in the Upper Colorado River Basin (Bezzerides and Bestgen 2002). Habitat alterations including flow modifications and establishment of non-native species are primary causes of decline of native fishes in western rivers and in general, those same factors are likely responsible for the decline of the three species in the Dolores River (Petts 1984; Carlson and Muth 1989; Minckley and Deacon 1991; Stanford et al. 1996; Poff et al. 1997; Bezzerides and Bestgen 2002; Olden et al. 2006; 2008).

A result of reduced distribution and abundance of those species has been listing by various Colorado River Basin states under some conservation status (Table 1, in Bestgen 2011, Appendix I) and formation of a range-wide conservation agreement that has numerous signatories including: six Colorado River Basin states (AZ, CO, NV, NM, UT, WY); the Bureau of Land Management in CO, NM, WY, UT; U. S. Forest Service, Intermountain Region; National Park Service, Intermountain Region; U. S. Bureau of Reclamation, Rocky Mountain Region; U. S Fish and Wildlife Service, Mountain-Prairie Region, and Region 2; the Jicarilla Apache Nation, and Southern Ute Tribe (Rangewide Conservation Agreement). The Conservation Agreement was developed to implement conservation measures for the three species so that threats to persistence and the need to list those taxa under the Endangered Species Act are diminished.

Dolores River fish distribution, abundance, and status.—Several studies described the distribution and status of Dolores River fishes and were used to develop conclusions regarding status of flannelmouth and bluehead suckers and roundtail chub (details in appendices). The three species were presumed widespread and abundant prior to 1886 in the Dolores River from upstream of the present-day McPhee Reservoir downstream to the confluence with the Colorado River, as they were in most streams in the Colorado River Basin (Bezzerides and Bestgen 2002). By 1971, and again in 1981 and 1991, investigators (Holden and Stalnaker 1975; Valdez et al. 1982; 1992) found the three species abundant near the dam site at Bradfield but either absent (bluehead sucker) or intermittent in occurrence (common to abundant) in several reaches downstream to the San Miguel River (see also Figure 4, in Budy and Salant 2011, Appendix II). However, successful reproduction by all species was apparently occurring during at least some years in the study area based on presence of multiple year-classes, at some sites (Holden and Stalnaker 1975). The reach upstream of the San Miguel River was especially affected by low flows, as only flannelmouth sucker was found in 1971, and the reach was nearly dry in 1981.

Adult fish of the three species were moderately common (present) in 1989-1993 (see appendices for details), particularly upstream from McPhee Dam downstream to near the Dove Creek pumps site (31 miles), and all were thought resident fish (i.e., not flushed downstream from the reservoir in 1993). However, recruitment was apparently lacking as no early life stages or juveniles were detected. Absence of juveniles suggested this population was a remnant of the pre-dam fish community and would likely disappear over time as adults die and are not replaced by young fish.

Sampling since the early 1990's indicated that the native fish populations in the study area have declined. Roundtail chub is now very rare in upstream reaches 1 and 2 (the 31 miles of river downstream of McPhee Dam), and populations may be declining or extirpated. In relative terms and in downstream reaches, roundtail chub is the most abundant of any of the native fishes, but populations are small and either highly fluctuating or declining. Flannelmouth sucker is rare in upstream reaches 1-3 upstream of Disappointment Creek and present in variable abundance throughout the remainder of the study area but declining in those reaches. Bluehead sucker is very rare in the entire study area and has declined to the point of near extirpation in most reaches; it is more common in the Dolores River downstream of the San Miguel River. Very low abundance of riffle-dwelling bluehead sucker in the study area may reflect low availability of that habitat, because riffles dry or become uninhabitable when base flows are low. Successful reproduction by native fishes in the study area appears to be extremely low, and obvious only for roundtail chub. No study area reaches have strong populations of the three species or evidence of high recruitment.

Comparisons of recent biomass estimates of the three species in the Dolores River to other times and other streams also indicated a decline in abundance. For example, in the Gunnison and Colorado rivers, Colorado, three species biomass estimates ranged from 138-422 kg/ha, and in the early 1990's, biomass of the three species in the Dolores River at Big Gypsum and upstream reaches was 20-60 kg/ha. This is compared to more recent estimates of biomass of 0.6 kg/ha at Big Gypsum in recent times. This trend is supported by Anderson and Stewart (2007) who showed that at present low baseflow levels (e.g., 30 cfs or less), less than 5% of bluehead sucker habitat was available compared to higher flows and would support only low (< 5 kg/ha) biomass of bluehead sucker (e.g., Figure 11, Bestgen 2011, Appendix I; Figure 9, Budy and Salant, Appendix II).

In contrast to the low abundance of the three species in the Dolores River upstream of the San Miguel River, the native fishes are relatively abundant downstream, especially in recent times. In addition to high abundance of native fishes in the reach of the Dolores River just downstream of the San Miguel River, length-frequency distributions of flannelmouth and bluehead suckers and roundtail chub showed a range of sizes including young and adult fish (e.g., Figures 9 and 10, Bestgen 2011, Appendix I). This is the only reach of the Dolores River documented to have a healthy distribution of size classes for all three species, indicating reproduction and recruitment. At a downstream site near Gateway, Colorado, a healthy size distribution of suckers is present as well, but as previously indicated roundtail chub are rare in that reach.

Abundance and size distribution data for reaches of the Dolores River downstream of the San Miguel River may indicate a potential source effect of the latter stream on the fish community of the former. This may be a result of relatively high native fish abundance in the lower San Miguel River and subsequent movement of young and perhaps adults from that relatively unregulated river, which exhibits relatively high peak and particularly, base flow levels, compared to the Dolores River. It likely also indicates improved habitat of the lower Dolores River as a result of inflows of the San Miguel River, particularly for native suckers. Concordantly, this disparity also suggests severe flow and habitat limitations for native catostomids in the Dolores River upstream of the San Miguel River. Abundance and size distributions of the three species in the lower reaches of the Dolores River are similar to other rivers such as the Green River in Lodore Canyon or the Colorado and Gunnison rivers, where self-sustaining populations of these taxa still exist (Bestgen et al. 2007a and b; Anderson 2005; Anderson and Stewart 2007).

We were also made aware of, and considered observations by, local ranchers and other residents in the Dolores River study area of the fish community in the period prior to and after construction of McPhee Reservoir (summery letter from M. Preston, Dolores Water Conservancy District). They suggested that native fishes of several size classes (few large-bodied non-native fishes were present [common carp and channel catfish would be identifiable] during that time, substantiating the claim of species identity) were common in isolated, clear pools during many summers in the period prior to construction of McPhee Reservoir, when few trout or other non-native fishes were present. Since that time when base flows were higher and also since establishment of larger populations of non-native fishes, such observations of native fishes have not been made. The implication was that native fishes could persist in a low-flow environment, particularly in the absence of non-native fish populations, and that additional base flow was not necessarily the main limiting factor for native fishes now.

Native fishes have the capacity to endure drought conditions and persist in dewatered environments, especially in the absence of deleterious non-native and predaceous fishes. We would further suggest that the present issue with fish populations in the Dolores River is a function of many interacting factors, including non-native fish predators and low flows. Flow-limited systems that consist mainly of disconnected pools do not represent viable habitat for native fishes over the long-term, especially in the presence of deleterious non-native fishes.

Evidence to support this hypothesis was continued decline of native fishes during periods of drought in the early 2000's when flows were very low, and even in reaches where non-native fish abundance was low (e.g., Appendix I, Bestgen 2011, Figure 6). It may also be that harsh habitat conditions associated with very low flows may also have restricted establishment, or reduced abundance of, certain non-native fishes, although green sunfish appeared to increase during the recent drought. Another potentially important factor reducing present-day native fish communities in the Dolores River study area relative to those in the pre-dam era is lack of connection to upstream populations that may have supplemented downstream ones. That factor is not associated with low flows or higher non-native fish abundance, but instead, the physical barrier of McPhee Reservoir.

We suggest that careful monitoring of fish population response to various flow levels may yield additional insights into the effects of low flows on both native and non-native fish populations. It is possible too that a quasi-experimental approach (e.g., non-native fish removal from selected pools and not from others) could be undertaken during low flow conditions, to better understand native and non-native fish interactions. Minimally, low flow conditions may represent an opportunity to remove non-native fishes from the Dolores River in an efficient manner, recognizing that access to many reaches is difficult or impossible when flows are low.

Overall Native Fish Status: Conclusions

The strength of conclusions regarding the declining status of native fish was high among individual scientists. This is due in part, to the relatively high level of convincing information describing trends in the fish populations over time.

Non-native fish abundance.—A major threat to native fishes in the Dolores River may be presence of non-native fishes, either through competitive interactions or predation. The non-native fishes currently of greatest concern are trout populations in cold water reaches just downstream of McPhee Dam and smallmouth bass in warmer reaches further downstream. The panel notes, however, that other non-natives that are currently present but in moderately low abundance, may proliferate in the future under different environmental conditions.

Trout abundance was high in the reach just downstream of McPhee Dam and highest through the early 1990's (Bestgen 2011, Appendix I; Figure 7, in Budy and Salant 2011, Appendix II; Miller 2011, Appendix III). That fishery doubtless benefitted from relatively high flows in the period after dam closure until about 1995. Similarly, reduced flows after that, particularly from 2002-2004 resulted in low trout abundance, and abundance has remained relatively low after that, although recent abundances have increased with slightly higher flows since 2008. Most of the fishery is supported by naturally-reproducing brown trout *Salmo trutta*, although rainbow *Onchorhynchus mykiss* and cutthroat trout (Snake River subspecies, *Onchorhynchus clarkii*), and even native Colorado River cutthroat trout are stocked, some on an annual basis.

Presence of abundant trout in the reach from downstream of McPhee Dam downstream to the Dove Creek Pump site may have limited recruitment of young native fish and, over time, abundance of native fishes in the post-dam period because of predation by trout, particularly brown trout (Yard et al. 2011). Presence of abundant adult native suckers in the reach in 1993, which were thought resident fishes (i.e., were not washed over the dam in 1993, Nehring 1993) especially flannelmouth sucker, may be explained by the presence of relatively large populations in the pre-dam and just post-dam period and prior to establishment of large trout populations. Because those sucker species are long-lived (Sweet et al. 2010) they can persist with low levels of recruitment for long periods of time. However, even relatively low mortality (i.e., senescence) of adult fish over time will result in population decline when recruitment is low or non-existent. In support of this hypothesis, young suckers were absent in length-frequency histograms of flannelmouth and bluehead suckers from data collected in 1993. Hence, because no fish were available to recruit in that upstream reach, populations have dwindled from once-abundant populations in 1993 to near extirpation.

Distribution and abundance patterns of smallmouth bass are something of an enigma in the Dolores River downstream of McPhee Dam. First, smallmouth bass were detected in the system in 1993 subsequent to high spillway releases (not just from the bottom of the reservoir) from the reservoir in the spring and summer of that year, along with reservoir-restricted species including kokanee salmon *Onchorhynchus nerka*. Smallmouth bass either remained at low abundance (Figure 13, Bestgen 2011, Appendix I) throughout the reach or were further enhanced from additional reservoir escapement after that time. In spite of repeated sampling at Dove Creek and Big Gypsum sites through 2007, smallmouth bass were apparently rare. Only when sampling occurred between those two reaches via raft electrofishing in 2007 by the Colorado Division of Wildlife were relatively abundant smallmouth bass discovered (Figure 14, Bestgen 2011, Appendix I), and perhaps three or four size classes were present (possibly hatched 2003-2006). Reasons for restricted smallmouth bass distribution were discussed previously (e.g., Appendix I, Bestgen 2011, pgs. 14-15). Bass reproduction occurred during the lowest flow periods in recent history (2002-2004), when no spills occurred and warm water temperatures prevailed.

Patterns of smallmouth bass distribution and abundance are similar to the situation in the in the Yampa River, northwestern Colorado, where bass were present since 1992, but did not expand dramatically in distribution and abundance until low flow years when water temperatures were very warm beginning about year 2000 through 2004 (Bestgen et al. 2007 a and b; Johnson et al. 2008; Hawkins et al. 2009). Since then, smallmouth bass have expanded downstream in that system and have invaded the Green River around 2002 (Bestgen et al.

2007a and b, Bestgen et al. 2008). Establishment of substantial populations of smallmouth bass in the Dolores River should be avoided at all costs, because they can prey upon many life stages of native fishes and reduce abundant native fish populations to near extirpation (e.g., Yampa River ; Bestgen et al. 2007a; 2008). Negative effects of smallmouth bass on roundtail chub populations in the Dolores River may have already been noted, as chub abundance in the reach from the Pyramid to Disappointment Creek has declined, which is the reach smallmouth bass are now relatively abundant (White et al. 2008, CDOW 2010). Smallmouth bass are also extremely difficult to control once established.

Another potentially problematic non-native species is white sucker *Catostomus commersonii*. White sucker is abundant in McPhee Reservoir and upstream but has not been detected in downstream reaches (pers. comm., J. White, CDOW). White sucker is abundant and problematic in other regulated and non-regulated streams in the upper Colorado River Basin, including the Yampa and Green rivers (Prewitt 1976; Bestgen et al. 2007a and b; Hawkins et al. 2009) because white sucker hybridizes with native catostomids including flannelmouth and bluehead sucker. Establishment of white suckers in the Dolores River should be avoided because they are tolerant of cold to warm water and may promote hybridization with native suckers, and subsequent loss of genetic integrity of native fishes. White suckers and their hybrids are also very difficult to control. White sucker control measures taken to date should be continued.

Flows and temperatures in the Dolores River.—Flows in the Dolores River have been altered since transbasin diversions began in 1886. The biggest impact on flows was base levels in summer, when the reach downstream of the present-day McPhee Reservoir was often dewatered or had very low flow; negative effects on fishes were noted by Holden and Stalnaker (1975) and Valdez et al. (1992). Subsequent effects of McPhee Dam were to lower the magnitude and duration of peak flows (Figure 15, in Budy and Salant 2011, Appendix II); base flows were enhanced compared to flows since the late 1800's when transbasin diversions took most summer flows because of releases of water designated to help the fishery and provide for other downstream users (e.g., the "fish pool").

Total runoff levels from 1981-2010 (Figure 15, in Bestgen 2011, Appendix I) are nearly identical to the long-term average since 1896 for the Dolores River near Dolores, Colorado. However, the nature of the flow alterations and regulation make this a challenging system to support aquatic biota. This is because most systems regulated by a mainstem dam have relatively low peak flows but higher base flow levels, due to releases for irrigation and irrigation water that returns to the river. The Dolores River has both reduced peak flows and reduced base flows because water is transported out of basin.

Flows of the Dolores River upstream and downstream of McPhee Reservoir in very low, moderately low, and moderately high hydrologic scenarios show storage patterns related to water temperature (Figure 16, in Bestgen 2011, Appendix I; see also Figure B2 in Appendix B, in Budy and Salant 2011, Appendix II, and Figure 11, in Budy and Salant 2011, Appendix II). In lower flow years such as 2000-2004 and 2006, not even a small peak flow (spill) was evident downstream of McPhee Dam (Figure 11, in Budy and Salant, Appendix II), and water temperatures warmed early and rapidly. One prevailing hydrologic pattern is called the “fill-and-spill” management scenario, because water is held in the reservoir until it is filled completely and only then is water allowed to pass downstream through McPhee Dam; in some years there is no spill. In comparison, the high flow year 2005 had a long spill period that began early and water temperatures warmed more slowly and in a more natural pattern. This second prevailing scenario is termed “spill-and-fill”, when water is evacuated from the reservoir relatively early knowing that it will eventually fill because snow pack is high.

In other fill-and-spill years such as moderately low flow years 2007 and 2009, water temperatures showed early warming perhaps due to unnaturally high levels (e.g., approaching or exceeding 16°C) because flow releases were very low (Figure 17, in part, in Bestgen 2011, Appendix I; see also Figure B2 in Appendix B, in Budy and Salant 2011, Appendix II, and Figure 11, in Budy and Salant 2011, Appendix II). In each year, cold releases from the reservoir caused sudden depression of water temperatures (e.g., changes approaching 10°C) during high but relatively late flow periods. This scenario was opposite to what would occur upstream of the reservoir under a natural flow regime, where water temperatures would have remained relatively low as flows would rise earlier in the year and maintain cooler thermal regimes.

The altered flow and temperature regimes have implications for both native and non-native fishes. Early seasonal warming of stream flows downstream of McPhee Dam likely caused early maturation of gonads of all fishes. Typically native suckers spawn prior to high stream flows, beginning as early as mid-April and for example, bluehead and flannelmouth suckers in the middle Green River then first emerge from mid-May to mid-June, later if flows are high and relatively cool and earlier if flows are lower and relatively warm. If native suckers spawn and emerge prior to high flows in the Dolores River due to early warming, small and weak-swimming early life stages are likely swept far downstream and mortality may be high. Downstream transport of larvae occurs in other rivers during high flows as well but perhaps the relatively low amount of low-velocity habitat and holding areas for larvae in the Dolores River may limit their recruitment success. A dramatic drop in water temperature is also likely to influence hatching success of embryos and survival of larvae if they are hatched when water temperatures drop because development times are increased and growth rates are decreased, each of which may reduce survival of those early life stages. Roundtail chubs would likely spawn after high flows, because that species spawns at warmer water temperatures. However, if water warms enough prior to high flows and spawning occurred, reproductive success of that species may also be negatively influenced.

Reproductive success of certain non-native fishes may also be affected by the fill and spill water management scenario in a negative manner. For example, smallmouth bass in the Yampa and Green rivers in northwestern Colorado begin spawning in post-peak flows when water temperatures reach 16°C (Bestgen et al. 2007 a and b). If smallmouth bass spawn in the Dolores River at 16°C in a pre-peak period rather than a post-peak period (e.g., see thermographs for 2002, 2006, 2007), egg and nest destruction may be high because eggs and the small, weak-swimming larvae will experience high mortality. This scenario may explain, in part, why smallmouth bass have a relatively restricted distribution and low abundance in the Dolores River at this time. Another reason may be that smallmouth bass are now only expanding in the Dolores River after years of residence (since 1993) at relatively low abundance levels. Yet another explanation may be lack of adequate habitat upstream and down from their present distribution, upstream perhaps because of relatively cool water temperatures, and downstream because of silty, turbid, and low flow conditions in that reach with mostly fine-grained (silt or sand rather than cobble) substrate. Downstream expansion of smallmouth bass into the San Miguel River may be possible because of presence of good habitat and strong flows (pers. comm., D. Kowalski, CDOW) and would then present a source population to invade the Dolores River.

Reasons for decline of native fishes.—Declines of native fishes can be attributed to two main factors, loss of habitat due to flow and thermal alterations and negative effects of non-native fishes. Specifically, reduced peak and base flows limit habitat quantity and quality for most life stages of native fishes. Flow regimes downstream of McPhee Dam also affect thermal regimes directly and indirectly. Direct effects are from releases of cold water that are drawn from relatively low levels of the reservoir. Indirect effects come from reduced flows that promote early spring warming to artificially high levels, followed by releases of high flows which are cold. Minimally, these patterns may affect reproductive cues and readiness of native fishes, and if embryos or larvae are present, may result in thermal shock and high mortality of early life stages. Additionally, habitat loss via separation of the reach downstream of the dam from upstream tributaries (e.g., by McPhee Dam) may eliminate important sources of recruitment of young or older life stages of fish. All factors are important and potentially interacting, and it is unlikely a single factor can be attributed as the most important cause of reductions in native fish distribution and abundance.

A reversal of these negative effects is needed to restore native fish populations in the Dolores River study area. In addition to restoration of biomass levels that were discussed earlier, other metrics of recovery should include re-establishment of basic population/life history processes. These may include but are not limited to: annual spawning and recruitment; wider distribution and higher abundance; and re-creation of populations with viable age-size structure (e.g., more similar to downstream of San Miguel). Below we present nine management opportunities for improvement of the physical and biotic environment that may assist with recovery of native fishes in the Dolores River study area. Rationale for each is discussed and those opportunities are then ranked and the relative importance of each to recovery of native fish is discussed.

OPPORTUNITIES FOR IMPROVEMENT

The opportunities presented here are formulated from the synthesis of individual scientist reports by Bestgen (2011), Budy and Salant (2011) and Miller (2011) (See appendices I-III for complete reports). We identified nine opportunities for improvement. In the discussion of each opportunity we include specific topical categories as follows:

- Action – Description of the recommended change and why it is needed
- Benefit – The benefit of the Opportunity to the native fish or the disadvantage to non-native fish
- Method – A general description of how to accomplish the Opportunity
- Schedule/Effectiveness – An estimate of when the Opportunity should occur and how effective it may be
- Issues/Concerns – A general description of issues related to the Opportunity and potential concerns to be considered before taking the action

OPPORTUNITY: SPILL MANAGEMENT

ACTION: IMPROVE MAGNITUDE AND TIMING OF SPILL

The nature of the flow alterations and regulation make this a challenging system to support aquatic biota. The peak flow magnitude is reduced in all years from pre-dam conditions. The current spill pattern follows the general "fill and spill" principle where the reservoir is filled before a spill occurs (Figure 1; see also Figures 16 and 17, Bestgen 2011; Appendix I; Figure 15, in Budy and Salant, Appendix II). The result is later than normal spill timing and a dampened spring run-off peak, except in wetter hydrologic conditions. A secondary effect of the late spill is an early warm-up of water releases downstream of McPhee Dam followed by rapid temperature suppression during the spill (Figure 2; see also Figure 19, in Budy and Salant 2011, Appendix II).

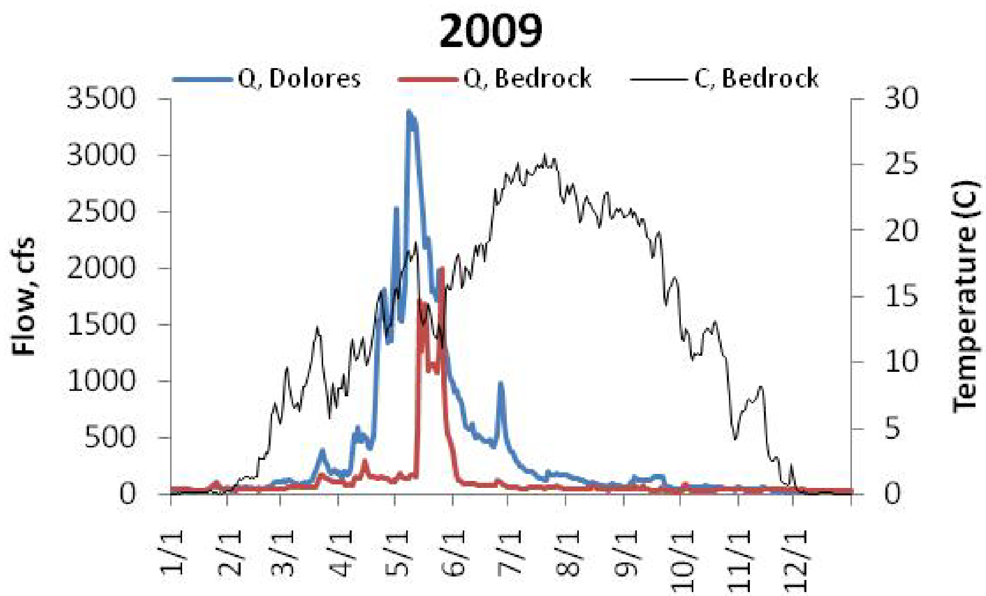

Figure 1. Flows of the Dolores River, upstream and downstream of McPhee Reservoir in 2009, illustrating a lower and later flow peak downstream from the dam. Water temperatures show a distinct depression after early warming during spring spill releases (see also detail in Figure 2).

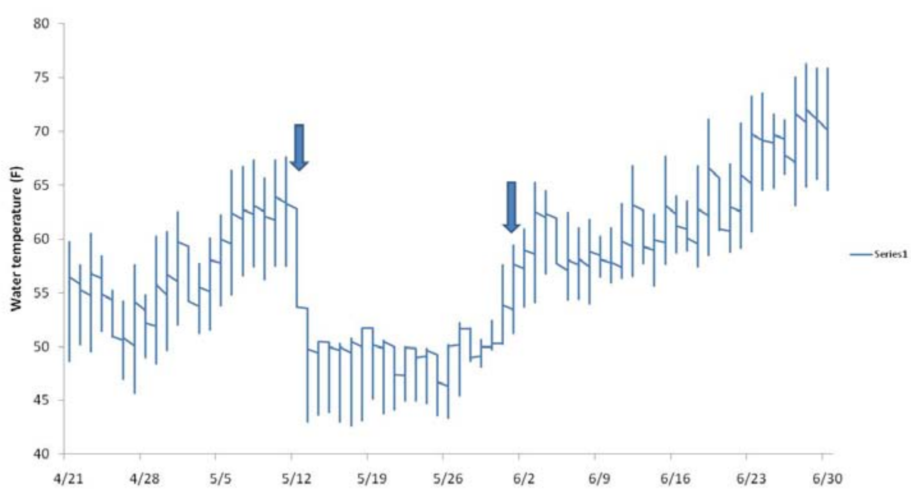

Figure 2. Rapid water temperature depression in the Dolores River 2009 downstream of McPhee Reservoir (just upstream of Disappointment Creek, Colorado Division of Wildlife data) caused by peak flow release (duration of spill denoted by arrows).

Spring time warming of water provides cues to native fish for spawning. If these fish spawn prior to the spill, there is a possibility of thermal shock to the eggs and larvae when the spill occurs which can reduce survival rates of these life stages and species.

Improvement to timing and magnitude of spring spills would provide the correct cues for native fish, and may result in higher survival rates of early life stages of fish. The magnitude and duration of the release should be patterned after the hydrologic condition present in any year, longer duration and higher magnitude flows in a wet year and lower and shorter flows in a dry year. Annual frequency of spills should be as often as possible.

Benefit: Improve magnitude and timing of spill

There are several potential benefits to native fish from spill management. The primary benefit is that it provides the correct cues for spawning. A secondary benefit is that it could disadvantage cold water non-native fish, in particular trout. The earlier release could be detrimental to newly emerged brown trout and reduce survival rates for those fish. The spills would also be beneficial to sediment transport and habitat maintenance (see below). Altered spill management may also conserve the fish pool by delaying the use of the fish pool water.

Method: Improve magnitude and timing of spill

The best method to improve the spill management would be to better match the inflow hydrograph timing, rather than the fill and spill management technique. This may require some additional snow pack and runoff forecasting, but nonetheless, the magnitude and duration of the spill should be determined by the type of hydrologic year. Some type of coordinated snow pack and run off forecast may be required to improve spill forecasts and timing.

Schedule/effectiveness: Improve magnitude and timing of spill

The first step in this opportunity is to develop an approach to match the inflow timing while still storing the contracted water supply. This could be accomplished using the historical data for inflows and snow forecasts to refine the reservoir spill management. This focused planning effort would determine how much and how often water is available. The closer the spills can replicate a natural hydrograph the more benefit to the river; a potential template is given in Shafroth et al. (2010).

Issues/Uncertainties: Improve magnitude and timing of spill

The main constraint would be the conflict with storage for other uses including rafting and storage of irrigation water. If the fish pool is excluded, then some type of planning would be needed to determine the potential to modify the releases from the current pattern. If the fish pool could be taken out of the dead storage via pumps or siphons, there would be additional water for spill management. The current operation is to fill the reservoir and then allow a spill to occur. To avoid the thermal impacts from high releases after initial warming, the operation should be spill and then fill. The planning effort discussed above could help to reduce uncertainty associated with spill management.

Opportunity: Base flow management

Action: Improve base flow regime

Several studies have recommended higher base flows to benefit native fish (e.g., see review in Budy and Salant; section "Opportunities for Base Flow Management: Recommendations", p. 17). We found a clear relationship between hydrology and native fish populations (see Figure 16, in Budy and Salant, Appendix II). Minimum flows were high in the years following dam construction, because releases from the dam restored perennial flows that had been previously removed for irrigation use during the summer (Figure 3). Populations of native species increased in the years following these high minimum flows (i.e., summer baseflows). However, the CPUE of non-native species increased and native species decreased following years of low baseflows (e.g., 1990-1992, 2000-2003), illustrating the strong effect of summer baseflow conditions on native populations. Historical (pre-1985) hydrographs show higher base flows during the ascending and descending limbs of the hydrograph but lower late summer flows (Figure 3). The biggest impact on flows was base levels in summer, when the reach downstream of the present-day McPhee Reservoir was often dewatered or experienced very low flow. The current base flows are held constant for long periods of time and are far below recommended flows for improved native fish populations. The inflows to the reservoir have higher base flows than the releases.

Benefit: Improve base flow regime

Higher base flows would provide more habitat for native fish and invertebrates (for food). There would be more escape cover and more diverse habitat, which would decrease competition and potentially predation, among native and non-native species. The higher flows could potentially provide some thermal buffering during times of very high air temperatures, because larger flow volumes require longer periods to warm rapidly. There also is the potential to improve water quality.

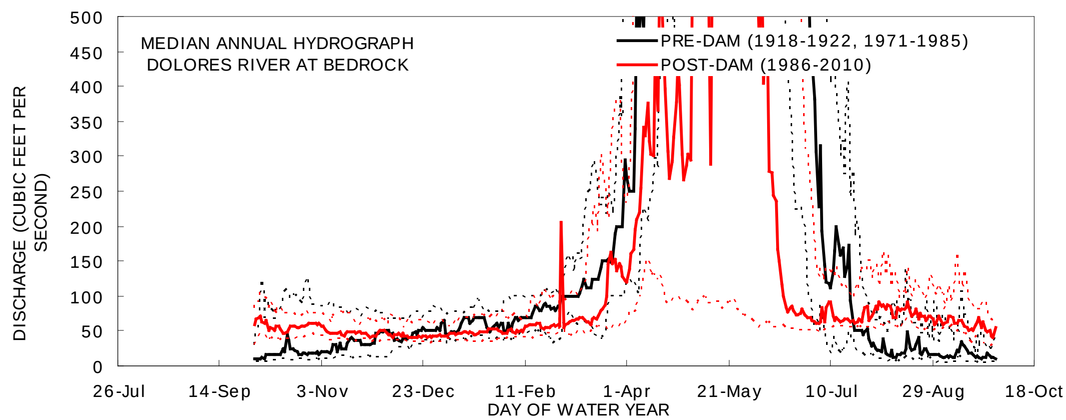

Figure 3. Low flow portion of the median annual hydrographs for the Dolores River at Bedrock, Colorado, for pre-dam and post-dam periods (Figure 15, from Budy and Salant 2011, Appendix II). Dotted lines indicate the 25th and 75th percentiles.

Schedule/Effectiveness: Improve Base Flow Regime

Some type of annual procedure for determination of flows during the base flow period should continue. Base flow scenarios could be developed during the analysis for spill management which would have an associated component of flow forecasting and runoff yields. From those determinations, a coordinated annual flow regime based on water year type should be considered, where base flows are linked to runoff flows. In other words, a wet hydrologic condition would result in a larger, longer spill and potentially higher base flows, whereas in a drier hydrologic condition, a shorter and lower magnitude spill and lower base flow would likely result.

Issues/Uncertainties: Improve Base Flow Regime

The primary uncertainty is water availability. The current active storage in the reservoir is fully allocated. If more water could be accessed, perhaps through a lease of water from a source upstream of McPhee Reservoir, or by use of allocated but unused water, operations for the fish pool and possibly an enlarged fish pool would be beneficial. Alternatively, the current water budget could be managed differently, with perhaps more flexibility across pools and years. Another potential source for more water is use of some portion of the dead storage in the reservoir. The use of the dead storage would require some additional infrastructure such as pumps or siphons.

OPPORTUNITY: GEOMORPHIC PROCESSES

ACTION: SEDIMENT FLUSHING FLOWS

Sediment accumulation in riffle substrates has been cited as the cause of degraded spawning habitat and reduced instream productivity in alluvial sections of the lower Dolores River (see literature summary in Budy and Salant 2011). Sedimentation has likely resulted from a reduction in the duration and magnitude of peak flows since construction of the McPhee Dam in 1984. High flow releases from the reservoir have been proposed as a means to remove fine sediment from the channel bed. However, given the large water demands on the reservoir and limited water availability for habitat maintenance, managers need to know what magnitude and duration of flow are required to mobilize fine sediment from the channel bed.

On the Dolores River, it has been suggested that a reduction in the frequency of sediment mobilizing flows has led to the overall fining of bed sediment in alluvial reaches downstream of McPhee Dam (see references in Budy and Salant 2011). Although reservoirs both store water and capture sediment, natural and anthropogenic sediment sources downstream of McPhee Dam far exceed any sediment trapped by the dam. Geology and hydrologic conditions of the basin upstream of dam result in a low rate of sediment delivery, such that the primary impact of the dam has been a change in hydrologic regime, rather than sediment supply to the Lower Dolores River (Richard and Wilcox, 2005).

Downstream of the dam, the effects of flow reduction have been exacerbated by increased sediment supply from grazed areas, banks disturbed by fishing and rafting, and roads. Sections of the river most susceptible to these impacts are the lower gradient, unconfined reaches, such as those from McPhee Dam to the top of Dolores Canyon and reaches flowing through Big Gypsum and Paradox Valleys. Other susceptible reaches are those downstream high sediment producing tributaries such as Disappointment Creek, the largest sediment source to the lower mainstem Dolores River in the study area. Sediment accumulation can cause the fining of bed material, channel narrowing, and homogenization of channel morphology. Furthermore, coarse sediment contributed from side canyons are likely rarely transported under flow regulated conditions, potentially causing the steepening of channel rapids and bar growth.

BENEFIT: SEDIMENT FLUSHING FLOWS

Controlled reservoir releases of flushing flows are often proposed as a way to remove accumulated fine sediments and loosen the gravel bed, in order to mitigate the effects of sedimentation on aquatic habitat (see references in Budy and Salant 2011). So-called "sediment maintenance flows" are generally smaller in magnitude than "channel maintenance flows", which are intended to maintain the channel and floodplain geometry. Designing sediment maintenance flows requires specification of the magnitude, duration, and timing of flow releases. Factors to consider when choosing the timing of flow releases include the life-history requirements of the target species, historical runoff period, flow availability, and desired survival rate of incubating fish eggs. Removal of excess fine sediment is expected to improve the quality of spawning habitat and thus reproductive success of native fishes, while also increasing primary and secondary productivity of the streambed and in turn improving rearing potential.

METHOD: SEDIMENT FLUSHING FLOWS

Previous studies have suggested that sedimentation on the Dolores River has led to the overall fining of bed sediment in alluvial reaches downstream of McPhee Dam and the subsequent degradation of instream habitat (see references in Budy and Salant 2011). Although this is a likely consequence of the reduction in peak flows by McPhee Dam and increased sediment supply downstream of the dam, there is not concrete evidence to show that these changes are in fact degrading fish habitat or reducing instream productivity. In order to determine whether these factors are affecting native fish populations, we recommend directly measuring streambed fine sediment and instream productivity (see our recommendations for a streambed sampling study).

On the Dolores River, Vandas et al. (1990) estimated that a discharge of 2000 cfs was required to mobilize the median particle size of riffle substrates and 7000 cfs was required to mobilize most of the bed materials in the section of river between Bradfield and Bedrock. In the post-dam period, those discharges corresponded to the 5- and 10-year recurrence interval floods, respectively. For the Big Gypsum reach, Richard and Anderson (2007) estimated a discharge of 3400 cfs for initial particle motion (return interval = 2.5 years in the post-dam regime) and 10,000 cfs for significant motion of the bed to occur (return interval > 35 years). However, both these studies estimated the threshold for particle entrainment from the Shields equation, using channel geometry and discharge to estimate average boundary shear stress and median particle size for the calculation of critical shear stress. Neither study therefore considered the effects of bed sand content and shielding effects of larger particles on smaller ones when estimating particle mobility. As a result, these are only very coarse estimates of the discharge required to mobilize a significant portion of the bed and flush fine sediment. A comprehensive study of bed mobility is needed to determine the flow magnitude and duration required to flush sediment (see recommendations for a bed mobility study in Budy and Salant, 2011, section “Analysis of Sediment Mobilizing Flows: Recommendations”, pp. 27-30).

Schedule/effectiveness: Sediment flushing flows

If sedimentation is determined to be a cause of habitat degradation and reduced instream productivity, then the implementation of a flushing flow release presents an opportunity to greatly improve instream conditions for fish and other aquatic biota. A flushing flow should be conducted in conjunction with the annual spring spill release but modified in duration and magnitude according to the results of the bed mobility study and any sediment modeling efforts (if completed). Even if a flushing flow is effective at removing accumulated fine sediment and loosening the gravel bed, it is possible that these changes will not significantly increase native fish populations if other factors are limiting – such as non-native fish or adult habitat availability. Also note that the effects (and benefits) could be spatially limited; the most susceptible locations are low gradient, unconfined alluvial reaches, whereas confined bedrock reaches are less likely to be affected.

Issues/Uncertainties: Sediment flushing flows

Designing sediment maintenance flows requires specification of the magnitude, duration, and timing of flow releases. Factors to consider when choosing the timing of flow releases include the life-history requirements of the target species, historical runoff period, flow availability, and desired survival rate of incubating fish eggs (see references in Budy and Salant 2011). Determining the magnitude and duration of flow requires consideration of bed sand content, water budget, and desired bed quality. However, these factors must also be balanced with potential economic and environmental costs of flow releases, including reduced water supply, and loss of spawning gravels. Specifying flow releases as accurately as possible can help minimize these costs, but doing so is often made difficult by the complexity of the flow and sediment transport system.

On the Dolores River, water managers may not be able to release the desired magnitude and duration of flow, or at the desired time or frequency, due to the demands of other water users (e.g., boaters, farmers). High flow releases can also potentially lead to environmental costs, such as the loss of spawning gravels, which may not be replaced if the supply of gravel to the river is limited by the presence of the dam.

OPPORTUNITY: GEOMORPHIC PROCESSES

ACTION: HABITAT MAINTENANCE FLOWS

We analyzed geomorphic data from the USGS Bedrock gage station located 94 miles downstream from McPhee Dam, following the methods of Smelser and Schmidt (1998). Plots of channel bed elevation over time and channel hydraulic geometry for several time periods suggest that the channel has incised at the location of the gage in recent decades (see Budy and Salant, 2011, section “Geomorphology”, pp. 23-26). Most of the observed incision appears to have occurred between 1993 and 1996, after an extended period of drought (annual peak flows from 1988 to 1992 were only ~1000 cfs) and immediately following the very high flows in 1993 (4550 cfs) and a second high flow event in 1995 (3140 cfs), with the bed dropping ~ 0.5 ft in the ~6 months following each storm. Although the channel incised following the drought period of 1988-1993, it remained stable (i.e., no consistent change in bed elevation) following the low flows of 2000-2004. These patterns of bed elevation change suggest that incision may be a result of vegetation encroachment during low flows; establishment of vegetation on lateral bars during low flows can force high flows into a narrower channel, promoting incision and an increase in flow depth to maintain channel capacity.

Possibly, a reduction in the frequency of overbank flows due to regulation by McPhee Dam has led to encroachment of the channel margins by vegetation that was historically removed during large floods (e.g., Figure 4); this reach is described as “dominated by tamarisks”, “broad and flat”, with “high amounts of fine sediment accumulation” (DRD Core Science Report 2005). During drought periods, lateral bars of fresh sediment become exposed and vegetation can establish. An extended period without overbank flows allows vegetation to grow without

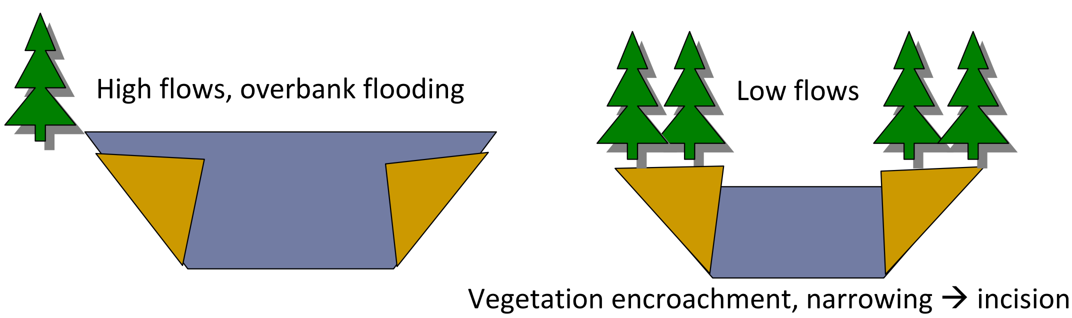

Figure 4. Schematic illustrating the possible effects of vegetation encroachment on channel geometry of the Dolores River at the USGS Bedrock gage station due to a reduction in overbank flows.

disturbance, reaching a density great enough to withstand higher flows and stabilize the channel margins. When high flows return, as occurred in late spring of 1993, the narrower channel must accommodate the increase in discharge by incising.

Although the bed elevation record suggests that channel incision has occurred at the gage location, it is unknown if other sections of the river have incised or if it is a localized, site-specific effect. Furthermore, we can only speculate what factors have led to this change and how it will impact habitat for native fishes. If incision occurs in other locations, it could reduce topographic variability, cause channel simplification, and lower hydraulic variability (e.g., Shields et al., 1994). However, despite the apparent bed degradation, we did not observe any changes in the hydraulic geometry relations for channel width or mean depth, indicating there have been few changes in channel morphology that might affect instream habitat. Vegetation encroachment could cause the loss of bars previously used for spawning when submerged at high flows, but further research is needed to determine if this has occurred in any areas. In an effort to identify changes in the sediment transport regime that might have caused the observed incision, we compared the pattern of bed elevation changes during high and low flows (i.e., patterns of scour and fill) between the pre- and the post-dam periods. Surprisingly, we found that in the post-dam era, high flows corresponded to a temporary increase in bed elevation (i.e., short-term fill), followed by scour during low flow periods. We did not observe this pattern during the pre-dam period; the frequency and regularity of scour and fill is not the same. Thus, patterns of stream incision and fill may be variable across locations and reasons for such are not apparent. Additional research may be needed to better understand the sediment transport regime of the river and its impact on channel morphology and instream habitat.

BENEFIT: HABITAT MAINTENANCE FLOWS

It is important to differentiate between sediment maintenance flows (i.e., the discharge required to mobilize the bed) and the discharge required for channel maintenance. In theory, the "channel-forming" or "dominant" discharge is the flow that if maintained indefinitely would produce the same channel geometry as the natural long-term hydrograph. Identifying the channel-forming discharge can be useful in assessing how an altered hydrology (e.g., flow regulation, diversions) might affect channel morphology, with subsequent impacts on fish habitat. The concept of a channel-forming discharge is generally applicable to stable alluvial channels (i.e., those that maintain a long-term equilibrium with the imposed flow and sediment regimes), but may be less useful for rivers in arid environments characterized by localized high intensity storms and limited vegetation; under these circumstances, the channel adjusts to each major flood event. Nevertheless, characterizing the channel-forming discharge can aid management of regulated rivers by identifying how an altered hydrology might affect geomorphic conditions.

Pool-riffle-run sequences are the characteristic morphology of low gradient, meandering, gravel-bed rivers like the Dolores River, and provide critical habitat for the various life stages of native fish. Although there is still some debate over the exact mechanisms by which pool-riffle sequences are maintained (Sear 1996), it is generally accepted that high flows generate the conditions required for pool scour and riffle deposition, offsetting the gradual scour of riffles and deposition in pools that occurs during low flows. Without the occurrence of high flows to increase the amplitude of pool-riffle sequences, the channel would gradually homogenize into a continuous flatwater without the topographic and hydraulic heterogeneity necessary to support a healthy and diverse fish community.

In addition, relatively frequent overbank flows enhance floodplain connectivity and prevent the encroachment of riparian vegetation onto bars within the channel boundaries. Vegetation growth on and stabilization of lateral channel bars can force high flows into a narrower channel, promoting incision and an increase in flow depth to maintain channel capacity. Channel incision in turn can lead to simplification of instream habitats. Growth on gravel bars used for spawning at high flows plus reduced flooding may also reduce spawning habitat availability and affect reproductive success. Furthermore, a reduction in the frequency of overbank flooding may reduce wood recruitment into channel, with subsequent effects on physical complexity and cover.

Method: Habitat maintenance flows

We recommend attempting to reestablish the high flow regime (magnitude and duration) of the pre-dam regime (e.g., see Figure 5) via dam releases and management of diversions to initiate bed mobility, facilitate channel scour, and potentially return the channel to its pre-dam condition. We determined the pre-dam 2-yr recurrence interval flood at the Bedrock gage to be 4983 cfs (see Budy and Salant, 2011, section "Spill Management and Base Pool Management", pp. 12-17). Such reductions in flood level would be expected to result in a reduced frequency and extent of floodplain inundation, which would lead to bar and island stabilization, vegetation encroachment, less cottonwood recruitment, more invasive perennial species, and decreased abundance of disturbance-vulnerable species (e.g., narrowleaf cottonwood). However, more analysis is needed to determine the magnitude and duration of dam releases necessary to recreate the pre-dam high flow regime at multiple locations downstream from the dam, and continued monitoring is recommended to document the extent of floodplain inundation, the effects on vegetation establishment, and the patterns of bar growth during and following high flow releases.

SCHEDULE/EFFECTIVENESS: HABITAT MAINTENANCE FLOWS

We suggest reestablishing the high flow regime of the pre-dam era via annual or every other year spring releases similar in magnitude and duration to those experienced every 1-2 years prior to construction of the McPhee Dam. However, simply recreating the pre-dam hydrology (if feasible) may be insufficient to restore the natural patterns of scour, fill, and overbank flooding necessary for habitat maintenance. Extensive growth of vegetation on channel banks and bars may prevent bar scour and sediment mobilization, keeping the channel in a new stable state that even pre-dam high flows would be unable to change. Furthermore,

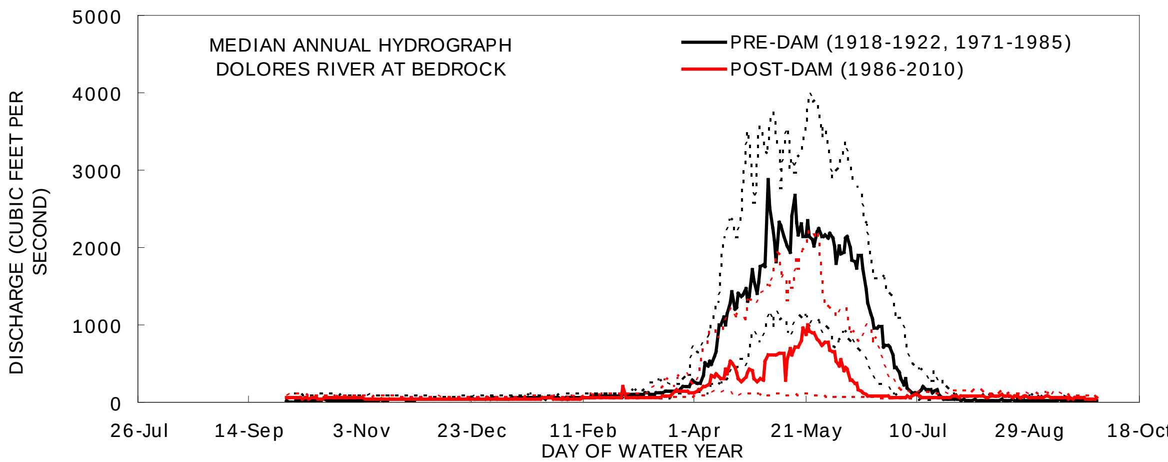

Figure 5. Median annual hydrograph of the Dolores River at Bedrock for the pre-dam and post-dam periods showing the reduction in high flows due to the dam. Dotted lines indicate the 25th and 75th percentiles.

we recognize that it may not be possible to release large flows this frequently, given the demands of other water users. In this case, a larger flood every 5 years, with a magnitude similar to the 5 year recurrence interval flood of the pre-dam period, may be sufficient to maintain channel form and prevent vegetation encroachment if it is of a great enough magnitude to scour the channel. We have estimated the pre-dam 5-year flood to be 6,929 cfs (see Budy and Salant, 2011, section "Spill Management and Base Pool Management", pp. 12-17). A flow of this magnitude may be adequate to mobilize bed sediment and prevent vegetation encroachment, but we can't know for sure without more information. Other studies of experimental floods below reservoirs in desert environments have used wet years as opportunities to release high magnitude floods similar to the 1-3 year recurrence interval floods of the pre-dam period (see Shafroth et al., 2010 for an example of an integrated approach to using floods for environmental management in a desert river). Although river managers are increasingly turning to high flow releases as a tool to restore ecosystem processes of regulated rivers (i.e., 'environmental flows'), we still don't have a quantitative or comprehensive understanding of the relationships among streamflow, channel morphology, and biotic response; relationships are often descriptive and river- or species-specific. On the Dolores River, we need more information about how the channel and associated vegetation respond to high flows and what magnitude and duration of flows are needed to create and maintain the morphology of the pre-dam channel (see our recommendations under Issues/Uncertainties).

The potential benefit to native fishes is as yet unknown, but is expected to be moderate. Although it is highly plausible that the known hydrologic changes have resulted in significant morphological changes, with likely effects on instream habitat, we do not know for certain the spatial extent of these changes or the degree of impact on fish populations. Possibly, the observed incision could be localized to the Bedrock gaging station, with no significant changes (or different morphological changes) at other locations. The magnitude of effect will certainly vary among reaches depending on channel gradient, degree of confinement, and the nature of tributary inputs. The reaches most susceptible to change are the lower gradient, alluvial, unconfined reaches, such as the section from McPhee Dam to the top of the Dolores Canyon and portions flowing through Big Gypsum and Paradox Valleys; these reaches likely experience the fining of bed material, channel narrowing, and channel simplification. High gradient, confined, bedrock controlled reaches are less susceptible but may have also narrowed due to bar growth and vegetation encroachment. Given these changes, it is likely that native fish habitat has been affected, particularly the loss of channel complexity and hydraulic variability. However, it is still unclear whether restoring the natural processes of scour, fill, and overbank flooding will have a significant effect on instream habitat or native fish populations if the effects are spatially limited or if other factors are limiting to fish health.

ISSUES/UNCERTAINTIES: HABITAT MAINTENANCE FLOWS

More information is needed or needs to be compiled to determine what is causing the bed lowering, if it is occurring at other locations, and what effect these geomorphic changes are having on instream habitat. Finally, as is the case for sediment flushing flows, water managers may not be able to release the desired magnitude and duration of flow, or at the desired time, due to the demands of other water users (e.g., boaters, farmers).

We recommend the following research to obtain more information about the nature and causes of channel change:

1. Locate and resurvey historic channel cross-sections (e.g., old Bedrock gage location before it was moved; 1974 CDOW cross sections) to determine changes in channel shape at different locations along river
2. Obtain and analyze the complete USGS records from the Bedrock station (see Smelser and Schmidt, 1998). Use the original discharge measurement notes to

verify the location of all measurements; determine the maximum depth of the channel at each measurement time; and compare actual cross-sections from different points in time to determine how the shape of channel has changed, not just the mean channel geometry.

3. Perform a historical analysis of the available aerial photograph record along with historic flow data to determine the relation between geomorphic processes and high flows, the history of vegetation establishment, and the history of changes in channel geometry

Environmental flow releases present a unique opportunity to learn more about the relationships between streamflow and channel response, if careful documentation and monitoring occurs following high flow releases.

OPPORTUNITY: THERMAL REGIME MODIFICATION

ACTION: CHANGE THERMAL RELEASE TO MATCH NATURAL PATTERN

The thermal regime downstream of McPhee Reservoir is modified from the natural pattern due to the low level, cold-water release. The current reservoir release pattern causes a warming followed in many years by abrupt temperature depression (e.g., Figures 2 and 6). This provides an incorrect cue for spawning native fish, and possibly results in thermal shock of incubating eggs or larvae of native warm water fish. In addition, the cooler water temperatures likely lower productivity and native fish growth. An example of the early warming and subsequent abrupt thermal change are illustrated with the 2009 data.

BENEFIT: MODIFY THERMAL REGIME

A more natural thermal regime would benefit the native species by providing the correct cues at times appropriate for natural life stage functions (e.g. spawning, growth; see the life history discussion above for thermal needs). A thermal regime with a more natural pattern could also return a more “natural” diversity and productivity to the invertebrate community. A more natural thermal regime may disadvantage cold water non native fish and restrict their downstream range. Note, there is a potential to benefit non-native warm water species.

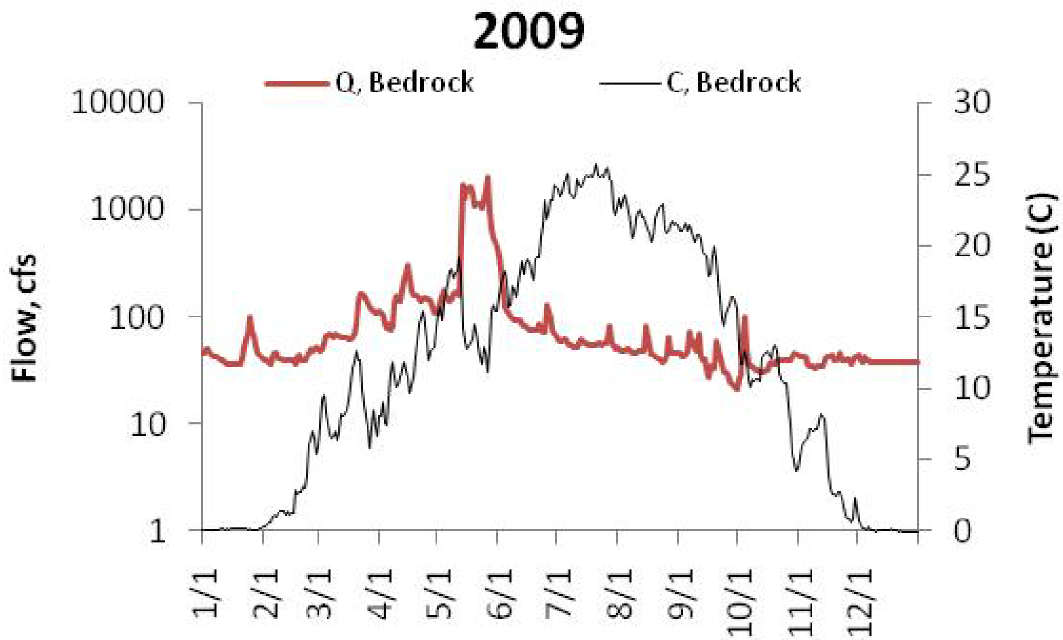

Figure 6. Comparison of 2009 water temperature and discharge for the Dolores River at Bedrock, Colorado, showing water temperature depression during the spring spill period after an early warming period.

METHOD: MODIFY THERMAL REGIME

There are several ways to implement cooler water temperatures. One means is to provide the modification with a change to the flow releases. A more natural release pattern as discussed in the sections for spill management and base flow management would also benefit the thermal regime. An example of such a release is shown in the conditions for 2005 (Figure 7). There was a steady ramp up to peak flow and then a gradual decrease to base flow. The thermal regime for that year shows a steady, slow warming of water temperature that remained at or below 10°C through April, which is at or below the level when most native fishes begin to spawn. Water temperature regimes show a subsequent peak in water temperatures in summer. Maintaining water temperature levels as they occurred in the spill and fill year 2005 may not always be possible, given differences in hydrology and timing of runoff, but that year may provide an example of a pattern to follow in most years. The dam also has a selective level outlet that is used for releases of colder or more water in spring. Higher releases may be feasible and deserves further study because it may avoid problems with release non-native fish downstream, given that reservoir fishes may not occur in the coldest areas of the reservoir.

SCHEDULE/EFFECTIVENESS:

The flow management opportunities could be implemented first and would provide a thermal benefit. The use of the selective outlet works would depend on whether the non-native species in the reservoir could be contained by some type of screening mechanism. The higher elevations of the selective level outlet works should not be used until non-native fish escapement issues are addressed. The effectiveness of this opportunity would depend on how much the temperature regime could be changed. This opportunity would be most effective when the thermal pattern more closely matches the natural pattern prior to the dam. Releases

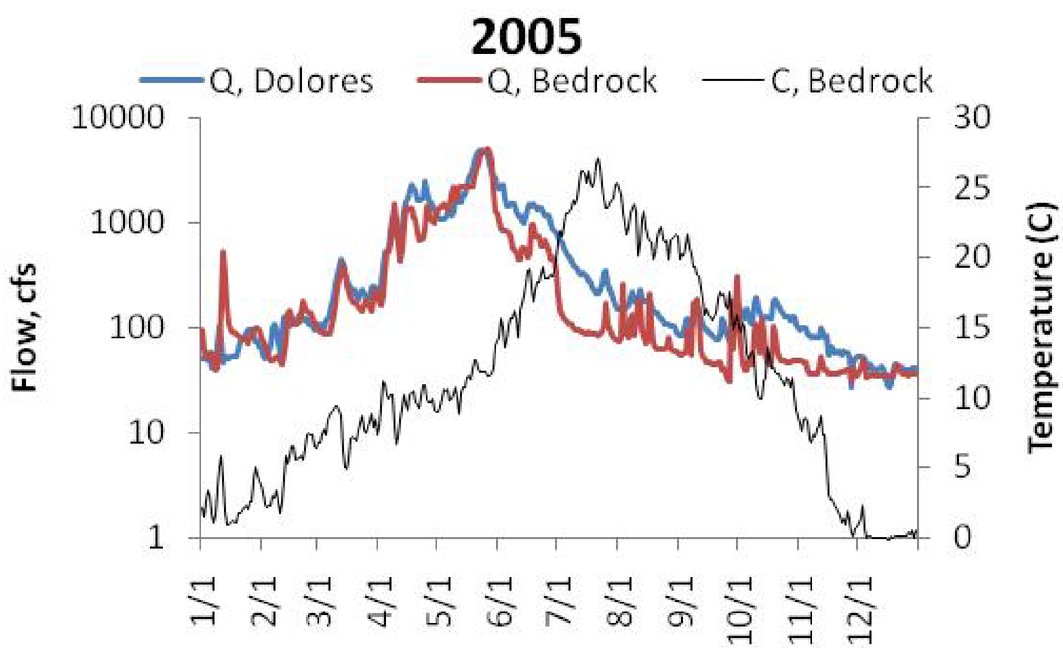

Figure 7. Flow of the Dolores River upstream and downstream of McPhee reservoir and water temperature downstream, 2005 (d < 10 cfs = 0, d > 800 = 57).

of cooler water in the spring to limit early season warming may also be feasible. However, caution is urged when considering alteration of selective level releases until the issue of non-native escapement is resolved.

ISSUES/UNCERTAINTIES:

The non-native fish could be entrained and released even if outlets are screened, because small, early life stages of fish are difficult to screen effectively. It is in fact, somewhat surprising that white suckers have not yet been introduced given presence of upstream populations. White suckers hybridize with native suckers and would likely reduce viability of existing small populations, as has happened in many other parts of the Upper Colorado River Basin including higher elevation populations in the upper Yampa and upper Green rivers, Colorado. Installation of fish screens may reduce escapement of larger life stages but may do little to reduce entrainment and escapement of early life stages.

There may be limitations on the amount of flexibility for the release (amount) and temperature depending on reservoir contents. Warm water non-native fishes that are already established downstream may also benefit from the release.

OPPORTUNITY: REDUCE COLDWATER INVASIVE SPECIES EFFECTS

ACTION: DISCONTINUE STOCKING

Thousands of cold water salmonids (mainly rainbow and cutthroat trout) are stocked each year in the Dolores River downstream of McPhee Dam to supplement the naturally-reproducing population of brown trout in that reach, and area where native fish were once common in the post-dam era (e.g., Appendix I, figures 2 and 3, Bestgen 2011). Most are sub-catchable size and are stocked to provide a diversity of opportunity for anglers. Those fish use substantial resources during growth and thus, compete with native fishes for food. Larger individuals are also potential predators on native fishes, particularly early life stages of native fish.

BENEFIT: DISCONTINUE STOCKING

Discontinuing stocking of non-native salmonids in the study area would potentially reduce competition between trout and early life history stages of the three species and increase native fish growth rates. Fewer salmonids may also reduce predation on native fishes, which would increase early life stage survival and abundance. Reductions in upstream salmonid populations may also allow warm water native fishes to expand upstream into habitat that is currently not occupied, and would increase recruitment and abundance of adults in places where they are now rare.

METHOD: DISCONTINUE STOCKING

Reduce or cease annual stocking of trout.

Schedule/effectiveness: Discontinue stocking

This action could be implemented immediately. We believe this action would be only moderately beneficial because stocked trout are less abundant than self-perpetuating brown trout, and because the species of trout that are stocked are typically less predaceous on other fish (piscivorous) than brown trout.

Issues/Uncertainties: Discontinue stocking

Primary issues and uncertainties are the level of benefit that will be achieved relative to the potential negative perceptions and reactions by the angling public and resource agencies, especially if this is only a moderately beneficial action

Opportunity: reduce coldwater invasive species effects

Action: Reduce brown trout reproductive success

Brown trout established a self-perpetuating population downstream of McPhee Dam by the late 1980's and at this time are widespread and relatively abundant. Brown trout are also the most warm-water tolerant of all trout species present and thus, can expand downstream and overlap broadly with native fishes and their habitat. This is problematic because brown trout can compete with native fishes for food resources and reduce their growth. Brown trout are also highly piscivorous, and large individuals could prey upon all life stages of roundtail chubs and juvenile and sub-adult life stages of the sucker species. Negative effects of predation and competition by brown trout on native fishes in the Colorado River Basin are well documented (e.g., Yard et al. 2011) and circumstantial evidence for such exists in the Dolores River, based on absence of juvenile suckers in reaches just downstream of McPhee Dam where brown trout were abundant (figures 4 and 5, Bestgen 2011, Appendix I).

Benefit: Reduce brown trout reproductive success

A benefit of reduced brown trout distribution and abundance would be to increase growth and survival of early life stages of native fishes. Reduced downstream distribution would also allow warm water fishes to expand upstream into habitat that may be only marginally suitable from both a predator abundance perspective and a thermal perspective, which would increase abundance of upstream populations of native fishes.

METHOD: REDUCE BROWN TROUT REPRODUCTIVE SUCCESS

There are several methods to reduce reproductive success of brown trout and eventually reduce their distribution. First, trout populations could be reduced by physical removal. Sampling techniques and access may permit relatively large reductions in larger adult size classes that are especially vulnerable to electrofishing sampling techniques. Adult mortality could also be increased by removal of bag limits on all trout species in the study area or a mandatory catch and kill regulation. The effectiveness of this technique would depend on the number of anglers that use the reach, and their willingness to remove captured fish.

Reduced reproductive success would be a means continue to reduce brown trout in addition to removal of spawning-sized individuals. This could be accomplished by flow reductions in late autumn, which would strand redds and eggs after deposition. Flow spike could also be used after early life stages of brown trout emerge from spawning redds in late winter or early spring, but would need to occur prior to spring runoff. Strong floods are known to reduce or nearly eliminate year-classes of brown trout in other streams, and large magnitude releases from McPhee Dam may be effective at reducing recruitment.

Finally, release of much warmer water from the reservoir may reduce the suitability of the habitat for cold water trout species. Minimally, increased water temperatures may reduce the downstream extent of salmonids in the reach. This would also increase the suitability of the reach for warm water fishes.

SCHEDULE/EFFECTIVENESS: REDUCE BROWN TROUT REPRODUCTIVE SUCCESS

Efforts to reduce brown trout abundance could begin immediately. This is especially true for efforts that aim to reduce abundance of adult life stages. These actions are potentially highly beneficial because brown trout are abundant and highly piscivorous.

ISSUES/UNCERTAINTIES: REDUCE BROWN TROUT REPRODUCTIVE SUCCESS

Acceptance of this action by the angling public and resource agency acceptance is an issue, but perhaps establishment of a trout fishery in a different location could be a solution. This action would likely take several years to accomplish because large brown trout are long-lived, and efforts to reduce reproductive success may take several consecutive years to accomplish.

A large uncertainty is the efficacy of releasing warmer water from McPhee Reservoir to reduce suitability of the habitat for coldwater fishes. Warmer water released from higher levels of the reservoir has potential to introduce additional fishes into the Dolores River. This is a high risk activity, and introduction of additional reservoir fish should be avoided because larger populations of smallmouth bass and introduction of white sucker have the potential to undo any positive benefits of other management actions (see above). It is also possible that the brown trout population will experience a density-dependent release after adult removal, and juvenile brown trout recruitment will increase (Saunders and Budy; in prep). As such, removal efforts will need to be maintained over additional years.

OPPORTUNITY: REDUCE WARM WATER INVASIVE SPECIES EFFECTS

ACTION: DISADVANTAGE SMALLMOUTH BASS REPRODUCTIVE SUCCESS

Invasive species are a main reason for the demise of native fishes in western streams, and piscivorous smallmouth bass are especially problematic because of their large size, high abundance, adaptability, and high reproductive output. They are especially problematic for the three native species because of high habitat overlap and tolerance for warm water and seasonal turbidity. Because all life stages of smallmouth bass are piscivorous and they grow quickly, all but the largest life stages of native fish are susceptible to negative effects of competition and predation.

BENEFIT: DISADVANTAGE SMALLMOUTH BASS REPRODUCTIVE SUCCESS

Smallmouth bass presently have a restricted distribution in the Dolores River and every effort should be made to maintain that status. Low abundance of smallmouth bass will enhance growth rates and survival of native fishes, allow for upstream expansion of native fish, and ultimately increase their population size.

METHOD: DISADVANTAGE SMALLMOUTH BASS REPRODUCTIVE SUCCESS

Several methods may be available to reduce abundance and reproductive success of smallmouth bass. First, reduced abundance of adults would result in fewer offspring which could be effected through enhanced exploitation (angling) or mechanical removal (electrofishing). This action is difficult to implement in the Dolores River because access is difficult and angling or removal sampling opportunities are limited. Thus, those conditions place a premium on maintaining low abundance levels.

Another means to reduce reproductive success is to disadvantage bass during the reproductive season. Smallmouth bass are nest spawners, building loosely constructed spawning beds over gravel-cobble substrate in relatively low velocity habitat. Males guard nests after female bass deposit eggs, and they guard larvae after hatching for 1-2 weeks. Cold water temperatures cause males to abandon nests, and high velocity flows may sweep eggs and just hatched larvae away because they are weak swimmers. Short-term releases of cold water, or a higher flow at any temperature at the correct time, may cause nest abandonment or result in high mortality of unguarded and weak swimming larvae. Onset of smallmouth bass spawning in the Yampa and Green rivers, Colorado, occurs once water temperatures reach 16°C (K. Bestgen, unpublished data). Onset of smallmouth bass spawning in the Dolores River could be monitored by observing spawning bass or by back-calculating bass hatching and spawning dates via analysis of otolith daily increments, so that disruptions to spawning success could be timed for maximum effectiveness.

Schedule/effectiveness: Disadvantage smallmouth bass reproductive success

Immediate implementation of flow or temperature disturbances may be effective, but it is not known if smallmouth bass in the Dolores River spawn before or after the spring peak in most years, and what management action (e.g., flows, water temperatures shifts) may be the best choice. Thus, more information is needed regarding bass spawning times to ensure management actions are effective. Measures to maintain smallmouth bass in a restricted distribution and abundance in the Dolores River are important, noting that current management or fortuitous hydrology and geology (e.g., silt, turbidity downstream) has maintained bass at a low level since their likely introduction date in 1993. This is important because once bass are established and widespread, it is unlikely that anything except massive removal efforts with piscicides will be effective, and even that will be a temporary solution due to reinvasion.

Issues/Uncertainties: Disadvantage smallmouth bass reproductive success

It is uncertain if present management practices are limiting smallmouth bass in the Dolores River at this time. For example, warm water temperatures early in the season may promote early spawning prior to peak flows. If that occurred, it is likely that most or all smallmouth bass produced prior to peak flows would be destroyed. Understanding when smallmouth bass reproduction is occurring in this system, under a variety of flow and water temperature regimes, would provide useful clues about when to implement flow/temperature disruptions.

Another uncertainty is whether flow disruptions might negatively affect reproduction by native fishes, especially later spawning roundtail chub. Flow disruptions may also increase the potential to introduce reservoir fishes to the Dolores River. Uncertainties are perhaps highest for this management option, because once smallmouth bass are widely established they may be very difficult to control. This is a good example of how flows, water temperatures, and biological factors may interact.

OPPORTUNITY: SUPPLEMENT NATIVE FISH

ACTION: SUPPLEMENT ADULT NATIVE FISH

Adults of the three species are in low abundance in the study area, particularly in upstream reaches. This is important because early life stages of these species drift downstream to populate reaches where reproduction may be lacking.

BENEFIT: SUPPLEMENT ADULT NATIVE FISH

Supplementing adult life stages of native fishes would improve a depleted upstream spawning stock, which would then be capable of seeding downstream reaches with early life stages. Using adult life stages would also ensure higher survival than early life stages and provide a stock ready for reproduction if enough fish were supplemented. Successful population response would be easy to monitor with early life-stage sampling.

METHOD: SUPPLEMENT ADULT NATIVE FISH

Adult fish should be captured within the same drainage, either from reaches upstream of McPhee Reservoir or downstream in the lower reaches of the San Miguel or Dolores rivers. This would ensure that the genetic structure of supplemented fish was similar to that which historically existed, and ensure that travel time and associated stress and mortality of moving fish is minimized. Fish should be stocked at a non-stressful time of year (e.g., autumn) to avoid high water levels and high water temperatures and in a year (years) when flows are relatively high.

SCHEDULE/EFFECTIVENESS: SUPPLEMENT ADULT NATIVE FISH

This action could be accomplished relatively soon, but not immediately. This is because other environmental issues such as low water temperatures or detrimental flow regimes (see other Opportunities 1-8) and high abundances of non-native predators need to be resolved first, in order for supplemental stocking to be effective.

Supplemental stocking could be moderately to highly effective if enough fish in good condition were available and assuming other limiting factors had been addressed. An additional advantage would be ability to monitor effectiveness of management actions without the constraint of inadequate numbers of adult fishes to respond to conditions.

ISSUES/UNCERTAINTIES: SUPPLEMENT ADULT NATIVE FISH

A main issue would be obtaining enough non-hybridized fish of the correct genetic lineage to elicit a response, likely several hundred to a thousand or more individuals. It would be desirable to initiate this in a water year when flow conditions were relatively high, and as discussed above, after most important flow, thermal, and non-native fish constraints have been minimized or removed. This action would also require monitoring to ensure success, mostly in the form of early life stage fish sampling. The main goal would be to document reproduction and relative abundance of young fish, and eventually recruitment. Minimally, that sampling should occur in the period just after presumptive reproduction (July) and again in autumn along the longitudinal gradient of the river study area to document successful reproduction and survival through the summer. Funding sources for this type of activity are available (please see below).

RELATIVE BENEFITS AND RANKINGS

Below is a listing of the management opportunities to restore the native fish community and relative benefits we assigned to each (Table 1). There were no low benefit opportunities, because we chose not to discuss any options that were either not beneficial or completely out of consideration. We then independently ranked the list of management opportunities relative to the benefit we thought may be attained for native fishes (Table 2). It should be noted that unlike for Phase I reports, the three authors worked collaboratively to create this Phase II report in all aspects but one. Here, we thought it would be interesting to present independent rankings of the relative benefits of the nine management opportunities, and then combine them in a mean ranking, which is presented below.

Thus, columns headed by 1, 2, or 3 represent each scientist's view of the most beneficial management options (1=highest rank, 9=lowest rank); mean is the mean ranking of all nine management opportunities. Some differences existed among scientists, and for different reasons, but in sum, there was good agreement about the most beneficial management actions. For example, we agreed that base flow and spill management ranked high, along with the need to enhance the thermal regime and reduce negative effects of the trout population on native fishes. It should be noted that any factor that we ranked higher than a 4 or a 5 is considered important, and that small differences among top rankings (e.g., a difference of 1) should not be interpreted as having a much greater weight than a lower ranked opportunity.

Table 1. Opportunities to improve populations of native fishes and the benefit to those taxa.

Opportunity	*High*	*Medium*	*Low*
A - Spill	X	X	
B - Base flow	X	X	
C –Sediment flushing		X	
D –Habitat maintenance flows		X (Unknown)	X (Unknown)
E - Thermal regime	X	X	
F –Cease stocking		X	
G – Reduce trout	X		
H – Reduce bass reproduction	X		
I – Supplement native fishes	X	X	

Some differences among rankings were also noted. For example, one scientist ranked "Cease stocking" (trout) as a high priority, but mostly because of the ease with which it could be implemented and not because it would necessarily have the biggest benefit for native fishes. One scientist also ranked the smallmouth bass issue very highly, mostly because it is a problem that could be increasingly significant, and efforts should be made to contain this issue to the extent possible with current and future management actions.

Sediment flushing and habitat maintenance flows were ranked lower because, while recognized as important, it is unknown at this time what flow magnitude and duration is needed to accomplish those actions, and because those actions may occur as a consequence of other opportunities. For example, sediment flushing may occur as a consequence of spill management. We all thought supplementing native fishes was a potentially important action but gave it a lower priority because of the need to implement other actions first, or at least simultaneously.

Table 2. Opportunities to improve populations of native fishes and the rank of those opportunities for individual scientists.

Opportunity	*1*	*2*	*3*	*mean*
A - Spill	3	3	3	3
B - Base flow	1	1	1	1
C –Sediment flushing	3	6	6	5
D –Habitat maintenance flows	7	8	8	7.67
E - Thermal regime	3	1	3	2.33
F –Cease stocking	8	3	1	4
G – Reduce trout	3	3	3	3
H – Reduce bass reproduction	1	7	6	4.67
I – Supplement nf	9	9	9	9

SUMMARY

Fish Status

- Based primarily on long-term data available for Dove Creek and Big Gypsum (reaches 2 and 4) data
  - Native suckers are highly imperiled, and bluehead sucker may be locally extirpated
  - Roundtail chub appear to be declining but are still present in modest numbers
- Longer-term population viability of all three species appears tenuous given available data

- Native fishes have declined

  – in reaches where non-native fishes are abundant, native fishes are limited by predation/competition

  – in other reaches flow/habitat change may be mechanism

  – physical habitat/processes and biotic factors interact, both are important

- Population structure equates to lower population viability and probability of persistence
  - Note while we do have some size information, there is no to little age structure information, no/little recruitment information – these information gaps further restrict inferences about native fish status
- Not enough information to give reach-specific conclusions
  - Situation appears worse in upper reaches
- The goal for restoration depends on the overall goal designated for native fishes in the Dolores River (which has yet to be clearly defined), with several viable options for guidelines
  - Restore densities, distribution, and population structure to a minimum of 90's levels
  - Restore densities and population structure to levels apparent in other "healthy" populations. For example, three species biomass other systems and in the Dolores River in the early 1990's far exceeds that present now
  - Identify and remediate limiting factors and prevent further declines
- Keep existing small problems small, limit smallmouth bass, white sucker in downstream reaches

Many opportunities exist to improve the native fish community and those are listed below:

- Spill management
- Base flow management
- Sediment transport flows
- Habitat maintenance flows
- Thermal regime modification
- Reduce effects of introduced cold water species
- Reduce effects of introduced warmwater species
- Supplement native fishes

It is important to remember that certain management actions may have synergistic effects: flow management activities may produce habitat for native fishes and at the same time, reduce abundance of deleterious non-native kinds or improve water quality conditions. There is currently no single factor that is most responsible for native fish declines, and implementation of just a single management action is unlikely to produce the desired effect of native fish restoration.

More information is needed prior to implementation of some management opportunities, so that changes can be monitored most effectively. Examples of information needed to improve native fish status include:

- Sediment flushing studies
- Bed mobility studies
- Early life history sampling
- Continued monitoring of native and non-native fishes
- In-stream fish habitat monitoring including water temperature
- Reconnaissance of existing habitat-flow and other studies exist for use in preliminary examination of spill potential, sediment flushing and bed mobility needs.

EXTERNAL FUNDING:

The panel wanted to send the message that although there are existing uncertainties and information gaps, there are, especially for species that are in jeopardy of being federally listed (e.g., the three species) many potential sources of external funding that may be available. For example (not an exclusive list): funding from the U. S. Bureau of Reclamation under 'Activities to Avoid Jeopardy' , Keystone Species, or state or federal funding slated for native fish research and management.

A few considerations were apparent in order to improve native fish status:

- recognize the complex system and issues, unlike many regulated systems
- each improvement opportunity has complexities and costs
- no single factor is presently responsible for the demise of native fishes
- restoring a natural hydrograph and water temperatures are a fallback when no information exists, uncertainty should not equate to lack of action
- something different must be done to reverse the trend in native fish abundance, but at the same time "do no harm"

Implement these changes for success:

- release higher, warmer base flows,
- release spills that are well-timed, thermally compatible, and capable of flushing fines,
- create a much-reduced predator/competitor environment
- monitor changes well to understand most effective strategies and adapt accordingly

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Appendices I-III. Bestgen Phase I report (39 pages), followed by Budy and Salant Phase I report (92 pages total in two parts), followed by Miller Phase I Report (36 pages).

STATUS AND TRENDS OF FLANNELMOUTH SUCKER *CATOSTOMUS LATIPINNIS*, BLUEHEAD SUCKER *CATOSTOMUS DISCOBOLUS*, AND ROUNDTAIL CHUB *GILA ROBUSTA*, IN THE DOLORES RIVER, COLORADO, AND PRELIMINARY OPPORTUNITIES FOR POPULATION IMPROVEMENT: PHASE I REPORT

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EXECUTIVE SUMMARY

The main purpose of this Phase I report was to summarize information that described status and trends of flannelmouth sucker *Catostomus latipinnis*, bluehead sucker *Catostomus discobolus*, and roundtail chub *Gila robusta*, in the Dolores River, Colorado, and to discuss reasons for their decline. Once widespread and abundant in cool and warm water reaches of small to large streams, those species now occupy 50% or less of their range in the Colorado River Basin, including only 45-50% of their ranges in the Upper Colorado River Basin (Bezzerides and Bestgen 2002). Based on analyses of available data, the following conclusions were made regarding the status of three native fishes in the Dolores River. Roundtail chub is rare in upstream reaches 1 and 2 (the 31 miles of river downstream of McPhee Dam), where populations are declining or may be extirpated. In downstream reaches, roundtail chub is relatively the most abundant of any of the native fishes, but populations are small and either highly fluctuating or declining. Flannelmouth sucker is rare in upstream reaches 1-3 upstream of Disappointment Creek and present in variable abundance throughout the remainder of the study area but declining in those reaches. Bluehead sucker is very rare in the entire study area and is declining to the point of extirpation in most reaches; it is more common in the Dolores River downstream of the San Miguel River. No study area reaches have strong populations of the three species.

The strength of conclusions regarding status of native fish is high. This is due in part, to the relatively high level of information available to describe trends in the fish populations through time. The strength of conclusions regarding exact mechanisms for population decline (e.g., reduced base flow, lack of spills, non-native fish predation) is less certain. It seems unequivocal that reduced frequency, magnitude and duration of peak flows (spills) as well as reduced base flow had a negative effect on cold and warmwater fish communities of the Dolores River compared to pre-diversion and impoundment times. Non-native fishes have also likely had negative effects on native kinds in some reaches of the Dolores River, mainly via predation on early life stages. Opportunities for improvement of native fish populations include more regular spills that are timed with the natural hydrograph, a more natural thermal regime to aid fish reproduction and growth and survival of early life stages, higher base flows in summer, and suppression of non-native fish populations in the Dolores River. Opportunities for management and improvement of native fish populations will be the focus of the Phase II report.

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Introduction

The main purpose of this Phase I report is to summarize information that describes status and trends of flannelmouth sucker *Catostomus latipinnis*, bluehead sucker *Catostomus discobolus*, and roundtail chub *Gila robusta*, in the Dolores River, Colorado, and to discuss opportunities for enhancing those populations. This Phase I report is the first portion of a response to and participation in a project entitled "**Native Fish Synthesis and Identification of Management Possibilities to Protect 3 Species"**, relative to the Dolores River "A Way Forward" program and was developed from a slide show given to the Dolores River group in April 2011. The objective of the project is to describe the status of the three native fishes in the Dolores River downstream of McPhee Dam and Reservoir and offer means to improve those populations. The second and final phase will present a synthesis of the Phase I reports of the three expert scientists, Drs. William Miller, Phaedra Budy, and myself, and offer further suggestions on means to improve distribution, abundance, and trends for native fishes in the Dolores River.

Main objectives of this Phase I report were as follows:

- Describe status of the three species in the Colorado River Basin
- Describe status of the three species in the Dolores River between McPhee Dam and the confluence of the San Miguel River
- Describe potential reasons for population changes in the Dolores River
- Describe management options and opportunities for improvement of the Dolores River fish community

For this project overall, we were to address opportunities for improvement including:

- Spill management
- Base pool management at different levels
- Reduced NNF predation and/or competition
- Water quality
- Riparian ecology
- Best reaches for improvements
- Describe additional information needs

- Levels of certainty of conclusions
- Research to improve adaptive mgmt

Study Area

The Dolores River rises in southwestern Colorado, flows in a northwesterly direction, and is tributary to the Colorado River in southeastern Utah (Figure 1). We will consider mainly the reach of the Dolores River from downstream of McPhee Dam downstream to the San Miguel River. Consideration will be given to the reaches upstream and downstream of there for purposes of discussion of the historical fish community and opportunities for re-invasion of upstream reaches. The San Miguel River is the only permanent and large tributary of the Dolores River and is important because of its unregulated nature and potential to assist with restoration of native fishes in the Dolores River.

Methods

To prepare this report, I read widely from the available literature, and analyzed existing data that was provided by the Dolores River group. I borrowed extensively from the literature and analyses, particularly the fish data and reports prepared and provided by the Colorado Division of Wildlife, and the hydrologic analyses prepared by the U. S. Bureau of Reclamation. I also borrowed extensively from existing research that is presently being conducted in the Upper Colorado River Basin by me and others.

As the reader studies Phase I reports prepared by the other two scientists, much overlap may be noted. This is because each report was prepared independently so that analyses and conclusions are not affected by opinions of the others. Data and analyses will be solidified among various scientists in Phase II and conclusions and strengths of assertions may change at that time. Finally, the fish community changes discussed are relevant to pre-1886 and post-McPhee Dam periods.

Results and Discussion

Colorado River distribution and status.--Flannelmouth sucker, bluehead sucker, and roundtail chub are cypriniform fishes native to the Colorado River Basin. While once widespread and abundant in cool and warm water reaches of small to large streams, those species now occupy 50% or less of their range in the Colorado River Basin, including only 45-50% of their ranges in the Upper Colorado River Basin (Bezzerides and Bestgen 2002). Habitat alterations and non-native species introductions are primary causes of decline of native fishes in western rivers and in general, those same factors are likely responsible for the decline of the three species in the Dolores River (Petts 1984; Carlson and Muth 1989; Minckley and Deacon 1991; Stanford et al. 1996; Poff et al. 1997; Bezzerides and Bestgen 2002; Olden et al. 2006; 2007).

A result of reduced distribution and abundance of those species has been listing by various Colorado River Basin states under some conservation status (Table 1) and formation of a range-wide conservation agreement that has numerous signatories including: six Colorado River Basin states (AZ, CO, NV, NM, UT, WY); the Bureau of Land Management in CO, NM, WY, UT; U. S. Forest Service, Intermountain Region; National Park Service, Intermountain Region; U. S. Bureau of Reclamation, Rocky Mountain Region; U. S Fish and Wildlife Service, Mountain-Prairie Region, and Region 2; the Jicarilla Apache Nation, and Southern Ute Tribe (Rangewide Conservation Agreement). The Conservation Agreement was developed to implement conservation measures for the three species so that threats to persistence and the need to list those taxa under the Endangered Species Act are diminished.

Dolores River fish distribution, abundance, and status.—Several studies describe the distribution and status of Dolores River fishes and were used to develop conclusions regarding status of flannelmouth and bluehead suckers and roundtail chub. These include studies of Holden and Stalnaker (1975), Valdez et al. (1982; 1992), and reports and unpublished data from various Colorado Division of Wildlife (CDOW) biologists investigating both the status of trout and warmwater fish communities downstream of McPhee Dam (Nehring 1993, White et al. 2008, Colorado Division of Wildlife 2010, CDOW Adamas database).

Those studies collectively documented a total of seven native fishes and 17 non-native fishes in the Dolores River downstream of McPhee Dam (Table 2). Most species records were available from Reach 1, which is immediately below McPhee Dam downstream to Bradfield Bridge (CDOW Reach 3B, n = 385 records from 5 sites) that were collected mostly in the conduct of trout studies, the Dove Creek Pumps-Reach 2 area (CDOW Reach 3A) had the second-most fish records (n = 149), while a few others were scattered through the remainder of the reaches (Big Gypsum, CDOW reach 2A, n = 32; CDOW Reach 1, downstream of the San Miguel confluence, n = 14).

Holden and Stalnaker (1975) sampled in the pre-dam era using mostly seining as a collection technique and found the three species abundant in the Bradfield reach, and present but in varying abundance in the Dolores River downstream of the San Miguel River. Presence and abundance of flannelmouth sucker and roundtail chub was variable at the three sites between the Bradfield Reach and downstream of the San Miguel River and bluehead sucker was absent, perhaps reflecting the lack of riffle habitat in that flow depleted reach. Flows were apparently very low just upstream of the San Miguel to the Bradfield site which limited presence of some species at some sites. Reproduction by all species was apparently occurring in the study area based on presence of multiple year-classes at some sites.

Valdez et al. (1992; data and conclusions apparently similar compared to 1981 surveys, Valdez et al. 1982) in the post-dam era (since 1986) found relatively high % abundance of flannelmouth sucker and roundtail chub in the Dolores River between McPhee Dam and the San Miguel River confluence and evidence of reproduction at all sites. Similar to Holden and Stalnaker (1975), bluehead sucker was rare but present at all sites as large and small fish. Percent composition of flannelmouth sucker and particularly roundtail chub was generally lower downstream of the San Miguel River, but percent composition of bluehead sucker increased in that area, perhaps reflecting increased flows and habitat availability in that area.

Colorado Division of Wildlife sampled reaches of the Dolores River downstream from McPhee Dam in two reaches at intervals beginning in 1987 (Figures 2 and 3). Flannelmouth and bluehead suckers were relatively common until about 1993, and declined in abundance after that, particularly since 1997. Roundtail chub were relatively uncommon throughout that period, and apparently absent after 1993, with the exception of 2003 and 2004 (n = 4 fish total) and those few individuals may represent stocked fish (White et al. 2008). Length frequency histograms of relatively abundant flannelmouth sucker from those same reaches downstream to Dove Creek Pumps reach showed populations dominated exclusively by adult sized fish > 30 cm with no evidence of reproduction and/or recruitment (Figure 4); bluehead suckers collected from those reaches also showed a similar trend of mostly adult-sized fish > 17 cm total length (Figure 5).

Perhaps the best native fish data trend series for the Dolores River is from the Dove Creek Pumps site, which has been sampled from 1986-2010, with the exception of 1988 and 2001 (Figure 6). Those data showed that roundtail chub (top panel) was highly variable in abundance over the years of sampling, perhaps because the pool habitat that species occupies is largely unaffected by flow fluctuations, even in drought years such as 2002-2004. Trout abundance was at most, moderate at this site in every year, and declined later in the time series when flows declined from 2002-2004, and increasing slightly after that when flows increased after

2005. Green sunfish abundance was low through time with the exception of 2004, when abundances increased after the low flow period where no spring spills occurred; populations have since declined with the resumption of slightly higher flows and presence of spills in most years. Abundance of bluehead and flannelmouth sucker (lower panel) was relatively high from 1988-1991 but declined severely after that, with each species being absent in several years. Similar declines in native fishes were noted in the 19 mile-long Ponderosa Canyon reach just upstream of (ends at) the Dove Creek Pump site, where in July 1993 flannelmouth sucker abundance was estimated at 1,610 (±1,460, 95% confidence limits) but had declined to 0 captured in similar surveys in June 2005 and 2007. Bluehead sucker also declined dramatically from 132 (±172) in 1993 to 1 and 0 individuals captured in 2005 and 2007, respectively. Roundtail chub in that reach were uncommon in all periods, with 11, 11, and 31 individuals captured in 1993, 2005, and 2007, respectively.

Smallmouth bass abundance at the Dove Creek Pump site was low throughout the period, being present only in 2008 and 2009. Annual and seasonal flow fluctuations at the site over time were extreme but seemingly did not affect most species in a regular pattern. Size structure of roundtail chub was mixed, with individuals from 12.5 to 35 cm TL. Length frequency of flannelmouth and bluehead suckers was similar to upstream reaches in 1993, with mostly adult-sized fishes present. Lower abundance and lack of smaller size classes of suckers perhaps reflects their higher dependence on riffles and runs compared to roundtail chub, and reduced availability of those habitat types during low flows.

Downstream of the Dove Creek Pump site at the Big Gypsum site, sampling from 2000-2008 showed very low abundances of all native species, including flannelmouth sucker, bluehead sucker, and roundtail chub (Figure 7). Additionally, each species showed a declining abundance trend for flannelmouth sucker and roundtail chub and very low and declining abundance of bluehead sucker.

A series of four reaches (sites) were sampled in 2007 to obtain a rare view of the longitudinal distribution of fishes in the Dolores River in a single year; a 2009 sample reach was added for the Dolores River just downstream of the San Miguel River to add to the longitudinal trend (Figure 8). Sucker abundance was very low at the three upstream reaches and upstream of Disappointment Creek, while roundtail chub abundance was relatively high only at the Big Gypsum site. Native fish abundance was higher downstream of Disappointment Creek, and highest for all three species just downstream of the San Miguel confluence, and declined at the downstream Gateway site. Thus, sucker abundance was moderately high downstream of Disappointment Creek, and relatively high only just downstream of the San Miguel River. Percent native fish abundance was low at the most upstream reach, but from Big Gypsum to the reach just downstream of the San Miguel was relatively high at nearly 90%, and declining at the most downstream Gateway reach.

In addition to high abundance of native fishes in the reach of the Dolores River just downstream of the San Miguel River, length-frequency distributions of flannelmouth and bluehead suckers and roundtail chub showed a range of sizes including young and adult fish (Figure 9). Unlike reaches upstream of the San Miguel River, this is the only reach of the Dolores River documented to have a balanced distribution of size classes for all three species, indicating reproduction and recruitment. At a downstream site near Gateway, Colorado (Figure 10) a balanced distribution of suckers is present as well, but as previously indicated roundtail chub is rare in that reach.

Abundance and size distribution data for reaches of the Dolores River downstream of the San Miguel River may indicate a restoration effect of the latter on the fish community of the former. This may be a result of relatively high native fish abundance in the lower San Miguel River and subsequent movement of young and perhaps adults from that relatively unregulated and strongly-flowing river. It likely also indicates improved habitat of the Dolores River as a result of inflows of the San Miguel River, particularly for native suckers. This suggests severe flow and habitat limitations for native catostomids in the Dolores River upstream of the San Miguel River. Abundance and size distributions of the three species in this reach are similar to other rivers such as the Green River in Lodore Canyon or the Colorado and Gunnison rivers, where self-sustaining populations of these taxa thrive (Bestgen et al. 2007a and b; Anderson 2005; Anderson and Stewart 2007).

Dependency of habitat and flow and biomass and flow relationships for native suckers were also illustrated by Anderson and Stewart (2007, here figure 11). The low flow levels at Big Gypsum site apparently severely limit habitat availability and abundance of bluehead sucker (similar to relationships for flannelmouth suckers). The shape of the curves suggested that with relatively small increases in flow, habitat and biomass levels of native catostomids in the Dolores River would increase rather substantially.

Non-native fish abundance.—A major threat to native fishes in the Dolores River may be presence of non-native fishes, either through competitive interactions or predation. The non-native fishes of most concern are trout populations in cold water reaches just downstream of McPhee Dam and smallmouth bass in warmer reaches further downstream.

Trout abundance was high in the reach just downstream of McPhee Dam and highest through the early 1990’s (Figure 12). That fishery doubtless benefitted from relatively high flows in the period after dam closure until about 1995. Similarly, reduced flows after that, particularly from 2002-2004 resulted in low trout abundance, and abundance has remained relatively low after that, although recent abundances have increased with slightly higher flows since 2008. Most of the fishery is supported by naturally reproducing brown trout, although rainbow and cutthroat trout (Snake River subspecies), and even native Colorado River cutthroat trout are stocked, some on an annual basis.

Presence of abundant trout in the reach from downstream of McPhee Dam downstream to the Dove Creek Pump site may have limited recruitment of young fish and, over time, abundance of native fishes in the post-dam period because of predation by trout, particularly brown trout (Yard et al. 2011). Presence of abundant adult native suckers in the reach in 1993, especially flannelmouth sucker, can be explained perhaps by presence of relatively large populations in the pre-dam and just post-dam period and prior to establishment of large trout populations. Because those sucker species are long-lived (Sweet et al. 2010) they can persist in the face of low recruitment for long periods of time. However, mortality of adult fish over time will result in population decline when recruitment is low or non-existent. In support of this hypothesis, absence of young suckers was demonstrated in length-frequency histograms of flannelmouth and bluehead suckers from data collected in 1993. Hence, because no fish were available to recruit in that upstream reach, populations have dwindled from once-abundant populations in 1993 to near extirpation.

Distribution and abundance of smallmouth bass are something of an enigma in the Dolores River downstream of McPhee Dam. First smallmouth bass were detected in the system in 1993 subsequent to high releases from the reservoir, along with reservoir-restricted species including kokanee salmon. Smallmouth bass either remained at low abundance (Figure 13) throughout the reach or were further enhanced from additional reservoir escapement after that time. In spite of intensive sampling at Dove Creek and Big Gypsum sites through 2007, smallmouth bass were apparently rare. Only when sampling occurred between those two reaches via raft electrofishing in 2007 were relatively abundant smallmouth bass discovered (Figure 14), and perhaps three or four size classes were present (possibly hatched 2003-2006). That reproduction occurred during the lowest flow periods in recent history (2002-2004) when no spills occurred and warm water temperatures prevailed.

Patterns of smallmouth bass distribution and abundance are similar to the situation in the in the Yampa River, northwestern Colorado, where smallmouth bass were present since 1992, but did not expand dramatically in distribution and abundance until low flow years beginning about year 2000 through 2004 (Bestgen et al. 2007 a and b; Johnson et al. 2008; Hawkins et al. 2009). Since then, smallmouth bass have expanded downstream in that system and have invaded the Green River around 2002 (Bestgen et al. 2007a and b, Bestgen et al. 2008). Establishment of substantial populations of smallmouth bass in the Dolores River should be avoided at all costs because they can prey upon many life stages of native fishes and can reduce abundant native fish populations to near extirpation such as has happened in the Yampa River (Bestgen et al. 2007a; 2008). Negative effects of smallmouth bass on roundtail chub populations in the Dolores River may have already been noted, as chub abundance in the reach from the Pyramid to Disappointment Creek has declined, which is the reach smallmouth bass are now relatively abundant (White et al. 2008, CDOW 2010). Smallmouth bass are also extremely difficult to control once established.

Another potentially problematic non-native species is white sucker. White sucker is abundant in McPhee Reservoir and upstream but has not been detected in downstream reaches (pers. comm., J. White, CDOW). White sucker is problematic in other regulated and non-regulated streams in the upper Colorado River Basin, including the Yampa and Green rivers (Prewitt 1976; Bestgen et al. 2007a and b; Hawkins et al. 2009) because white sucker hybridizes with native catostomids including flannelmouth and bluehead sucker. Establishment of white suckers in the Dolores River should be avoided because they are tolerant of cold to warm water and may create hybrid swarms with native suckers. White suckers and their hybrids are also very difficult to control.

Flows and temperatures in the Dolores River.—Flows in the Dolores River have been altered since transbasin diversions began in 1886. The biggest impact on flows was base levels in summer, when the reach downstream of the present-day McPhee Reservoir was often dewatered or had very low flow; negative effects on fishes were noted by Holden and Stalnaker (1975) and Valdez et al. (1992). Subsequent effects of McPhee Dam were to lower the magnitude and duration of peak flows; base flows were enhanced compared to flows since the late 1800's when transbasin diversions took most summer flows because of releases of water designated specifically to help the fishery (e.g., the "fish pool").

Total runoff levels from 1981-2010 (Figure 15) are nearly identical to the long-term average since 1896 for the Dolores River near Dolores, Colorado. However, the nature of the flow alterations and regulation make this a challenging system to support aquatic biota. This is because most systems regulated by a mainstem dam have relatively low peak flows but higher base flow levels, due to releases for irrigation and irrigation water that returns to the river. The Dolores River has both reduced peak flows and reduced base flows because water is transported out of basin.

Flows of the Dolores River upstream and downstream of McPhee Reservoir in very low, moderately low, and moderately high hydrologic scenarios show storage patterns related to water temperature (Figure 16). In lower flow years such as 2002 and 2006, nearly no peak flow was evident, and water temperatures warmed early and rapidly. This hydrologic pattern is called the "fill-and-spill" management scenario, because water is held in the reservoir until it is filled completely and only then is water allowed to pass downstream through McPhee Dam. In comparison, the high flow year 2005 had a long spill period and water temperatures warmed more slowly and in a more natural pattern. This scenario is termed "spill-and-fill", when water is evacuated from the reservoir relatively early knowing that it will eventually fill because snow pack is high.

In other fill-and-spill years such as moderately low flow years 2007 and 2009, water temperatures showed early warming perhaps to unnaturally high levels (e.g., approaching or exceeding 16°C) because flow releases were very low (Figure 17, in part). In each year, cold water was eventually released from the reservoir and caused sudden depression of water temperatures (e.g., approaching 10°C) during high but relatively late flow periods. This scenario was in opposition to what would occur upstream of the reservoir where water temperatures would have remained relatively low as flows would rise earlier in the year and maintain cooler thermal regimes.

The altered flow and temperature regimes have implications for both native and non-native fishes. Early seasonal warming of stream flows downstream of McPhee Dam likely caused early maturation of gonads of all fishes. Typically native suckers spawn prior to high stream flows, beginning as early as mid-April. For example, bluehead and flannelmouth suckers in the middle Green River first emerge from mid-May to mid-June, later if flows are high and relatively cool and earlier if flows are lower and relatively warm. If native suckers spawn and emerge prior to high flows in the Dolores River due to early warming, small and weak-swimming early life stages are likely swept far downstream and mortality may be high. Downstream transport of larvae occurs in other rivers during high flows as well but perhaps the relatively low amount of low-velocity habitat and holding areas for larvae in the Dolores River may limit their recruitment success. A dramatic drop in water temperature is also likely to influence hatching success of embryos and survival of larvae if they are hatched when water temperatures drop because development times are increased and growth rates are decreased, each of which may reduce survival of those early life stages. Roundtail chubs likely would spawn after high flows because that species spawns at warmer water temperatures, but if water warms enough prior to high flows and spawning occurred, reproductive success of that species may also be negatively influenced.

Reproductive success of certain non-native fishes may also be affected by the fill and spill water management scenario in a negative manner. For example, smallmouth bass in the Yampa and Green rivers in northwestern Colorado begin spawning in post-peak flows when water temperatures reach 16°C (Bestgen et al. 2007 a and b). If smallmouth bass spawn in the Dolores River at 16°C in a pre-peak period rather than a post-peak period (e.g., see thermographs for 2002, 2006, 2007), egg and nest destruction may be high because eggs and the small, weak-swimming larvae would have high mortality. This may be the reason why smallmouth bass have a relatively restricted distribution and low abundance in the Dolores River at this time. Another reason may be that smallmouth bass are now only expanding in the Dolores River after years of residence (since 1993) at relatively low abundance levels. Yet another explanation may be lack of adequate habitat upstream and down from their present distribution, upstream perhaps because of relatively cool water temperatures, and downstream because of silty, turbid, and low flow conditions in that reach with mostly fine-grained (rather than cobble) substrate. Downstream expansion of smallmouth bass into the San Miguel River may be possible because of presence of good habitat and strong flows (pers. comm., D. Kowalski, CDOW) and would then present a source population to invade the Dolores River.

CONCLUSIONS

Based on analysis of available data, the following conclusions were made regarding the status of three native fishes in the Dolores River. Roundtail chub is rare in upstream reaches 1 and 2 (the 31 miles of river downstream of McPhee Dam), where populations are declining or may be extirpated. In downstream reaches, roundtail chub is relatively the most abundant of any of the native fishes, but populations are small and either highly fluctuating or declining. Flannelmouth sucker is rare in upstream reaches 1-3 upstream of Disappointment Creek and present in variable abundance throughout the remainder of the study area but declining in those reaches. The unusual situation with reproductive flannelmouth suckers that have small body size noted by Kowalski et al. (2010) is inexplicable and not previously reported in the Colorado River Basin. Bluehead sucker is very rare in the entire study area and is declining to the point of extirpation in most reaches; it is more common in the Dolores River downstream of the San Miguel River. No study area reaches have strong populations of the three species.

The strength of conclusions regarding status of native fish is high. This is due in part, to the relatively high level of information available to describe trends in the fish populations through time. The strength of conclusions regarding exact mechanisms for population decline (e.g., reduced base flow, lack of spills, non-native fish predation) is less certain. It will be important in the future to continue to monitor population levels of native fishes and others (e.g., trout) to understand mechanisms and if proposed management actions are having the desired effects. Additional information needed includes early life stage data for native and invasive species on timing and strength of reproduction, and the relationship of that with flow and water temperature patterns. Such information will enhance investigators ability to determine mechanisms for changes in status of native fishes.

The Natural Flow Paradigm (Poff et al. 1997) offers general guidelines for improvement of habitat for biota in river reaches affected by regulation. Basic principles are to re-establish more natural annual, seasonal, and daily flow and temperature patterns (Stanford et al. 1996; Poff et al. 1997), with the joint mission to create habitat for native biota and perhaps reduce abundance and effects of non-native species. The general hypothesis is that structure and function of river ecosystem, and adaptions of biota, are dictated by the temporal pattern of flows and temperatures. Therefore, natural flow and temperature regimes may restore ecosystem attributes and native biota.

Examples of Dolores River hydrologic scenarios for baseflow conditions and for low, moderate, and high runoff years (Figure 18, from “correlation report”) are in the spirit of recommendations for natural flows made by Poff et al. (1997) and demonstrates how the magnitude and duration of peak flows (spills) from McPhee Dam could be linked with hydrologic conditions. A similar pattern of peak and baseflows linked to snowpack and hydrologic conditions occurs in the Green River, Utah, and Colorado, (Muth et al. 2000). A main difference with that system and the Dolores River is that in the Green River system, transbasin water transfers are minimal.

Opportunities for improvement

The list of bulleted items below represents observations on means and potential consequences of improving native fish status in the Dolores River downstream of McPhee Dam and Reservoir. It seems unequivocal that reduced frequency, magnitude and duration of peak flows (spills) as well as reduced base flow had a negative effect on cold and warmwater fish communities of the Dolores River compared to pre-diversion and impoundment times. It also seems obvious that non-native fishes have also had negative effects on native kinds in some reaches of the Dolores River, mainly via predation on early life stages. Ideas discussed in development of the Phase I report and reported to the Dolores River group follow, along with questions to consider as a result of potential management actions. Opportunities for management and improvement of native fish populations will be the focus of the Phase II report.

-Regular spills to create/maintain habitat important, duration and magnitude uncertain, link with hydrology as discussed above

- Time spills similar to the natural flow regime, which will have benefits in and of itself, as well as to create a more natural thermal regime for fish reproduction

- Higher base flows, esp in low flow years, would stabilize native fish populations

-Improved flows would likely promote re-invasion by native fishes from stronger downstream populations, and stronger recruitment by existing populations

-Improved flows will enhance trout community, without management to reduce those species

-Enhanced flows may enhance predation and reduce native fishes in reaches where trout persist

Secondary effects of management to consider

-Will improved flows, magnitude, or patterns, enhance the now restricted smallmouth bass population?

-Are actions to manage to benefit native and disadvantage invasive fishes possible through flow and temperature regimes?

-Are native fish management goals and trout population goals compatible?

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Table 1. Listing status of flannelmouth and bluehead sucker and roundtail chub in various Colorado River Basin states.

Species	State	Status .
Bluehead sucker	Utah	Species of Concern
	Wyoming	Special Concern
Flannelmouth sucker	Colorado, Wyoming	Special Concern
		Utah Species of Concern
Roundtail chub	New Mexico	Endangered
	Utah	Species of Concern
	Arizona, CO, Wyoming	Special Concern

FM and RTC considered for listing (candidate species) by USFWS

Table 2. Fishes collected from the Dolores River, Colorado and Utah, downstream of McPhee Dam. Sources include Holden and Stalnaker (1975), Valdez et al. (1982; 1992), Nehring (1993), and various unpublished data provided by the Colorado Division of Wildlife.

Species and status
Native fishes
Colorado pikeminnow
bluehead sucker
flannelmouth sucker
roundtail chub
speckled dace
mottled sculpin
cutthroat trout
Non-native fishes
white sucker
bluegill
green sunfish
largemouth bass
smallmouth bass
common carp
fathead minnow
sand shiner
red shiner
plains killifish
black bullhead
channel catfish
brown trout
rainbow trout
cutthroat trout
kokanee
yellow perch

Table 3. Status (A = abundant, C = common, R = rare) of flannelmouth (FM) and bluehead (BH) sucker and roundtail chub (RT) in the Dolores River reproduced, in part, from Holden and Stalnaker (1975, Table 1). Data were collected prior to construction and closure of McPhee Dam in 1985.

Reach	FM	BH	RT
Bradfield	A	A	A
Hwy 141	-	-	A
Paradox	C	-	C
San Miguel confluence	A	-	-
Downstream San Miguel	A	R-C	C

Table 4. Percent composition of flannelmouth (FM) and bluehead (BH) sucker and roundtail chub (RT) in reaches of the Dolores River captured with gill nets, trammel nets, and electrofishing gear (mostly large fishes captured) which were reproduced, in part, from Valdez et al. (1992, tables 31). Parenthetical numbers are the % composition of those same species in seine samples (Table 32), reflecting presence of small fishes and reproduction at those sites in the post-dam era (construction and closure in 1985). Data for downstream of the San Miguel River are the ranges for several sites for large (Table 31, Valdez et al. 1991) and small (Table 32) fishes.

Reach	FM	BH	RT
Bradfield-Disappointment	22	4	27
Disappointment-Bedrock	45 (15)	8 (3)	30 (17)
Bedrock-San Miguel confluence	55 (15)	4 (2)	9 (14)
Downstream San Miguel (large fish)	16-58	11-18	2-3
Downstream San Miguel (small)	0.2-15	<0.1-3	0.5-8

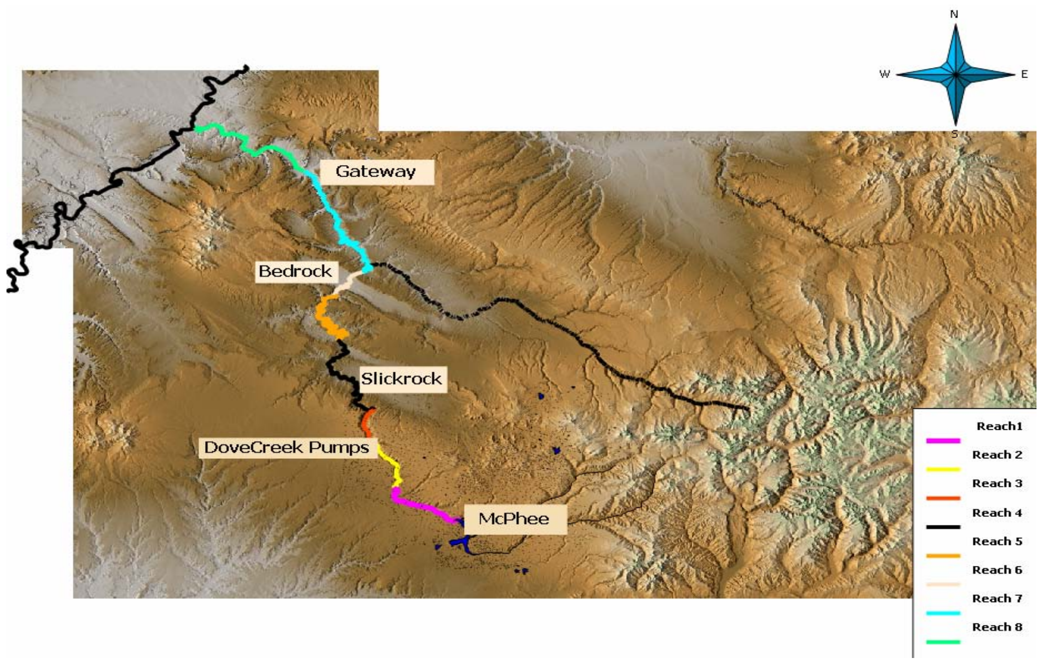


Figure 1. Map of Dolores River study area, southwestern Colorado, showing color-coded reaches 1-8.

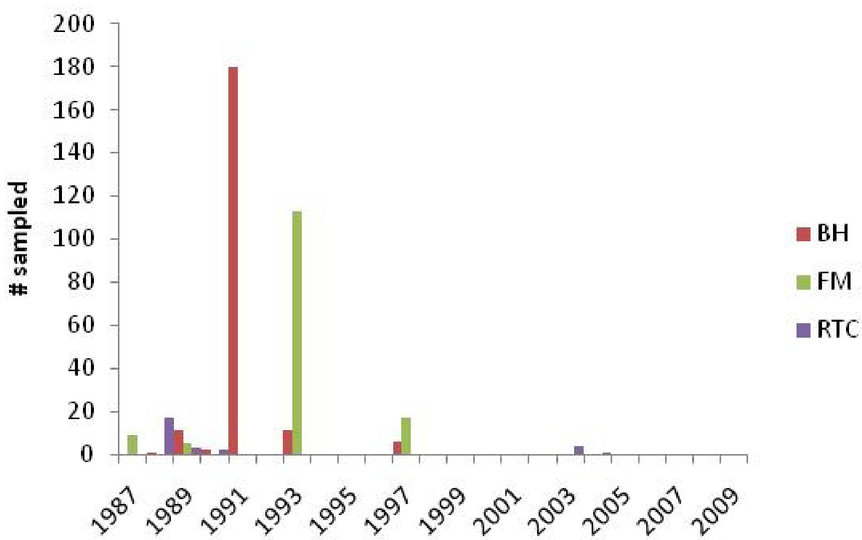


Figure 2. Abundance (number collected) of flannelmouth sucker (FM) and bluehead sucker (BH) and roundtail chub (RTC) in the Dolores River in Reach 1 (CDOW Reach 3B), from Metaska Campground downstream to Bradfield Bridge. Data were from various Colorado Division of Wildlife sources, collected mostly during the conduct of two-pass electrofishing removal sampling to estimate trout abundance, 1987-2009.

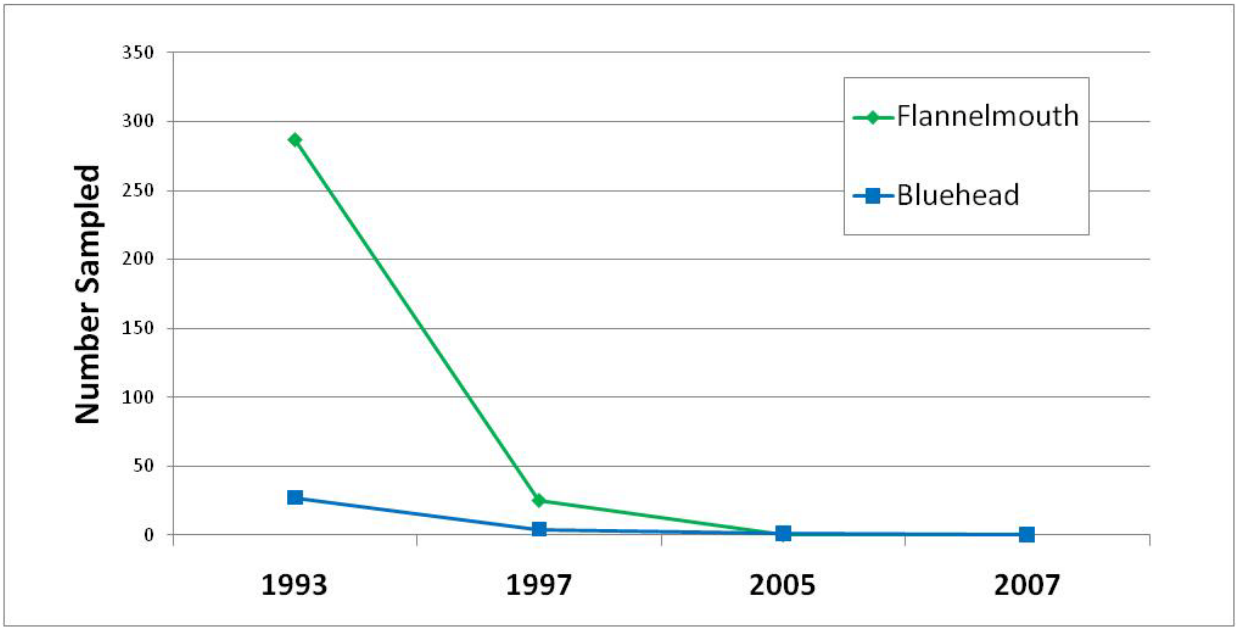


Figure 3. Abundance (number collected) of flannelmouth sucker (FM) and bluehead sucker (BH) in the Dolores River in Reach 1 (CDOW Reach 3B), from Bradfield Bridge downstream to Dove Creek. Data were from various Colorado Division of Wildlife sources, collected mostly during the conduct of two-pass electrofishing removal sampling to estimate trout abundance.

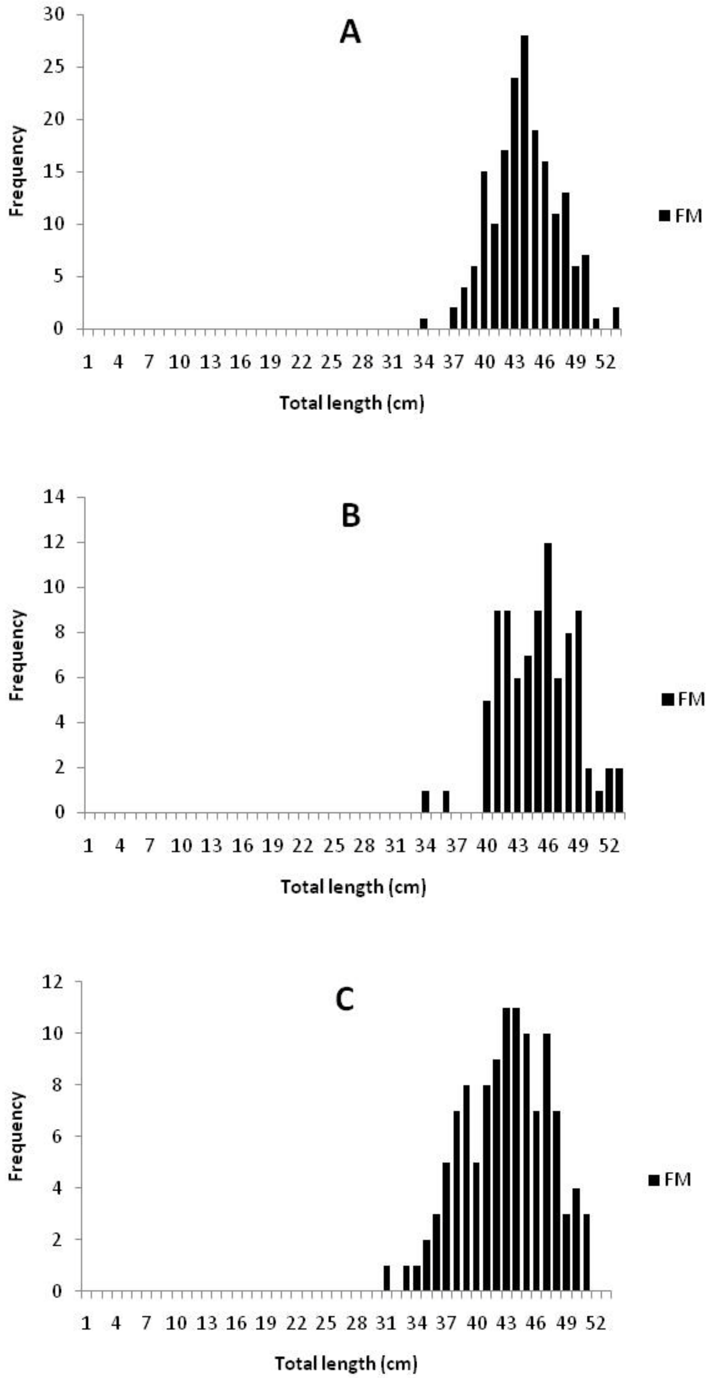


Figure 4. Length frequency histograms for flannelmouth sucker (FM) in three reaches (Metaska to Bradfield Bridge, panel A; Bradfield Bridge to Doe Canyon panel B, and RM 13 to Dove Creek, panel C). Data were from various Colorado Division of Wildlife sources, collected mostly during the conduct of two-pass electrofishing removal sampling to estimate trout abundance, 1993.

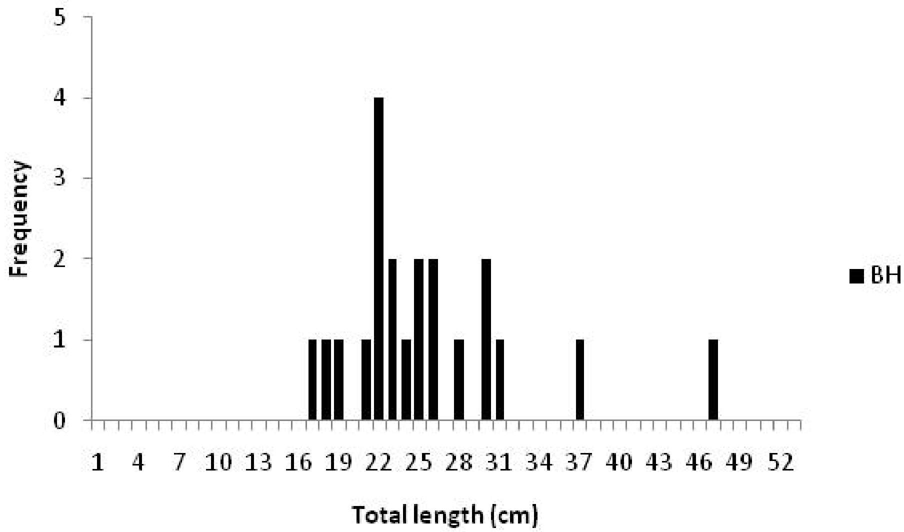
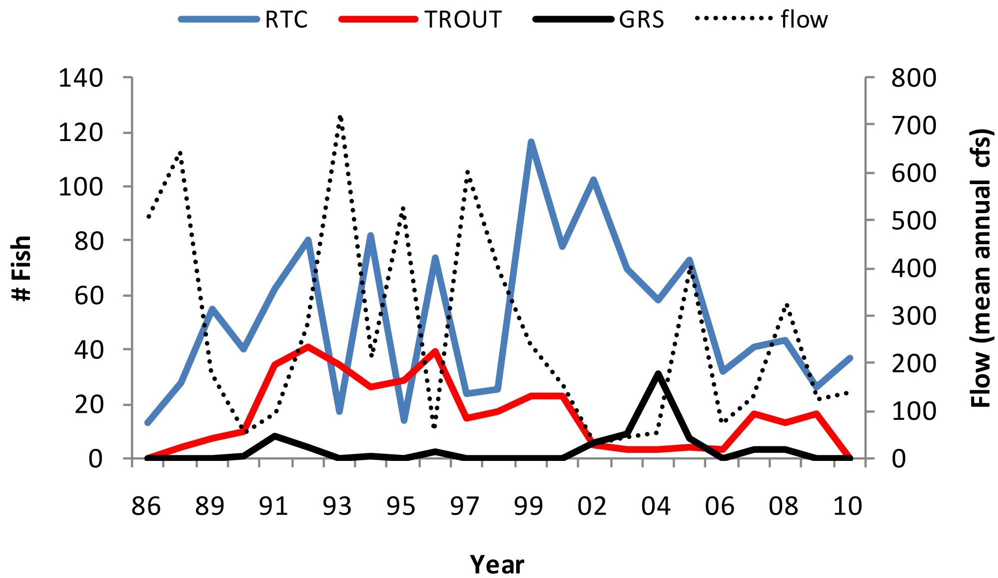


Figure 5. Length frequency histogram for bluehead sucker (BH) collected in three reaches (Metaska to Bradfield Bridge; Bradfield Bridge to Doe Canyon; and RM 13 to Dove Creek). Data were from various Colorado Division of Wildlife sources, collected mostly during the conduct of two-pass electrofishing removal sampling to estimate trout abundance, 1993.



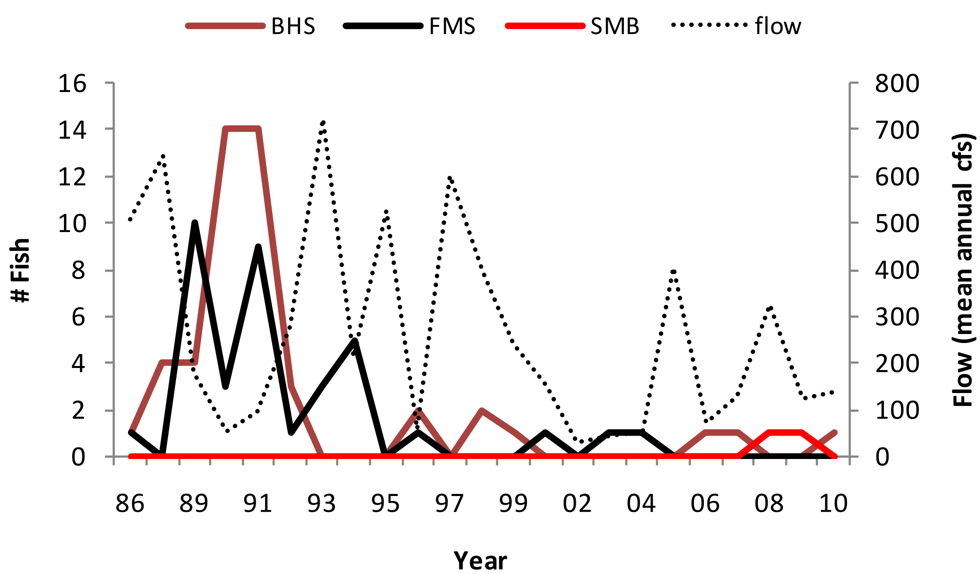


Figure 6. Abundance of roundtail chub, trout (combined cutthroat, rainbow, and mostly, brown trout), green sunfish (upper panel), bluehead sucker, flannelmouth sucker, and smallmouth bass (lower panel) at the Dove Creek Pumps site, 1986-2010 (missing 1988, 2001). Mean daily flow for the year is also portrayed. Data were from Colorado Division of Wildlife surveys, collected mostly during the conduct of two-pass electrofishing removal sampling.

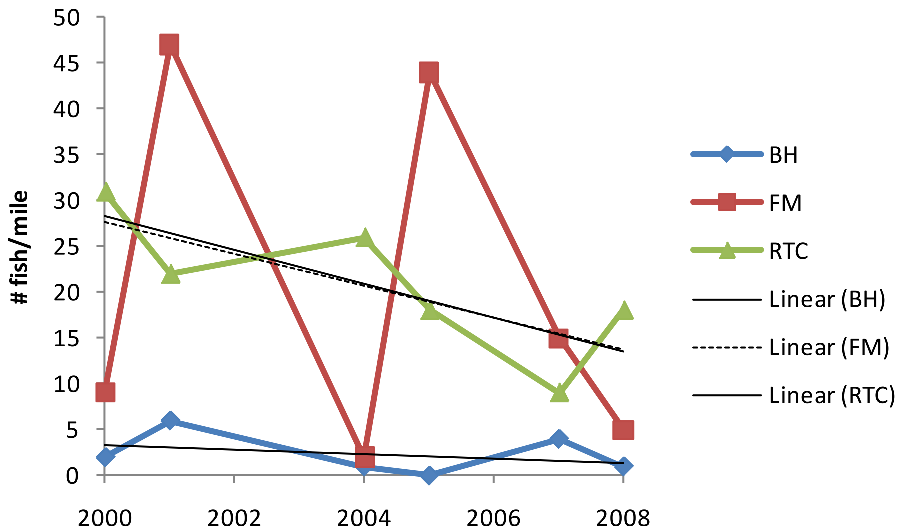


Figure 7. Abundance (fish/mile) of flannelmouth sucker (FM), bluehead sucker (BH), and roundtail chub (RTC) in the Dolores River in the Big Gypsum reach (CDOW Reach 2. Data were from various Colorado Division of Wildlife sources and converted to a fish per mile metric from samples from 2000-2008. Trend lines reflect declining abundance of each species through time.

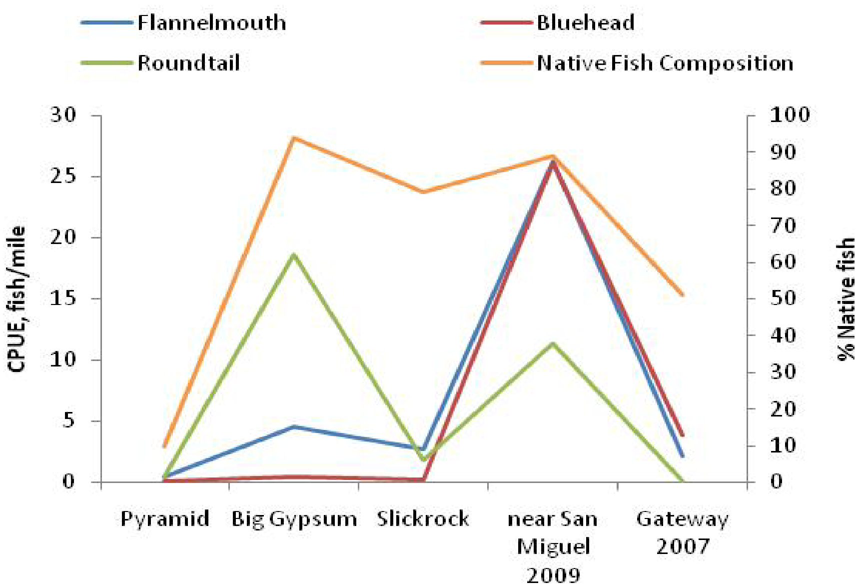


Figure 8. Longitudunal abundance (fish/mile) of flannelmouth sucker, bluehead sucker, and roundtail chub in the Dolores River in 2007 from upstream (Pyriamid) to downstream (Gateway site); a 2009 site just downstream of the San Miguel River was added to extend the longitudinal series. The percent of native fishes in the community at each site is the right y-axis.

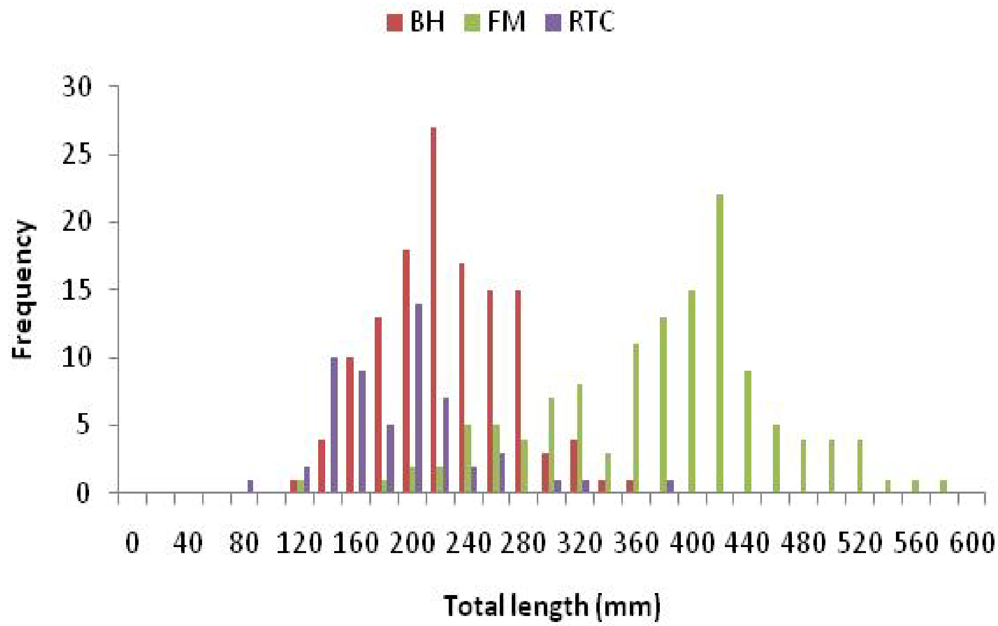


Figure 9. Length frequency distribution of flannelmouth sucker (FM) and bluehead sucker (BH) and roundtail chub (RTC) in the Dolores River in a reach just downstream of the San Miguel River.

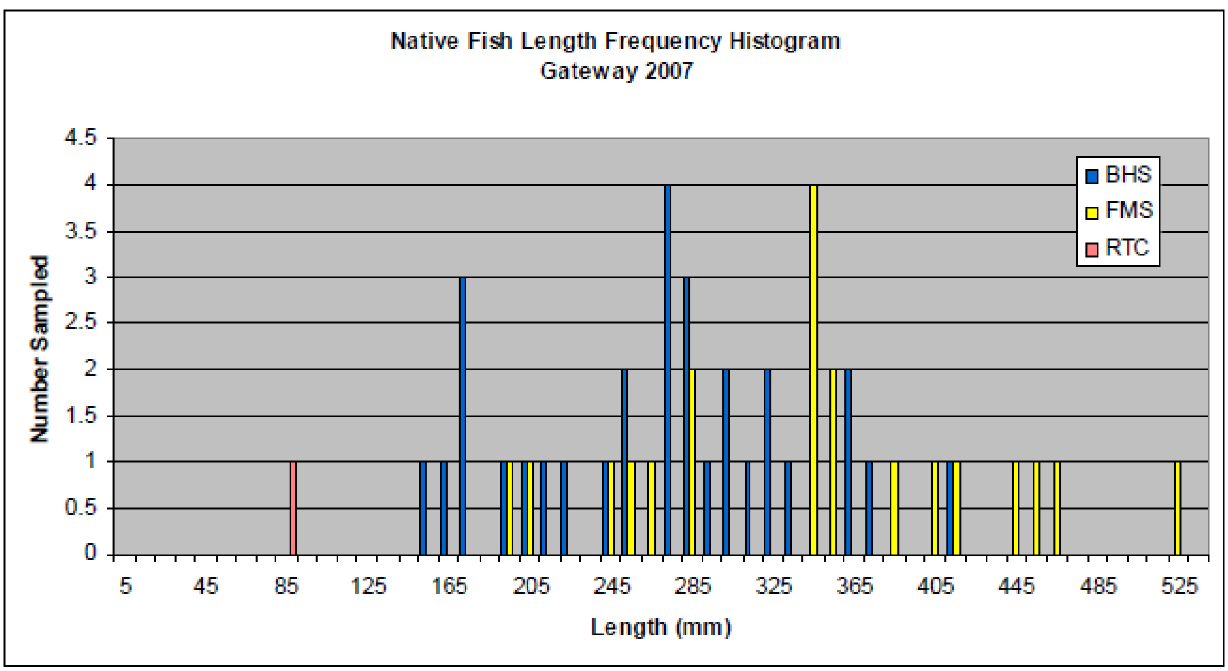


Figure 10. Length frequency distribution of flannelmouth sucker (FM) and bluehead sucker (BH) and roundtail chub (RTC) in the Dolores River in a reach near Gateway, Colorado, downstream of the San Miguel River.

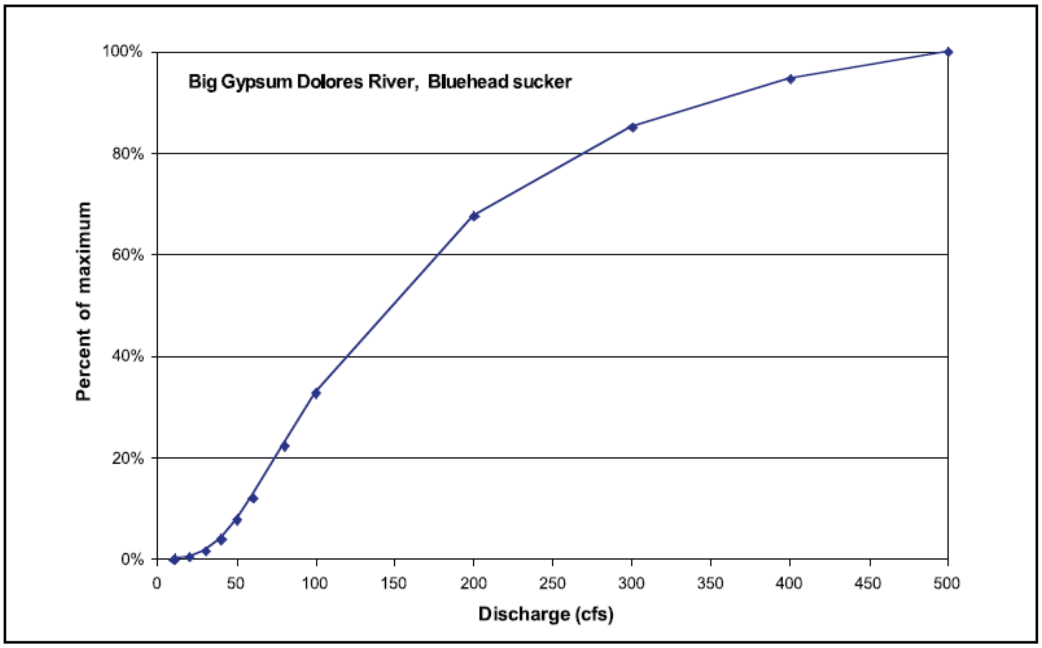


FIGURE II-18. Percentage of modeled maximum biomass (kg/ha) of bluehead sucker as a function of discharge at Big Gypsum, Dolores River.

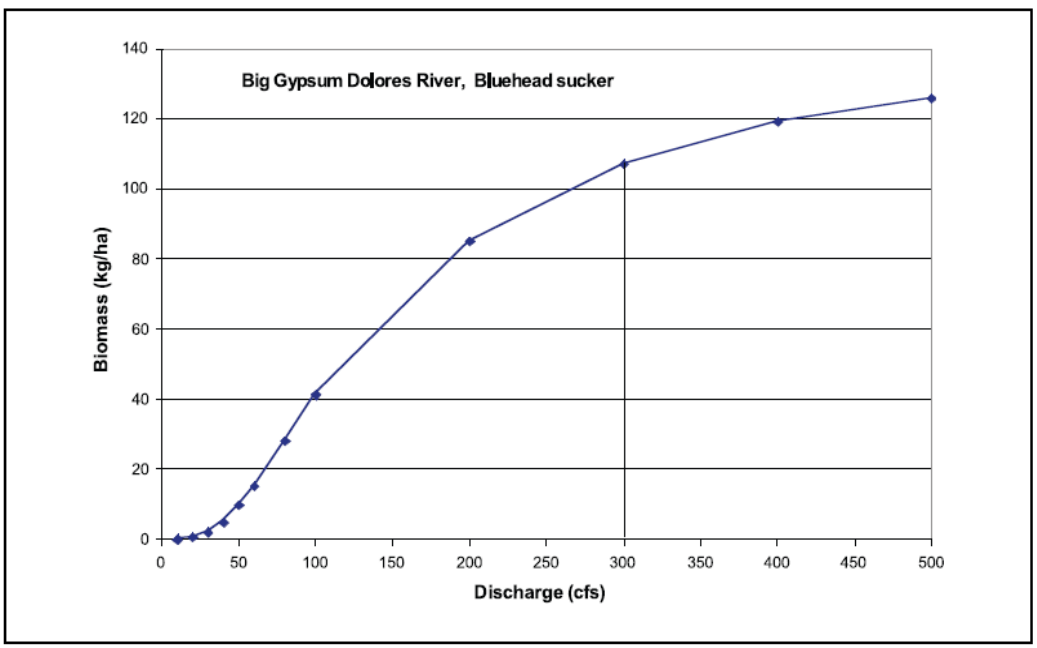


FIGURE II-17. Modeled biomass (kg/ha) of bluehead sucker as a function of discharge at Big Gypsum, Dolores River.

Figure 11. Relationships of habitat availability (top panel) and biomass (bottom panel) of bluehead sucker as a function of stream flow in the Dolores River, at the Big Gypsum site (Anderson 2007).

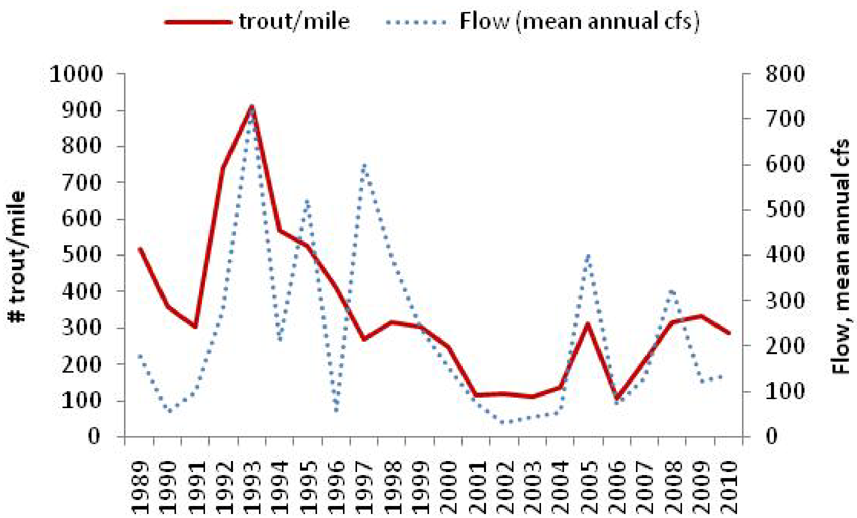


Figure 12. Abundance (number collected) of trout (brown, rainbow, and cutthroat species combined) in the Dolores River in Reach 1 (CDOW Reach 3B), from Metaska Campground downstream to Bradfield Bridge. Data were from various Colorado Division of Wildlife sources, collected mostly during the conduct of two-pass electrofishing removal sampling to estimate trout abundance, 1989-2010.

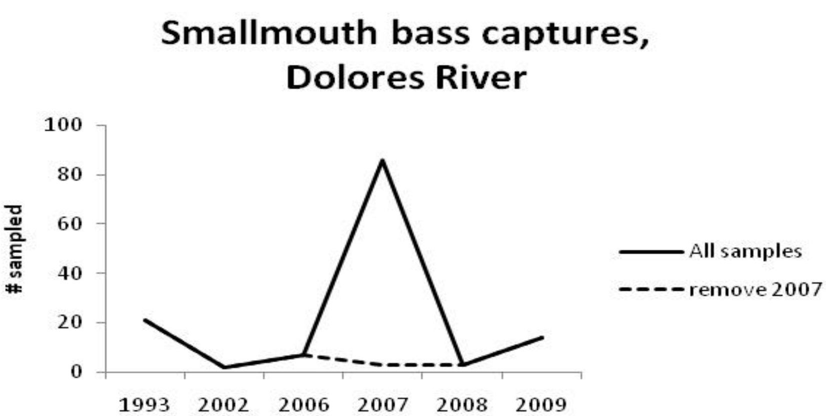


Figure 13. Abundance (number collected) of smallmouth bass collected in all reaches of the Dolores River downstream of McPhee Dam from the Colorado Division of Wildlife database over time. A single sample from 2007 resulted in most smallmouth bass in the period of record and was from a relatively poorly sampled reach and contained four-distinct size classes.

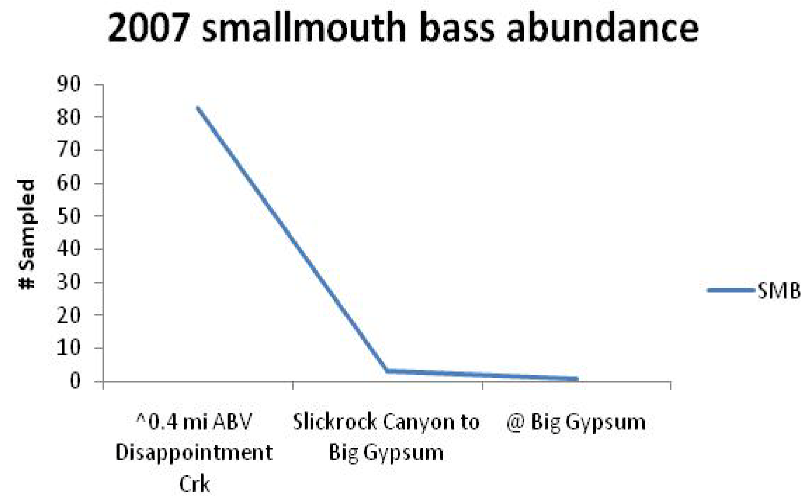


Figure 14. Abundance (number collected) of smallmouth bass collected in three reaches of the Dolores River downstream of McPhee Dam in 2007 longitudinal samples. The single sample from just above Disappointment Creek resulted in most smallmouth bass in the period of record and was a relatively poorly sampled reach and contained four-distinct size classes.

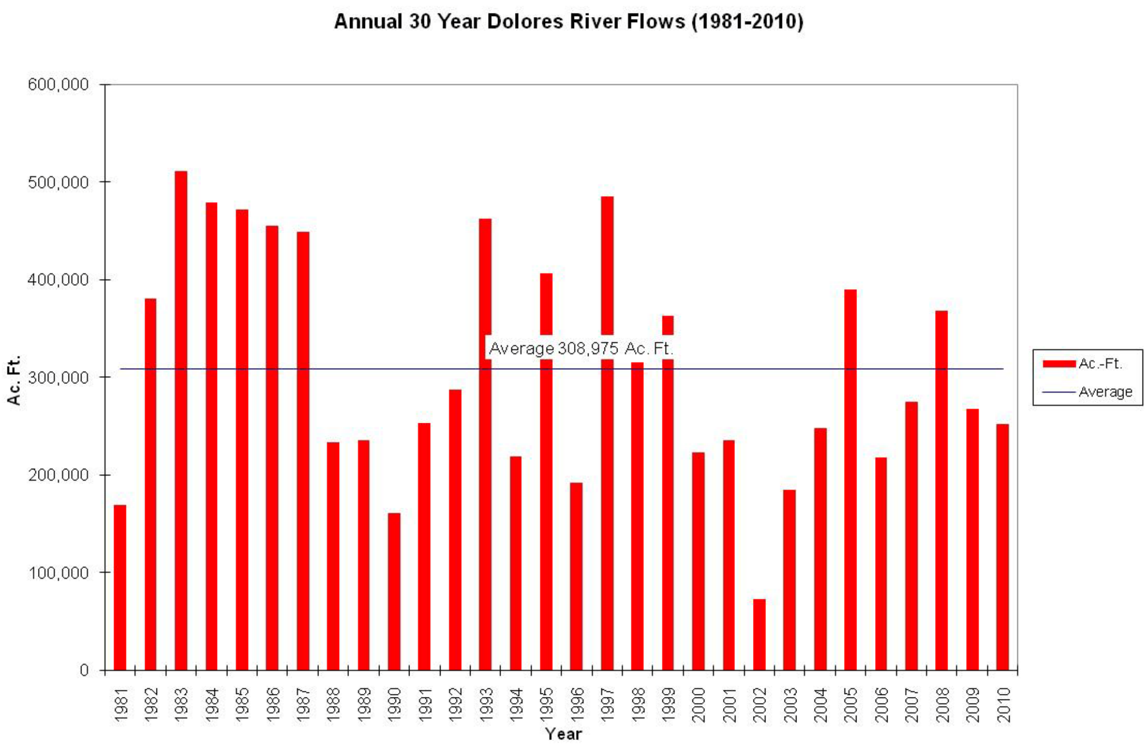


Figure 15. Total acre-feet of runoff of the Dolores River measured upstream of McPhee Reservoir and diversions. The average portrayed is nearly identical to the longer-term average since 1896.

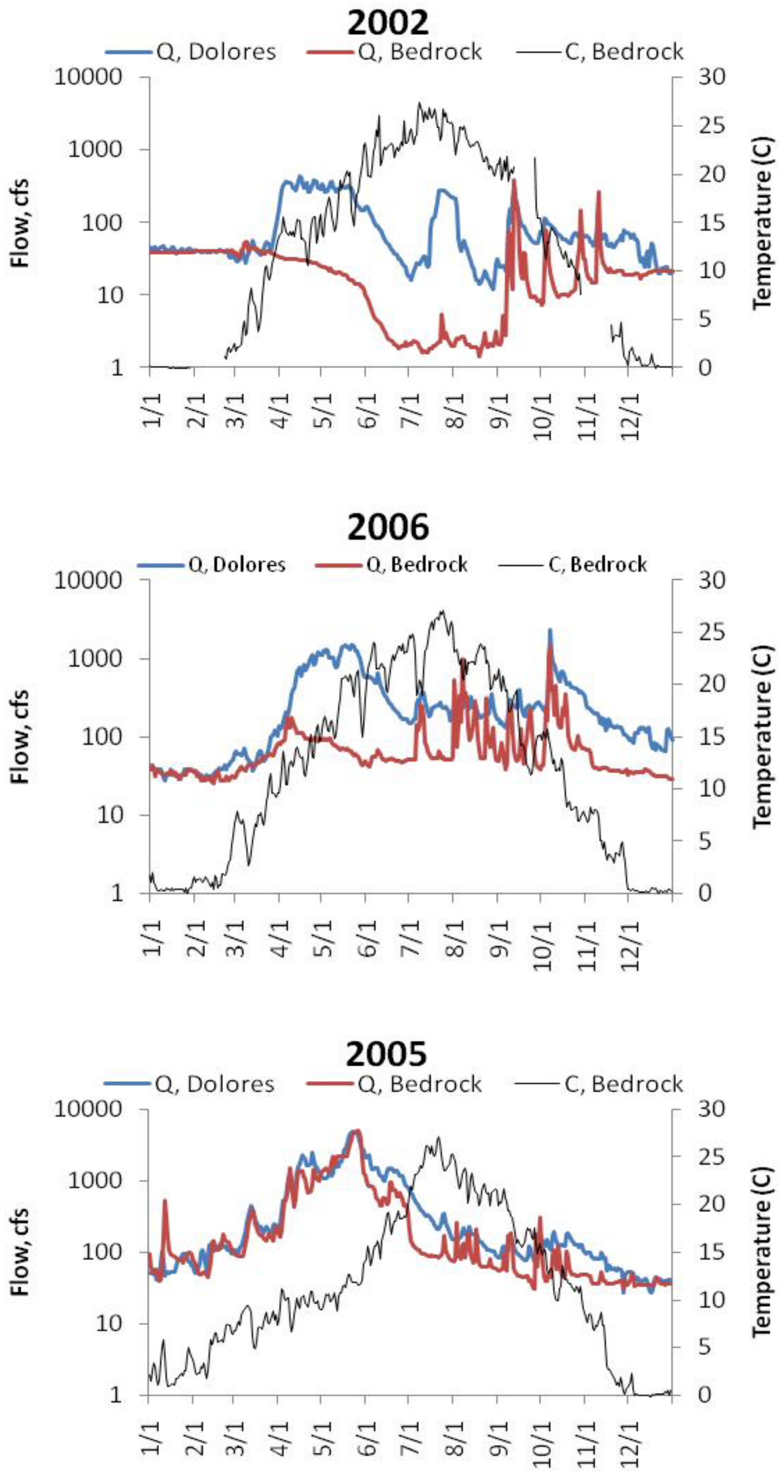


Figure 16. Dolores River flow upstream and downstream of McPhee Reservoir in very low (2002), moderately low, (2006) and moderately high (2005) hydrologic scenarios (see figure 12), and associated water temperature patterns measured downstream of the reservoir near Bedrock, Colorado.

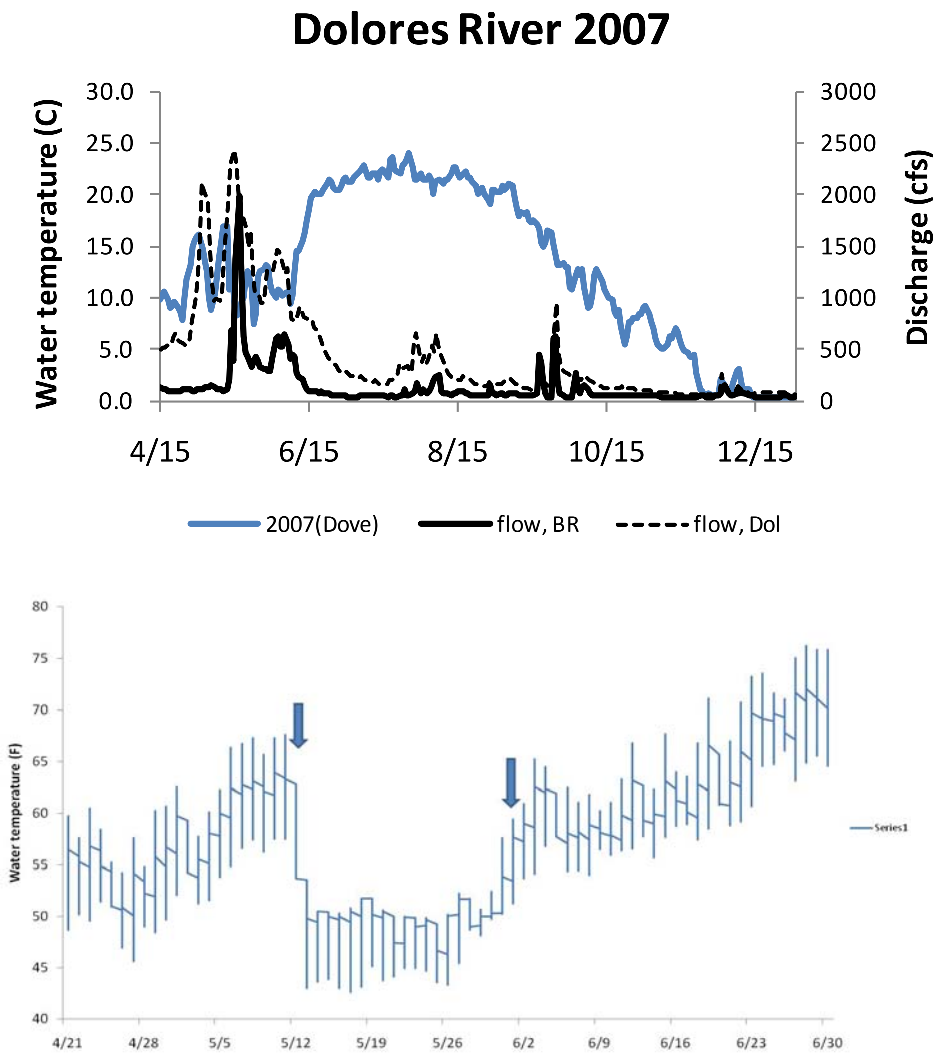


Figure 17. Dolores River flow upstream (at Dolores) and downstream (at Bedrock) of McPhee Reservoir in 2007 and associated water temperature (Dove) measured downstream of the reservoir near Dove Creek (top panel), and 2009 temperature pattern associated with McPhee Dam flow releases (between arrows) in the lower panel.

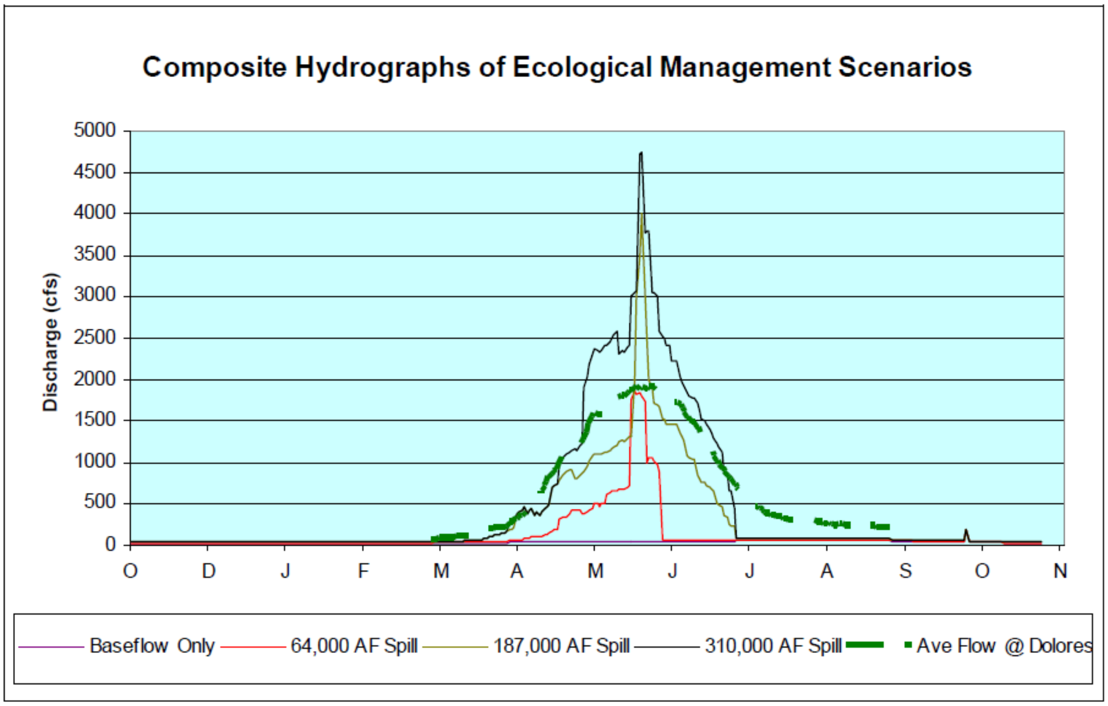


Figure 18. Hypothetical Dolores River flow patterns under baseflow conditions and for years with low, moderate, and high hydrology settings (from DRD Correlation Report).

Native Fish Population Status and Trends and Opportunities for Improvement on the Lower Dolores River: Phase I

Synthesis and summary of findings presented to the Lower Dolores Plan Working Group - Legislative Committee on April 6-7, 2011

by

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Report submitted to the
Lower Dolores Plan Working Group - Legislative Committee

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Executive Summary

In this document, we synthesize and summarize the data presented to the Lower Dolores Plan Working Group - Legislative Committee on April 6th and 7th, 2011, by Dr. Phaedra Budy, entitled "Native fish population status and trends and opportunities for improvement on the Lower Dolores River: Phase I Report." Although we provide some supplementary information to what was presented, we do not intend this report to be an exhaustive review or detailed discussion of the issues. Rather, this report and attached appendices serve to consolidate and highlight the main findings from our study in a relatively concise format that is useful to Dolores River managers and lays the groundwork for Phase II of the DRD project "A Way Forward: The Dolores River Below McPhee Reservoir."

Fish population status and trends

In our approach to assessing the status and trend of the native fishes of the Dolores River, we were highly opportunistic and used a diversity of population status metrics as available. We also relied heavily on those data sets that were repeated over time in roughly the same area, as these data sets provided the best information about temporal trends, or changes across time. The duration, frequency, and spatial extent of major fish sampling efforts varied among sites on the Dolores. The most consistent data collected over time was within DRD Reach 2, which corresponds with CDOW site Dove Creek, and in DRD Reach 4, or the CDOW Big Gypsum site. Given this, we have focused much of our analysis of fish population status on these two sites. In addition to other metrics, we consistently report on our interpretation of: 1) species composition, 2) density and catch per unit effort (CPUE), and 3) size and biomass. We then summarize our interpretation of status and provide recommendations of population status that would most likely lead to persistence. Lastly we provide a preliminary assessment of opportunities for improvement.

Based on the Big Gypsum and Dove Creek sites, our interpretation of native fish population status as demonstrated by species composition indicates that the percentage of roundtail chub (RTC) has remained relatively high and stable, the percentage of flannelmouth sucker (FMS) has been variable at Big Gypsum and low at Dove Creek, and the percentage of bluehead sucker (BHS) has remained consistently very low (<20%). In addition, the percentage of non-natives (not including trout) has been slowly increasing over time with large increases in the early-mid 2000's, the percentage of non-natives (including trout) has ranged from 10-60% since late 1980's, and the percentage of non-natives exceeded natives in some years. In sum, we believe this species composition does not reflect a healthy native fish complex, yet compared to other systems (e.g., Green River) it also suggests that non-natives are neither the only nor the most limiting factor affecting fish populations in the Dolores.

Since species composition provides no information about the number or density of fish, we also summarized density and CPUE data from Big Gypsum and Dove Creek (the most complete datasets available). Density and CPUE offer the best surrogates for true population abundance. Roundtail chub numbers were variable but "stable" until the late 1990's and now appear to be in decline, while sucker densities have been negligible since the late 1990's. Native and non-native fishes all showed a notable increase in 2005 (esp. Big Gypsum). All three species (especially suckers) have declined in CPUE since the 1990's (69-100%) at Dove Creek, and the density of non-natives has increased in recent years at both sites. All catch and density data indicate that suckers are highly imperiled and roundtails appear to be in decline.

Data on the size and biomass of fish are the best surrogates available for population structure (i.e., the size or age distribution) from which we can determine whether there are likely reproducing, mature adults and juvenile fishes from successful reproduction and recruitment. Although data on size and biomass are limited to the Big Gypsum site for four years between 2000 and 2005, the available evidence suggests that native species of the Dolores are smaller on average and at maturity than in similar systems. In 2005, the mean length of the three species at the Big Gypsum site was less than 150 mm. In addition, native suckers in 2005 were substantially smaller than in the similarly sized San Miguel and Gunnison rivers (~30% smaller) and as much as 50% smaller than in the smaller San Rafael Swell system. Based on these and the Dove Creek data, the CDOW concluded that native fish in the Dolores are smaller than average, smaller at maturity, and have poor year class representation. We observed little to no evidence of successful reproduction and recruitment. All of the above typically equate to lower population viability and a higher probability of extinction, since smaller fish typically have lower fecundity. Furthermore, the biomass of channel catfish and carp exceeded constituted a large proportion of total fish biomass at the Big Gypsum site in most years, further indicating the imperiled status of native fish.

In sum, native suckers are highly imperiled, bluehead sucker may be close to local extinction, and roundtail chub appear to be declining but are still present in modest numbers. Longer-term population viability of all three species appears tenuous given available abundance data; the current population structure equates to lower population viability and a higher probability of extinction.
We note that the population structure information is limited to size only, with no age information and little to no recruitment information for YOY fishes. In addition, there is not enough information to give more reach-specific conclusions; our analysis is based primarily on Big Gypsum and Dove Creek (DRD reaches 2 and 4). In general, the situation appears worse in upper reaches.

Fish population status to ensure persistence: preliminary recommendations

Recommendations for restoring native fish population status necessarily depend on the Goal of the restoration effort and on available benchmark data. In the Dolores River, at a minimum to ensure persistence, there are two complementary options for benchmarks: 1) restore densities, distribution, and population structure to a minimum of 1990's levels; or 2) restore densities and population structure to levels apparent in other "healthy" populations in systems of similar size and extent. The biomass of the three species in similar systems ranges from ~10-450 (kg/ha). In the early 1990's in the Dolores (at Big Gypsum), the biomass of the three species ranged from 20-60 (kg/ha). In contrast, the biomass of the three species in the contemporary Dolores River is < 1 (kg/ha). The age/size structure of the sub-population in the San Miguel provides a good benchmark for an apparently healthier sub-population. In addition, ensuring the persistence of the native fishes in the future requires identifying the most limiting factors and preventing further declines.

Preliminary opportunities for improvement (focus of Phase II):

(1)Spill management and base pool management: To identify whether there are opportunities for spill management and base pool management, we evaluated the current regulated (post-dam) hydrologic regime and made comparisons to the pre-dam regime; however, we do not know what the natural (pre-disturbance) hydrologic regime would be since a substantial amount of water has been removed from the river for irrigation since the late 1800s (prior to any available records). In fact, dam releases during the summer helped restore perennial flows to the river. Despite this, low base flow releases (20-40 cfs) in some years reduced native fish habitat through decreased fish holding areas, dewatered nursery backwaters, impeded movement, and enhanced sedimentation. Habitat modeling indicates that base flows of 60-70 cfs and lower are insufficient to sustain native populations in the long-term and can exacerbate native/non-native interactions. Furthermore,, we observed a dramatic reduction in peak flow magnitude (and duration) for most years in the post-dam period. Prior to construction of the McPhee Dam, channel scour appears to have occurred every 1-2 years, helping to maintain the riffle-pool habitats used by native fish. In the post-dam period and in drought years, the reduction in peak flows likely led to the accumulation of sediment in riffles and pools, resulting in channel homogenization and potentially reducing habitat availability for natives. Available geomorphic and hydrologic evidence suggests that the 2005 flood scoured pools and runs, flushed fine sediment from riffles, and improved water clarity. In sum, in addition to direct effects on native fishes, these hydrologic alterations appear to have resulted in an associated alteration of geomorphic processes and consequently fish habitat, including: 1) a reduction in the frequency of scouring/habitat-maintaining floods (i.e., those that initiate bed movement), 2) reduced abundance and diversity of runs and riffles, 3) decreased channel width-to-depth ratios, 4) increased pool frequency, and 5) sediment accumulation in riffle substrates due to a lack of flushing flows (reduced quality of spawning/rearing habitat and instream productivity).

A series of comprehensive flow and habitat studies have been completed that offer guidelines for base flow and spill management, if the goal is native fish persistence and recovery. A flow of 300 cfs maximizes BHS and FMS habitat. A minimum flow recommendation of an 80 cfs base flow (60 cfs with spill) at Big Gypsum would protect 12-22% of maximum native fish habitat. Current operations annually produce base flows of <30 cfs; 30 cfs supports < 5% of potential native fish habitat. Furthermore, peak flows are poorly timed for native fish and of insufficient magnitude or duration to flush sediment in most years. In sum, for native fish persistence and recovery, current peak flows are of insufficient magnitude and duration to maintain adequate habitat availability, base flows are too low in drought years, and the fish pool is insufficient or should be differently managed. Spill management and a movement towards a more natural hydrograph (timing and magnitude) appear to offer the greatest opportunity for improvement, with the potential for additional benefits to natives though synergistic effects on non-natives (*see also below*).

(2) Non-natives: Based on a review of previous studies, the percentage of non-native species has increased since first documented in 1971; there are 13 non-native species documented today and they currently make up high proportion and biomass of non-natives (*see also above*). However, these non-natives do not appear to be as dense or as widely distributed as in other similar systems. Elimination efforts are unlikely to be effective because of the species present and problems with access; but we do believe it is possible to minimize the negative effects of non-natives. To this end, we recommend the following actions: 1) increase base flows to minimize overlap (competition); more cover and habitat heterogeneity leads to more food and less predation, 2) increase peak flows to improve and maintain fish habitat and discourage warmwater non-natives (poorly adapted to natural flood regime), 3) mechanical control where feasible (will not eliminate, but can aid in reducing local abundance), and 4) minimize synergistic effects (non-native predation * flow and habitat degradation). The control of nonnatives alone does not appear to offer an isolated opportunity for great improvement; however the effects of nonnatives should not be ignored, could grow worse over time, and should be minimized where possible.

(3) Water Quality: From reported information about optimal temperatures for the three species, the two native suckers species have an optimal temperature of 68° F (20° C) and roundtail chub has an optimal temperature of 74-75° F (23-24° C). Recent temperature data from four sites on the Dolores River show that for much of the year the river is below these optimal temperatures due to manipulation of the hydrograph. Low volume releases during summer cause extreme temperature variation (small thermal mass in flow), particularly in low velocity habitats (pools, backwaters), along with low dissolved oxygen (DO). In addition, early warming during unnaturally low flows in April and May may prematurely initiate gonadal maturation and spawning of the three species. Subsequent cold high flow releases likely kill eggs and larvae. Other water quality issues (e.g., nutrients, contaminants) appear minor and not influential; there is little evidence in the information we reviewed to indicate a significant history of pollution, and some sources suggest a general improvement in water quality since the 1960s. Opportunities for improvement in the temperature regime exist but the magnitude and direction are uncertain and spatially variable. Using 2009 as example, temperature was too cold in upper reaches and too warm in lower reaches. Nonetheless, mimicking the natural hydrograph (timing and base flow magnitude) should minimize or eliminate most temperature and DO water quality issues.

(4) Riparian Vegetation: Reduced cottonwood growth in favor of hydrophytic rushes and sedges, plus a reduction in the frequency of overbank flooding, may reduce wood recruitment into channel, with subsequent effects on physical complexity and cover. Vegetation establishment on bars plus reduced flooding may reduce the amount of spawning habitat during high flows. Encroachment of tamarisk has resulted in ubiquitous channel incision throughout the range of the three species with associated narrowing, channel simplification, and habitat homogenization. However, overall there is not enough information on

riparian vegetation of the Dolores River to make a rigorous assessment; our preliminary impression – based primarily on communication with local biologists – is that this factor is less important than hydrological and non-native impacts.

(5) Geomorphology: We analyzed the full time series of geomorphic data from the USGS Bedrock gage station located 94 miles downstream from McPhee Dam to assess changes in channel bed elevation and hydraulic geometry. Available evidence indicates that significant channel change at the Bedrock gage occurred following the drought period of the early 1990s, including a drop in the bed elevation and widening of the channel. We also found a correlation in the timing of high flows and bed aggradation in the post-dam period that was absent from the pre-dam period, possibly reflecting sediment inputs from Disappointment Creek and other tributaries. Although these observations suggest the possible influence of vegetation encroachment and reduced mainstem flows on channel morphology and instream habitat, the exact mechanisms and spatial extent of these changes are unknown. We recommend obtaining and analyzing in more detail geomorphic data from this and other locations along the river to determine if the observed changes are localized or widespread and what factors are driving channel change.

Critical uncertainties, data gaps, and preliminary suggestions for monitoring and investigation

The value of the existing fish data cannot be underestimated. Repeated surveys across time (Big Gypsum and Dove Creek) and space (longitudinal surveys) are critical to understanding the current population status and investigating the effect of management actions in the future. Every effort should be made to continue and support this monitoring. Information describing spawning activities and success, as well as recruitment of the native fishes presents a critical data gap. While we recognize the logistical difficulty of these types of sampling activities in this system (e.g., difficulty accessing canyon), targeting reproductive fishes to investigate spawning onset and gonadal maturation, as well as YOY and age 1 native fishes, should be a priority. Perhaps these sampling activities could be targeted at some key index areas where they are logistically feasible (e.g., shore seining or electroshocking, larval drift nets); once established, they should be repeated each year in a standardized fashion. In addition, determining the magnitude and duration of sediment-mobilizing or "flushing" flows (i.e., those required to remove fine sediment from the streambed) will inform management efforts to improve the quality of spawning habitat and increase instream productivity. Data on particle mobility, bed composition, and channel morphology in relation to flow events already collected by David Graf (CDOW) and others, as well as previous calculations of entrainment thresholds, could be used as a foundation for a more comprehensive analysis. We discuss two simple approaches to assessing bed mobility for the initial stages of planning, after which more complex modeling of flushing flows may be considered: (1) painted particle tracers and (2) photographs before and after flow events. Furthermore, the predatory potential of nonnatives (including trout) should be quantified, perhaps by using bioenergetics. Such an analysis would require data describing diet composition and growth rates (or size structure) of nonnative predators, as well as temperature regime; these data could be collected during other sampling events and/or during removal efforts. Lastly, it may be worthwhile to consider some type of spatially continuous habitat mapping (e.g., LiDar; high resolution aerial photography) at a range of different discharges to better quantify the relationship between flow level and habitat availability.

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Assessing Fish Population Status and Trends

Metrics used to determine the status of any population:

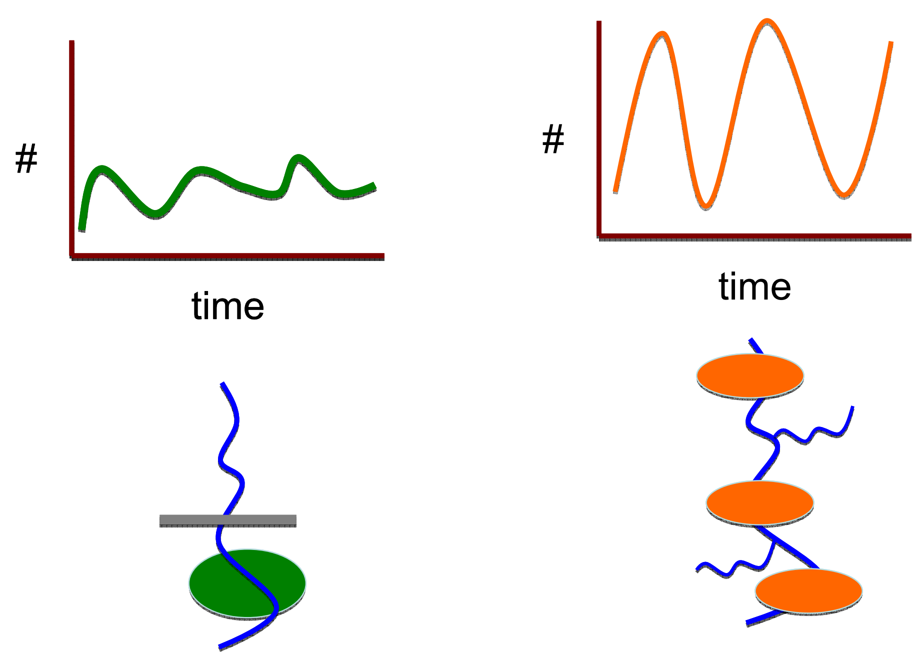
- Population Viability Analysis
    - Vital Rates: growth, survival, fecundity, age etc.
- Population Trend (λ)
- Abundance
- Population structure
- CPUE
- Species Diversity/ Composition/ P/A

These metrics are loosely arranged in order of most rigorous to least, but they are also ranked loosely in order of most data hungry. As such, these top options are not always options. Nonetheless, for determining population status, the most rigorous evaluation would be to use empirical measures (i.e., field and site based measurements of vital rates, growth, survival fecundity, etc). We would use these measures to populate a PVA model of some type, which would allow us to estimate a population growth rate or trend with some confidence interval, extinction probability, time to extinction, etc.

In the absence of that information, the next best option would likely be a time based model of trend using repeated measures of population abundance. From there, we might just compare abundance (e.g., density, number) across space and time. Following that, information about size or age classes could be used to assess the structure of the population and whether there is evidence of recruitment. Finally, we might use catch per unit effort, species diversity, species composition, or who is present or absent and in what relative proportions to assess population status.

Of course, we are also interested in how these metrics are arranged in both space and time (Fig. 1). In the example shown in Figure 1, the population on the left may be healthy and stable, but also isolated and therefore at a greater risk of extinction. In comparison, the population on the right may be highly variable, but well distributed and connected, so at a lesser risk.

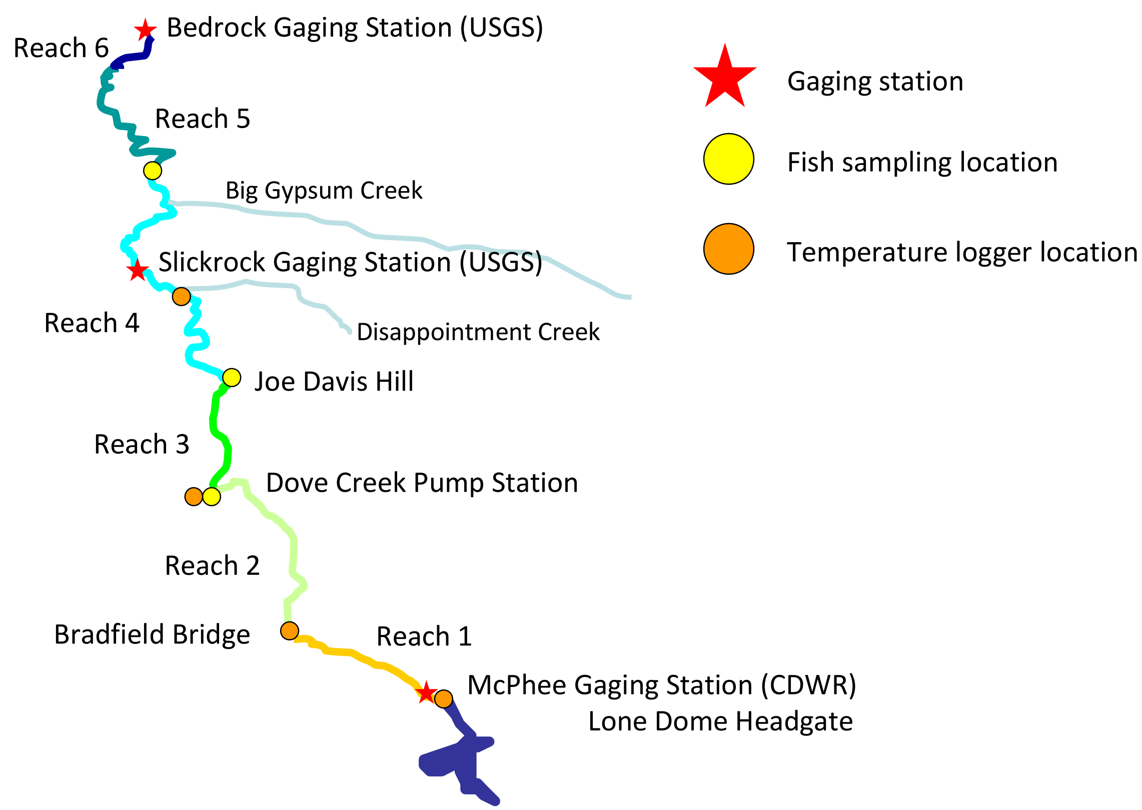
Figure 1: Two examples of population status that differ spatially and temporally.



Fish Population Status and Trends on the Dolores River

Major fish sampling efforts on the Dolores were all distributed a little differently along the river (Table 1). Reaches designated by the DRD are continuous from McPhee Dam to Paradox Valley. Sites surveyed in the earlier Valdez studies (1982, 1992) correspond to two of the DRD reaches, plus four additional sites downstream. CDOW has surveyed extensively at two sites corresponding to DRD reaches (Dove Creek, Big Gypsum) and less frequently at two additional sites. The most consistent data collected across space and time was within DRD Reach 2, which corresponds with CDOW site Dove Creek, and in DRD Reach 4, or the CDOW Big Gypsum site. Given this, we have focused our analysis on these two sites. Study reaches, sampling sites, and important locations are shown schematically in Figure 2.

Figure 2: Schematic of study reaches, sampling sites, and important locations on the lower Dolores River



In addition to the problem of different sampling sites, the different types of data pose another challenge to answering the question of present and future status (Table 2). Nevertheless, there has clearly been a great deal of good and useful data collected.

Table 1: Comparison of fish sampling sites on the Dolores River

DRD Reaches	Valdez et al (1992) Reaches	CDOW Reaches
1: McPhee Dam to Bradfield Bridge (12 miles)		
2: Bradfield Bridge to Dove Creek Pumps (19 miles)	6: Bradfield Bridge to Disappointment Creek	1: Dove Creek pump station
3: Dove Creek Pumps to Joe Davis Hill (9 miles)		
4: Joe Davis Hill through Big Gypsum Valley (38 miles)		
4a. Joe Davis Hill to Disappointment Creek		
4b. Disappointment Creek to Big Gypsum Valley		
4c. Reach through Big Gypsum Valley	5: Disappointment Creek to Paradox Valley at Bedrock	2: Big Gypsum Valley
5: Big Gypsum Valley to Wild Steer Canyon (42 miles): Slickrock Canyon		3: Slickrock
6: Wild Steer Canyon to San Miguel River (12 miles): Paradox Valley		
	4: Paradox Valley at Bedrock to San Miguel	
	3: San Miguel to Salt Creek	4: Gateway
	2: Salt Creek to Utah-Colorado Stateline	
	1: Utah-Colorado Stateline to Colorado River	

Table 2: Summary of fish sampling efforts on the Dolores River

Year	Agency	Locations	Methods	Metric	Source
1971		Several points from mouth to Dolores	Seines	Relative abundance	Holden and Stalnaker (1971, 1975)
1981	USFWS	Reaches 1-6 (Valdez et al. 1992)	Netting, electrofishing	CPUE	Valdez et al. (1982)
1986-present	CDOW	Dove Creek pump station (same as Reach 6 of Valdez et al. 1992)	2-pass wade electrofishing	Counts/CPUE	Mike Japhet, CDOW
1990-1991	BIOWEST/UDWR	Reaches 1-6 (Valdez et al. 1992)	Seines, gill nets, trammel nets, boat electrofishing	CPUE	Valdez et al. (1992)
2000-2001, 2004	CDOW	Big Gypsum Valley (~15 miles d/s of Reach 5 of Valdez et al. 1992)	Mark-recapture	Density/biomass	Anderson and Stewart (2003, 2007) Anderson (2005, 2006)
2007	CDOW	Pyramid, Big Gypsum, Slickrock, Gateway	(?) Boat eletrofishing?	CPUE	Kowalski (2010)

Population Status Metrics on the Lower Dolores River

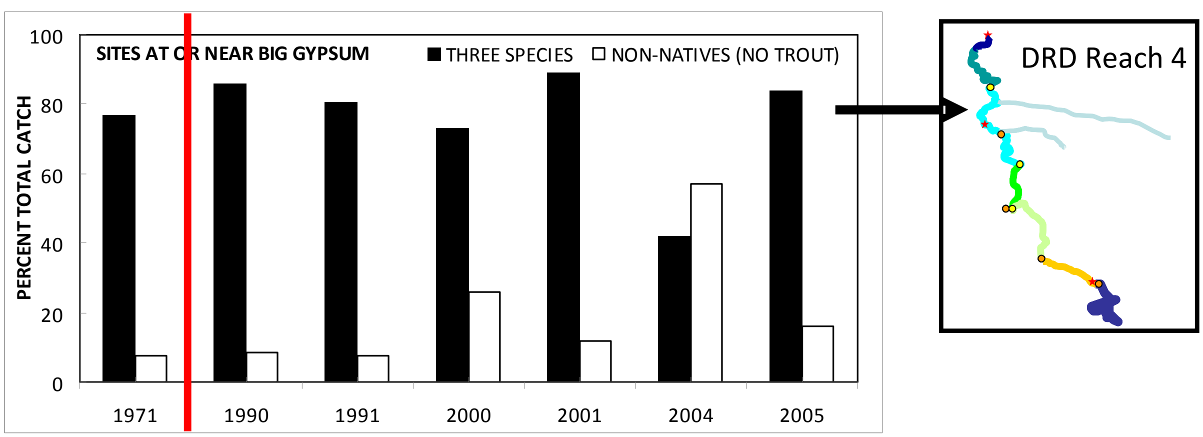
Species Composition: Proportion of Total Catch

Note that the proportion or percentage of total catch tells us nothing about abundance, just which species are present in what relative proportions. The absolute number of each species could be increasing or decreasing, but we would not see that here.

Sites at or near Big Gypsum (DRD Reach 4)

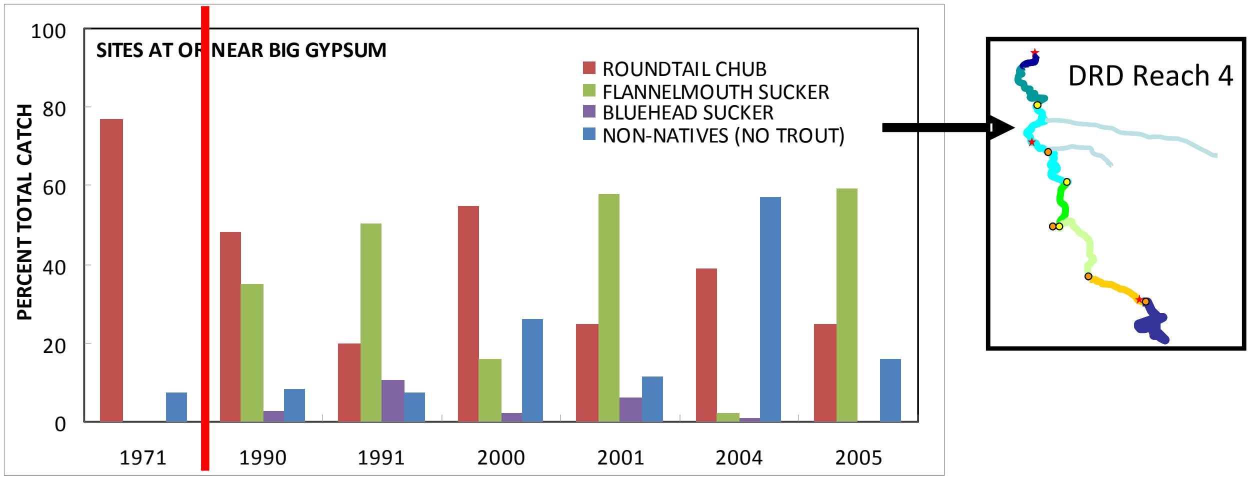
The proportion of the three species relative to the proportion of non-native species for several years from 1971 to 2005 shows that the proportion of the catch made up of the three species has been variable, but at ~ 60-80 % in all years except 2004 (Figure 3). In addition, the proportion of non-natives also appears to be increasing over time, and that in 2004, more of the catch was composed of non-natives.

Figure 3: Proportion of the three species and non-native species at sites at or near Big Gypsum. Red line indicates the date of dam closure (1984). Sources: Holden and Stalnaker, 1975; Valdez et al., 1992; Anderson and Stewart, 2003; Anderson, 2006.



Although the total proportion of the three species remained relatively high, this was not the case for suckers (Figure 4). The proportion of total catch for roundtail chub has remained high throughout the record, whereas the proportion of flannelmouth suckers varied widely among years and the bluehead sucker was less than 20% of total catch in all years. Also notable is that the percentage of non-natives increased over the years, with a huge pulse in 2004. This sudden increase was mostly green sunfish and some black bullheads.

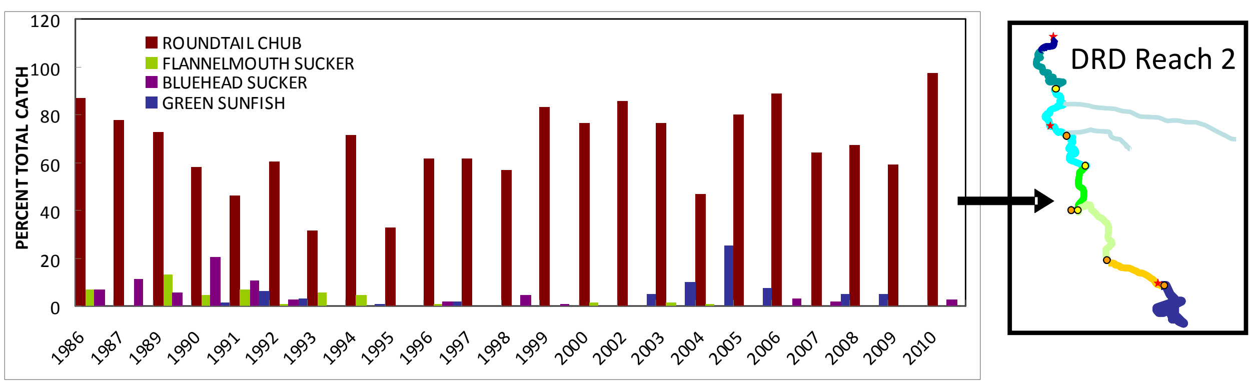
Figure 4: Proportion of roundtail chub, flannelmouth suckers, bluehead suckers, and all non-native species at sites at or near Big Gypsum. Red line indicates the date of dam closure (1984). Sources: Holden and Stalnaker, 1975; Valdez et al., 1992; Anderson and Stewart, 2003; Anderson, 2006.



Dove Creek Pumping Station (between DRD Reaches 2 and 3)

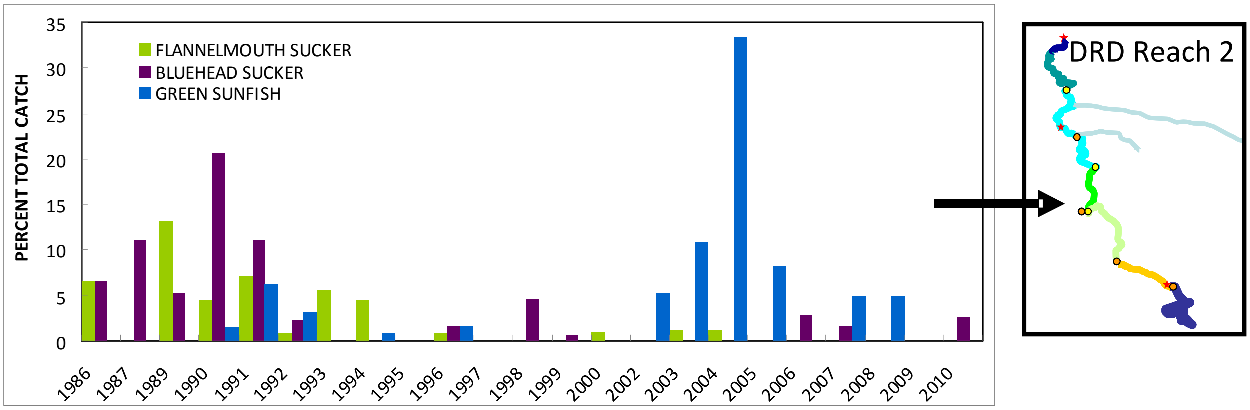
A record of fish population abundance from 1986-2010 at the Dove Creek Pumping Station shows that the proportion of the catch composed of roundtail chubs remained relatively high over time (Figure 5), like at the Big Gypsum site. In contrast, the proportions of flannelmouth and bluehead suckers were very low. We also see a pulse of non-native green sunfish in the late 2000s.

Figure 5: Proportion of the three species and non-native species at the Dove Creek Pumping Station. Source: CDOW unpublished data (John Alves, CDOW, unpublished data)



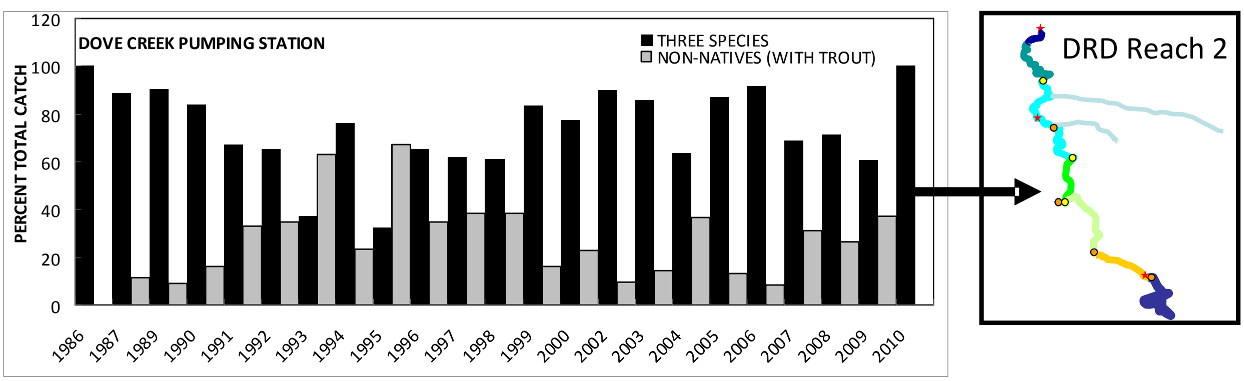
By removing roundtails from the plot, it is easier to see the pattern of sucker decline and green sunfish increase (Figure 6).

Figure 6: Proportion of suckers and non-native species at the Dove Creek Pumping Station. Source: CDOW unpublished data (John Alves, CDOW, unpublished data)



Comparing the proportion of the three species to the proportion of non-natives including trout species, we see that the proportion of the catch composed of trout began to increase in the early 1990s (Figure 7), exceeding the proportion of three species in 1995 but becoming more variable in the following years.

Figure 7: Proportion of three species and non-native species (including trout) at Dove Creek Pumping Station. Non-natives sampled other than trout: green sunfish, smallmouth bass, common carp, and channel catfish. Source: CDOW unpublished data (John Alves, CDOW, unpublished data)



Summary of species composition (based on Big Gypsum and Dove Creek sites)

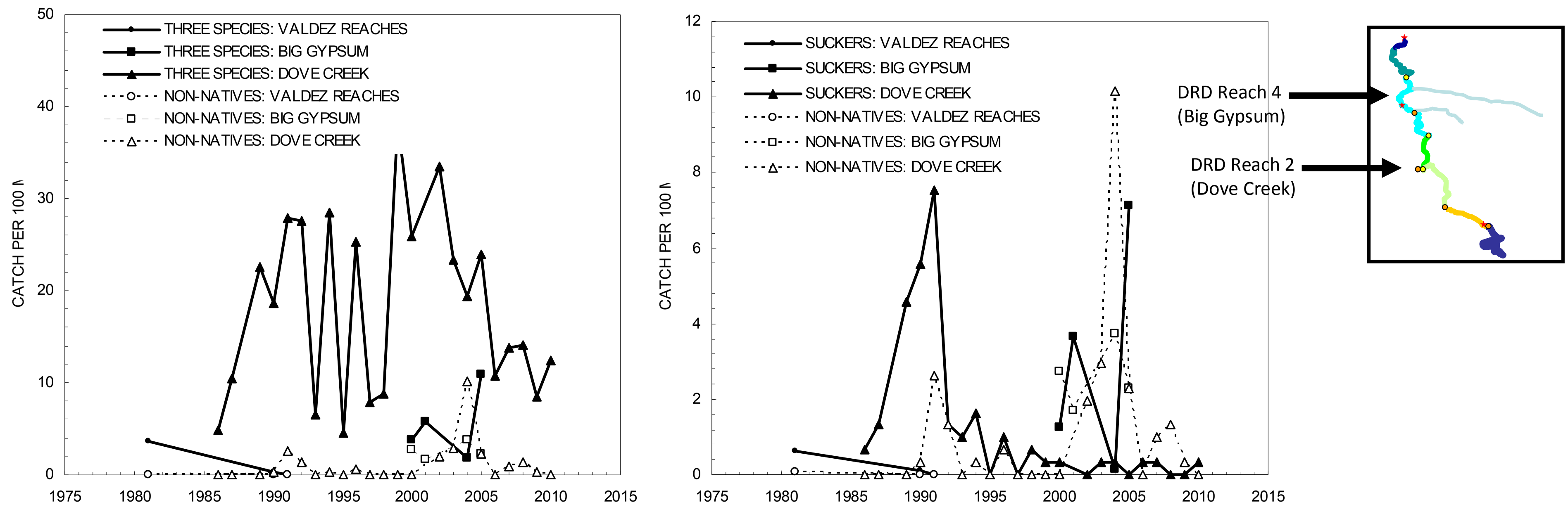
- % of RTC has remained relatively high and stable
- % of FMS has been variable at BG and low at DC
- % of BHS has remained consistently very low (~20%)
- % of non-natives (non-trout) has been slowly increasing over time with large increases in early-mid 2000's
- % of non-natives (including trout) has ranged 10-60% since late 1980's
  - Non-natives exceed natives in some years
- Does not reflect a healthy native fish complex
- Suggests non-natives are not the only or most limiting factor

Density and Catch per Unit Effort (CPUE)

Since species composition provides no information about the number or density of fish, we also summarized density and CPUE data from Big Gypsum and Dove Creek (the best datasets available). Density and CPUE offer the best surrogates for true population abundance.

CDOW caught fish with a two-pass electrofishing of an 1000-ft reach; we used the total number caught to compute catch per 100 m of river for comparison with data from Big Gypsum and all the reaches sampled by Valdez et al. (1992) (Figure 8a). For the first part of the time series, the density of the three species was highly variable, but since 1990 the catch has consistently declined. We also see a large increase in non-natives in the early 2000s. Note, however, that most of the three species catch is composed on roundtail chub (60-80%). Looking instead at just the catch of suckers, we see a dramatic decline in suckers in the early 1990s and the catch remained low through the 2000s (Figure 8b). We also see a large increase in the catch of non-natives in 2004 and a jump in the number of suckers in 2005 at Big Gypsum.

Figure 8: Catch per unit effort (number per 100 m) of a) the three species and non-natives and b) suckers and non-natives at multiple sites along the lower Dolores River. Sources: Valdez et al., 1992; Anderson and Stewart, 2003; Anderson, 2006; CDOW unpublished data.



In an attempt to try and quantify the decline in the number of the three species, we took the highest observations on record (which generally occurred in the 1990s) and calculated the change relative to the recent mean density (average from 2006-2010).

- Blueheads:
  - Max: 1990 and 1991 = 14
  - Mean 2006-2010: 0.6
  - Percent change = -95.7%

- Flannelmouths:
  - Max: 1989 = 10
  - Mean 2006-2010: 0
  - Percent change: -100%

- Roundtail:
  - Max: 1999 = 116
  - Mean 2006-2010: 35.8
  - Percent change: -69.1%

Summary of density/CPUE

- Roundtail chub numbers were variable but "stable" until late 1990's and now appear to be in decline
- Sucker densities have been negligible since the late 1990's with an apparent increase in later years (Dove Creek)
- Native and non-native fishes all showed a notable increase in 2005 (esp. Big Gypsum)
- Nonnative catfish spp. make up a substantial proportion of the density of fish (Big Gypsum)
- All three species have declined (suckers = dramatically) in CPUE since 1990's (69-100%) (Dove Creek)
  - Recent years show increase in non-natives
- All data indicates suckers are highly imperiled and roundtails appear to be in decline

Size and Biomass

Data on the size and biomass of fish are the best surrogates available for population structure, meaning the size or age distribution, from which we can determine whether there are mature adults likely reproducing and juvenile fishes from successful reproduction and recruitment.

Unfortunately, there is not a lot of available information about population structure on the Dolores River. At Big Gypsum, biomass estimates are available for a relatively recent five year period (Figure 9; from Anderson, 2006; Table 19). We see an apparent decline in overall biomass, but also see that channel catfish and, in some years, non-native carp make up a large portion of total biomass. We also see no obvious decreases in flannelmouth sucker or roundtail chub biomass. However, the mean size of the three species does appear to be declining or to be low relative to other populations (Figure 10). In 2005, all three species average less than 150 mm, representing relatively small fish, perhaps only 2 years old, which would be barely sexually mature.

Figure 9: Biomass of different fish species at Big Gypsum. Source: Anderson. 2006, Table 19.

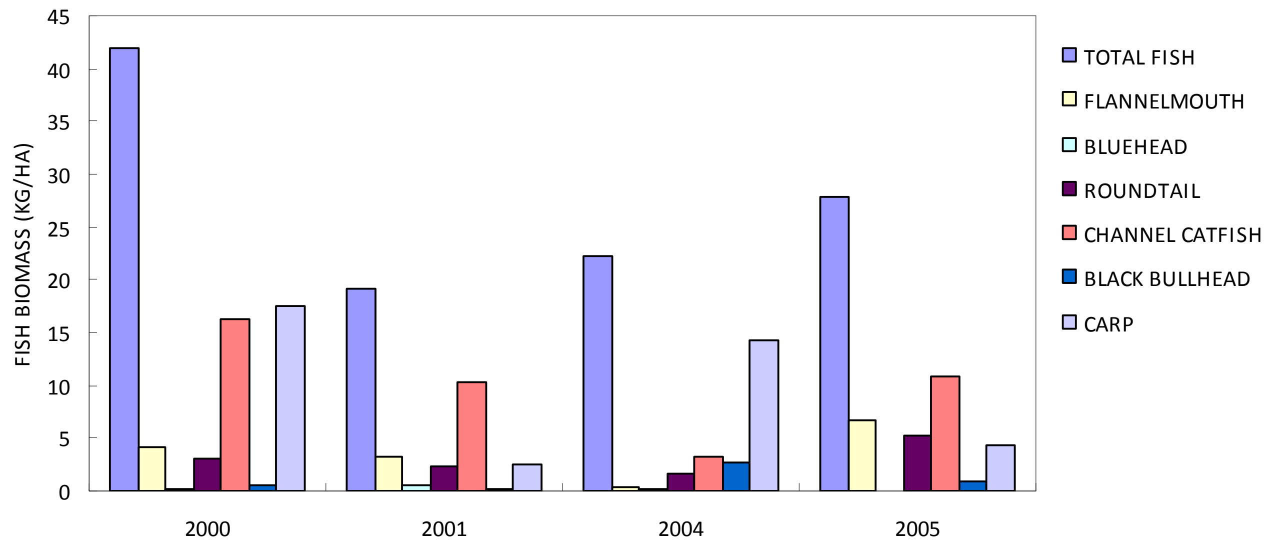
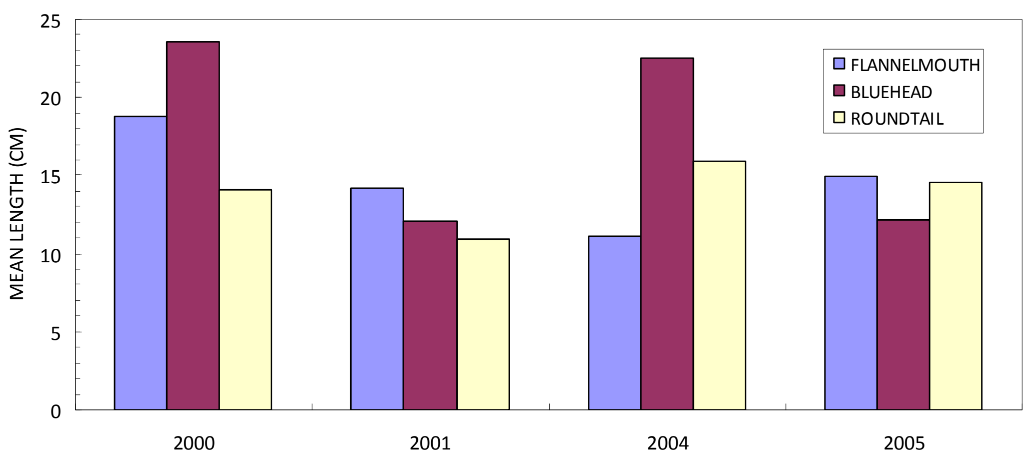


Figure 10: Mean length of three species at Big Gypsum. Source: Anderson, 2006; Table 20.



For comparison, consider the mean size for the three species in the San Rafael swell (P. Budy, unpublished data):

FMS: 279 mm (139-385), 46% bigger
BHS: 178 mm (99-251), 16% bigger
RTC: 148 mm (80-221)

These numbers come from a relatively healthy subpopulation, but one that is a sink population isolated from the lower river and the Green River, so not the healthiest. In this system, RTC are doing very poorly. Although there are adequate base flows, there is a diminished spring flood.

Size and biomass data can be used to assess evidence for recruitment (presence of young-of-year fish). At Big Gypsum:

- RTC YOY collected in all years except 2004
    - 2004 = year with the most sedimentation and also the year with the highest black bullhead density

- No FMS YOY were collected in 2004 and 2005
- No BHS YOY collected
- Age1+ bluehead sucker abundant in 2001, rare in 2004 and 2005

These data indicate successful reproduction and recruitment occurred in 2000, likely due to spawning upstream of Disappointment Creek and migration to Big Gypsum (Anderson, 2006).

Size and biomass summary

- Biomass of catfish and carp exceeds native fish biomass
- 2005, mean length < 150 mm
  - Suckers are substantially smaller than in San Miguel and Gunnison (~30% smaller)
  - Suckers are as much as 50% smaller than San Rafael Swell
  - Smaller fish have lower fecundity
- CDOW note smaller than average, smaller size at maturity, poor year class representation
- Little evidence of successful reproduction and recruitment
  - Targeting YOY?
- Both of above typically equate to lower population viability
- Significantly lower native biomass in the Dolores River today than in the early 1990s and in other systems
  - In the early 1990s, the biomass of the three species at Big Gypsum the biomass of the three species ranged from 20-60 kg/ha.
  - Today, the biomass of the three species in the Dolores River is < 1 kg/ha
  - In comparison, current biomasses of the three species in the smaller San Rafael system are (Budy, unpublished data):
    - BHS: 3.84 kg/ha
    - FMS: 9.36 kg/ha
    - RTC: 0.45 kg/ha

Fish Population Status and Trends Summary

- Our analysis is based mostly on Big Gypsum and Dove Creek (reaches 2 and 4)
  - Native suckers are highly imperiled, bluehead sucker may be close to local extinction
  - Roundtail chub appear to be declining but are still present in modest numbers
  - Longer-term population viability of all three species appears tenuous given available data
- Population <u>structure</u> equates to lower population viability and p. of persistence
  - Size only, no age info, no/little recruitment info*
- Not enough information to give more <u>reach-specific</u> conclusions
  - Situation appears worse in upper reaches

Fish Population Status to Ensure Persistence: Recommendations

- Restore densities, distribution, and population structure to a minimum of 90's levels
- Restore densities and population structure to levels apparent in other "healthy" populations
- CDOW Comparison :
    - Three species biomass other systems: 138-422 (kg/ha)
    - Early 1990's Dolores (Big Gypsum): 20-60 (kg/ha)
    - Contemporary Dolores (Big Gypsum): 0.6 (kg/ha)
    - Age/size structure in San Miguel

- Identify most limiting factors and prevent further declines

Opportunities for Improvement

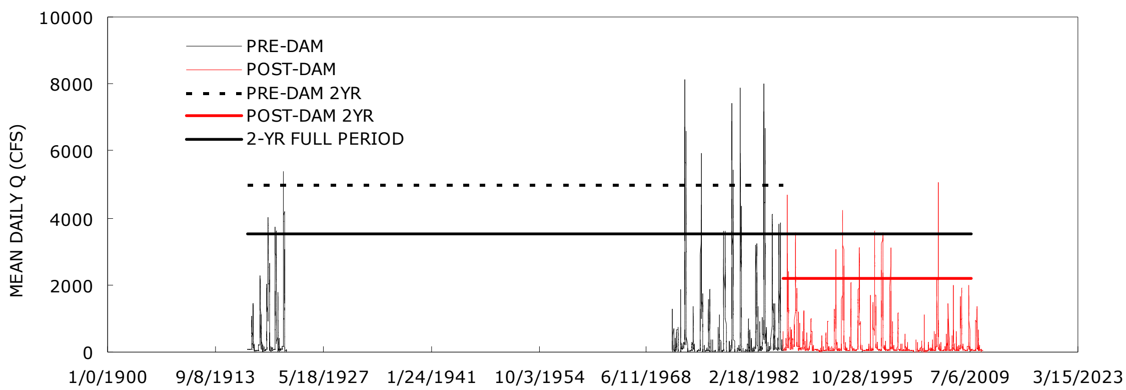
Spill Management and Base Pool Management

Hydrologic regime of the lower Dolores River

To identify whether there are opportunities for spill management and base pool management, we start by evaluating the current hydrologic regime and where possible, compare that to the prep-dam regime. However, an important qualifier here is that we do not know the natural hydrograph, since a substantial amount of water has been removed from the river for irrigation since the late 1800s (prior to any available records).

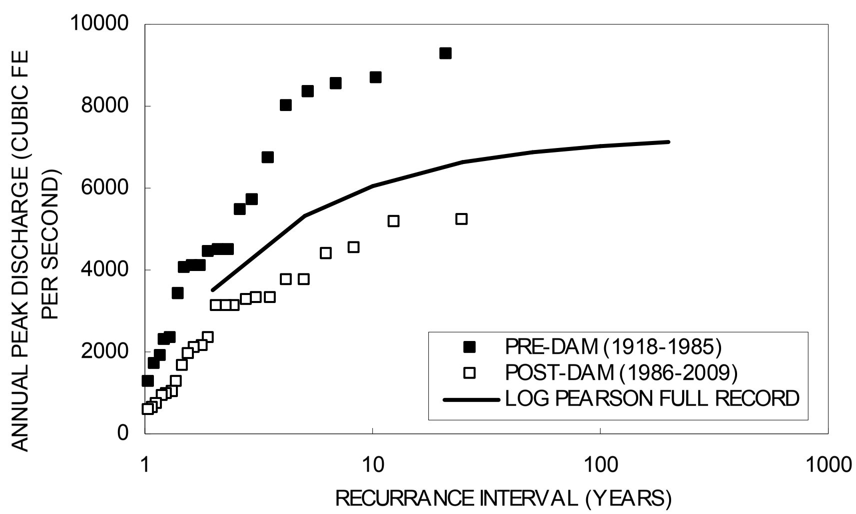
A plot of mean daily discharge and the two-year flood for the pre-dam, post-dam and full period (based on a log Pearson flood frequency analysis) at the Bedrock gage station (~94 miles downstream from McPhee Dam) shows that the dam has significantly reduced the two-year flood (Figure 11). An Indicators of Hydrological Analysis done at this station in 2005 (Richard and Wilcox, 2005) found that the dam reduced the two-year flood by 27% and the mean annual flood by 50%. Previous estimates of the discharge required for significant bed motion were 7,000-10,000 cfs (Vandas et al., 1990; Richard and Anderson, 2007), magnitudes of flow never met in the post-dam period. In this plot we can also see the extended drought periods of the mid 1990's and early 2000s

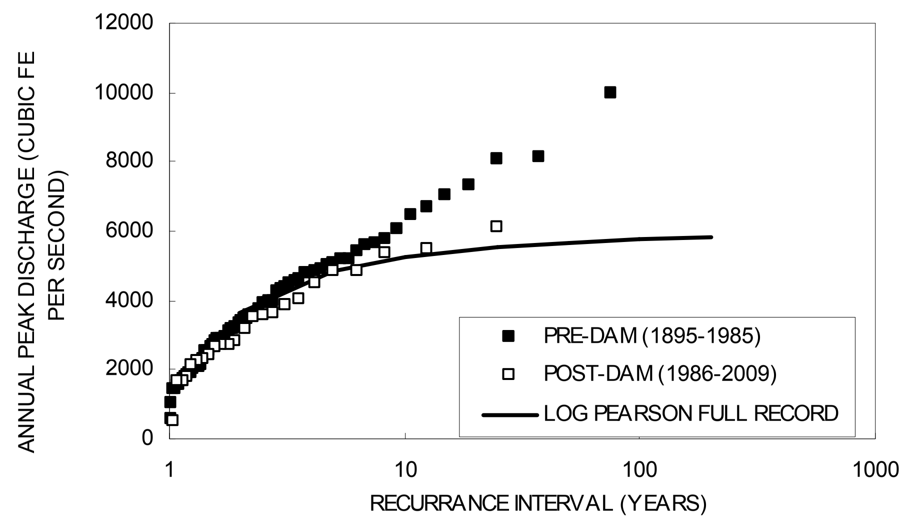
Figure 11: Mean daily discharge of Dolores River at the USGS Bedrock gage station. Horizontal lines are the two-year flood discharges for pre-dam, post-dam and full record.



We performed a flood frequency analysis on instantaneous peak flow data (Bedient and Huber 2002) from the Bedrock gage station to determine the recurrence intervals and exceedence probabilities of given discharges. The recurrence interval of a flood is based on the probability that a flood of a given magnitude will be equaled or exceeded in any given year. For example, a 25-year flood has a 1 in 25 chance of occurring in a given year; over 100 years, a 25-year flood is expected to occur four times, but not necessarily every 25 years. A flood frequency analysis uses the statistics of a historical peak flow record to construction frequency distributions that can be used to predict the likelihood of various discharges. We fit a Log Pearson Type III distribution to the discharge frequency distribution data (Bedient and Huber 2002) to estimate the discharge of floods for various recurrence intervals. We computed standard flood frequency statistics for the entire record (1914-2009) and the pre- and post-dam periods separately (1914-1984 and 1984-2009) (Fig. 12). We conducted the same analysis on data from the Dolores gage station upstream from the dam for the same time periods. Flood frequency plots clearly show the effect of the dam on the frequency and magnitude of peak flows.

Fig. 12: Flood frequency analysis of the Bedrock and Dolores gage stations for the full period and pre- and post-dam periods.

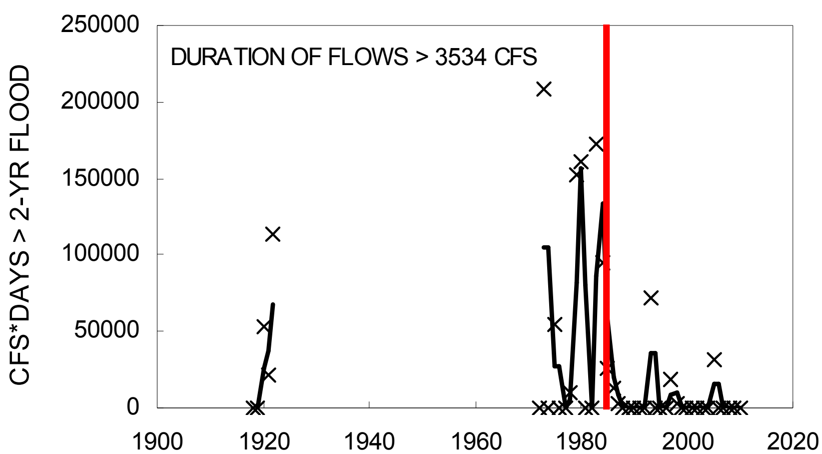




Using results from the flood frequency analysis, we calculated the flood duration as "m^3/s*days" for each year on record (Fig. 13). For each daily discharge that exceeded the 2-year flood of that period, we computed the difference (in m^3/s) from the 2-year flood; we then summed the cumulative differences for each year. Duration of floods > 2-year flood provides an index of the potential for geomorphic change. Above an entrainment threshold, sediment transport capacity increases exponentially with discharge. Over long periods, erosion is a function of flood magnitude and frequency of occurrence (Wolman and Miller 1960). It has been well-established that most channel change occurs due to relatively frequent events of moderate magnitude such as the 2-year flood (Wolman and Miller 1960, Leopold et al. 1964). Flows that equal or exceed the 2-year flood are presumed to be capable of causing channel change; the duration of these floods determines the magnitude of channel change that might occur during a given period.

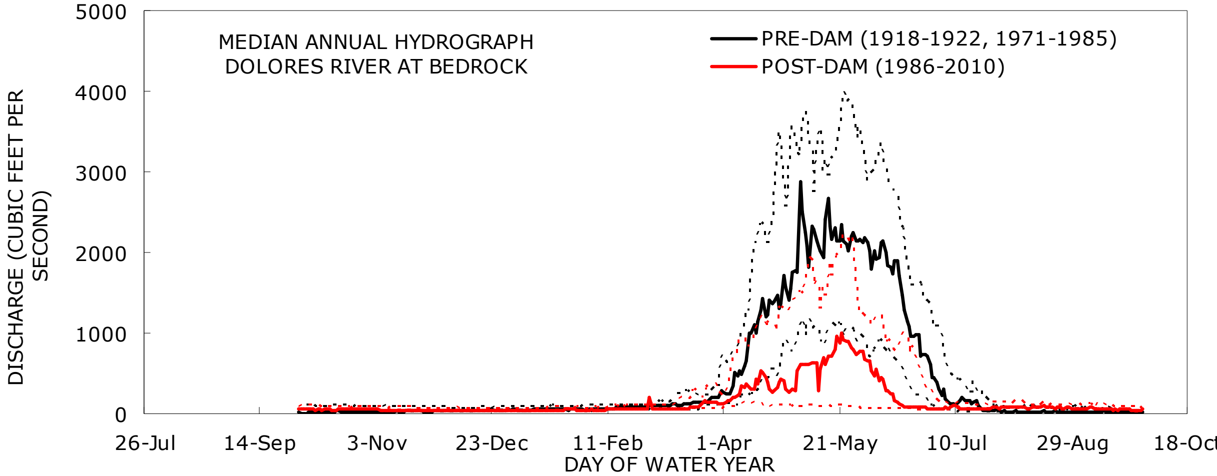
Previous studies have estimate that the flow that inundates most of floodplain and flow that initiates bed mobility are in the range of 2000-3400 cfs (Vandas et al., 1990; Richard and Anderson, 2007), corresponding to 1.8-2.5 year flood frequency in post-dam regime. As such, marginal transport and significant floodplain inundation should occur on a ~2 yr frequency in post-dam era. However, it is difficult to identify the current floodplain because of vegetation encroachment by tamarisk, Russian olive, and willow, due to reduced overbank flooding. In theory, a reduced 2-yr flood should result in a smaller channel and a smaller bankfull discharge; but the new floodplain may not yet be evident if channel is still adjusting to the pre-dam hydrologic regime.

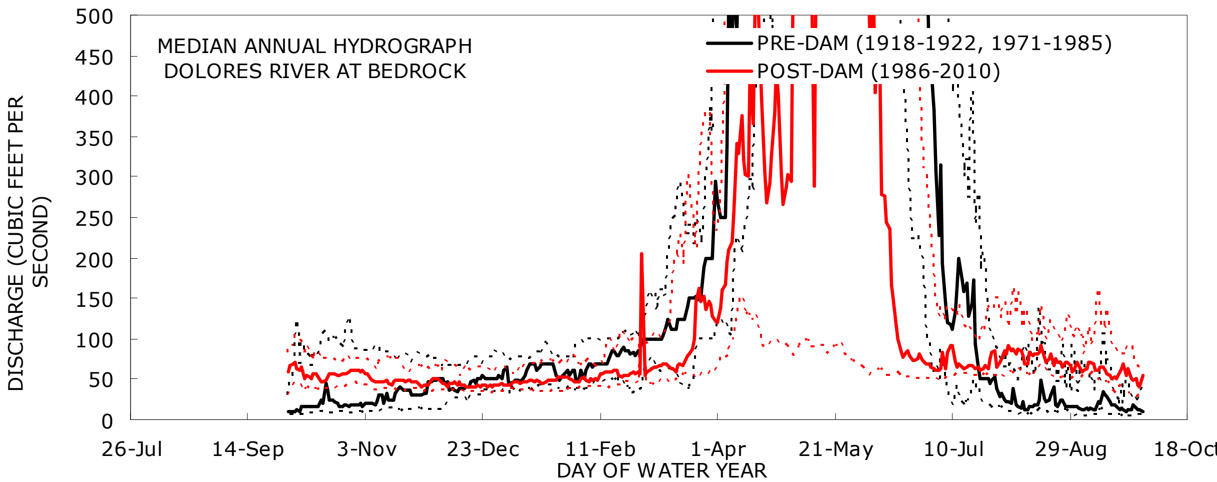
Figure 13: Flood duration record for the Dolores River at Bedrock gage station, calculated as the number of days multiplied by the mean daily flow on each day that flows exceeded the 2-year flood discharge (3534 ft^3/s) in a given year. Trendline is moving average with 2-year period; vertical red line indicates year of completion of the McPhee Reservoir (1985).



Another way to evaluate hydrologic information is to compare the median annual hydrographs for the pre- and post-dam periods (Fig. 15). Here again we see a dramatic reduction in the magnitude of peak flow, as well as a shift in the timing of the peak and receding limb.

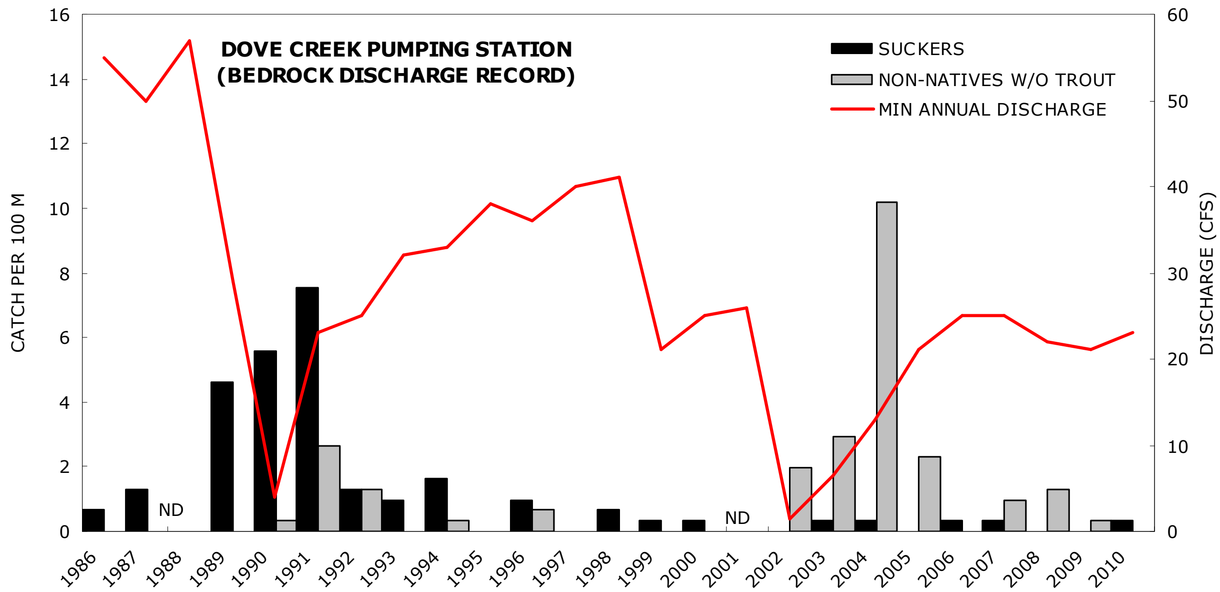
Figure 15: Median annual hydrograph of Dolores River at USGS Bedrock gage station for the pre- and post-dam periods, presented in two plots with different y-axis scales to show differences in peak and base flows between periods. Dashed lines are 25-75 percentiles.





We can see a clear relationship between hydrology and native fish populations, as well as the impact of the dam on river hydrology (Fig. 16). Minimum flows were actually high in the years following dam construction, because releases from the dam restored perennial flows that had been previously removed for irrigation use during the summer. Populations of native species increased in the years following these high minimum flows (i.e., summer baseflows). However, the CPUE of non-native species increased and native species decreased following years of low baseflows (e.g., 1991-1993, 2000-2003), illustrating the strong effect of summer baseflow conditions on native populations.

Figure 16: Time series of sucker and non-native populations at Dove Creek Pumping Station plotted with the minimum annual discharge of the Dolores River at the USGS Bedrock gage station.



Hydrology summary

- Dramatic reduction in peak flow magnitude (and duration)
    - Altered geomorphic processes:
        - Habitat maintaining floods that initiate movement and move bed no longer occur
        - Reduced runs and riffles due attributed to low flows in 2002-2003, decreased width:depth, increased pool frequency
        - Subsequent effects on channel morphology and in-channel habitat = may be exacerbated by vegetation encroachment in the reaches downstream of Disappointment Creek (DRD Reaches 4b-6)
        - Sediment accumulation in riffle substrates due to lack of flushing flows (reduced quality of spawning habitat and instream productivity)

Sources*:* Richard and Wilcox, 2000; Anderson and Stewart, 2003; Anderson 2006*;* Anderson and Stewart, 2007

Opportunities for Spill Management: Recommendations

- If the management goal is native fish recovery, we recommend reestablishing the natural (unregulated) hydrologic regime
    - Increase annual peak flow (~ 3000 cfs in some years)
    - Time to historical spring spate (~mid-May)
- Current operations:
    - Spill is only declared when reservoir is assuredly going to fill
    - Usually, spill declaration occurs late in runoff season, leads to abrupt increase in flows and an unnatural hydrograph pattern (no gradual rising limb)
        - Cold water thermal shock to native fish when they are preparing to spawn /rearing
- CDOW recommendations (strategy used for other federal reservoirs) (CDOW 2010)
    - Use April 1st runoff forecast to plan for managed spill

- Minimize debts to fish pool by declaring spill earlier and start low volume spills

Opportunities for Base Flow Management: Recommendations

- Comprehensive and appropriate studies have already been completed
- Valdez et al., 1992:
  - Base flow releases of 20 to 40 cfs in 1990 and 1991 reduced native fish habitat through decreased fish holding areas, dewatered nursery backwaters, impeded movement, and enhanced sedimentation, *may enhance negative interactions with and conditions for nonnatives*
  - Recommended minimum base flow releases of 50 cfs during dry and normal years and 78 cfs during wet years
- Anderson and Stewart, 2007:
  - A flow of 300 cfs maximizes BHS and FMS habitat
  - 80 cfs (60 cfs with spill) minimum flow recommendation at Big Gypsum would protect 12-22% of maximum native fish habitat
- CDOW, 2010; Kowalski et al., 2010:
  - Current pool of 31,798 af is only 87% of target recommended pool
  - Current downstream allocation is 46% of pool required to meet 78 cfs year-round
  - Habitat modeling indicates 30 cfs supports < 43% of potential trout habitat and < 5% of potential native fish habitat
  - Current operations annual produce baseflows of <30 cfs
- If management goal is native fish recovery, then there is currently insufficient base flow, peak flow, and fish pool

Non-natives

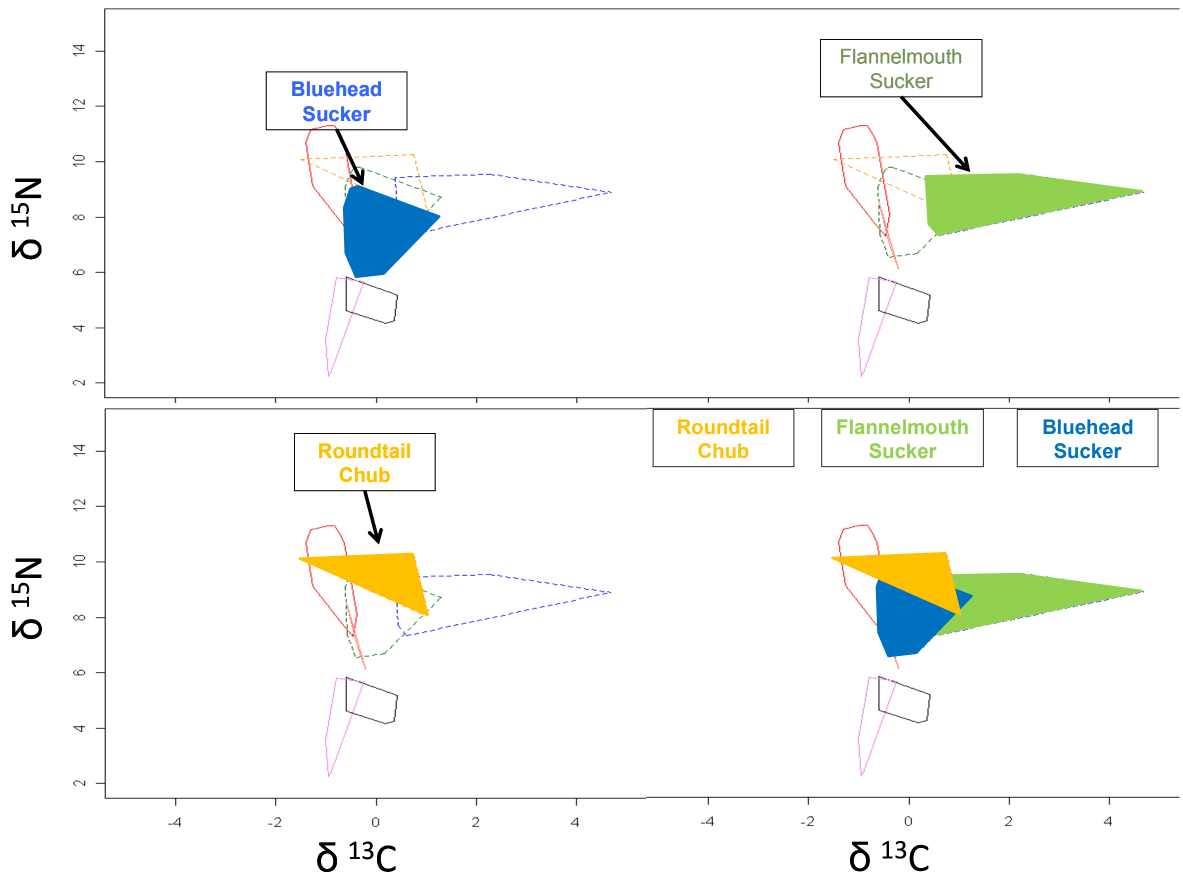
Review of previous studies:

- Percentage of non-native species has increased since first documented in 1971 (Holden and Stalnaker 1971)
- 13 non-native species documented today (Anderson, 2005; Anderson, 2006) (species composition varies by reach)
- Currently high proportion and biomass of non-natives
- Not as high as similar systems?
- Anderson (2005, 2006):
  - Increase in black bullhead corresponded with decline in flannelmouth sucker and roundtail chub following a period of drought (Big Gypsum site)
  - Although not efficient predator, black bullhead is strongly associated with backwater habitat types which were more prevalent during low flow years
- Anderson and Stewart (2007):
  - Impact of non-natives less than habitat problems
  - Control efforts not likely to be effective, b/c of species present and access
  - Improving and maintaining fish habitat critical to discouraging non-native fish expansion

To further evaluate opportunities for non-native management on the lower Dolores River, we can use the case study of the San Rafael River as an example of the influence of non-natives on the three species. We have been using a variety of different metrics to look at the potential for competition with and predation by non-natives. We use isotopic signatures to determine where a fish is eating, and to some degree living, in the food web. We take a non-lethal tissue sample and analyze it for heavy forms of nitrogen and carbon; together these two isotopes describe the niche space of each species.

In Figure 17, we represent the food web from a section of river upstream from a barrier on the San Rafael River, where there are no non-natives; the niche space of each of the three species is represented with a shaded polygon. Based on the location of the bluhead suckers polygon (Fig. 17a), it appears that they have a fairly narrow trophic niche (carbon range = 1.922, nitrogen range = 3.265, NW = 8.263) and are feeding at an average trophic position of 3.04 (assuming collector-filterer invertebrates, shown in black, feed at trophic position 2). This suggests that while blueheads are likely feeding heavily on algae, as previous studies (and their jaw morphology) suggest, they are assimilating most of their energy from invertebrates they ingest with the algae.

Figure 17: Trophic niche space diagrams for a section of the San Rafael River without non-natives for (a) bluehead sucker, (b) flannelmouth sucker, (c) roundtail chub, and (d) all three species.

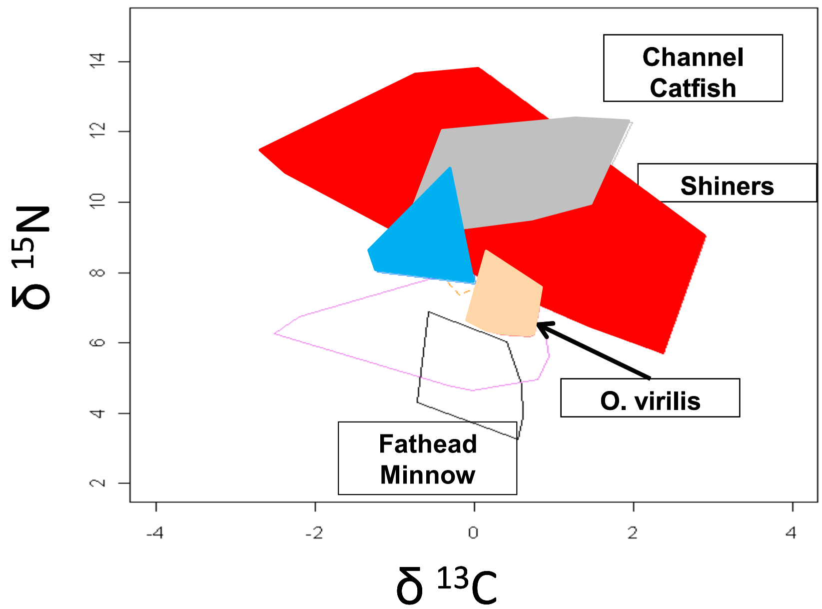


From the flannelmouth suckers trophic niche we can see that flannelmouth suckers occupy a trophic niche that is wider than the bluehead suckers (i.e., more diverse), but at same trophic level as bluehead suckers in the upper San Rafael River (CR = 4.28, NR= 2.201, NW=10.829) (Fig. 17b). However, they are less depleted in 13C, suggesting that they feed less in riffle habitats than bluehead suckers. The flannelmouth suckers feed at a trophic position of 3.08, again suggesting that they get most of their energy from invertebrates (TP = 2).

From the roundtail chub trophic niche space, we see that roundtail chub have a similar niche width to the bluehead sucker (CR = 2.535, NR =2.185. NW = 7.69), but feed at a slightly higher trophic position (TP = 3.26) than either of the two suckers in the San Rafael River (Fig. 17c). This suggests that the roundtails do not assimilate much energy from detritus or algae, and feed primarily on benthic invertebrates and some organisms at a higher trophic level, perhaps larval fish or small crayfish, or predatory invertebrates. All three species are located in a similar trophic space, but are differentiated from each other enough to minimize overlap (Fig. 17d). This suggests strong evolutionary pressures to feed within a narrow range of available resources, but also to partition the resources among the three species.

However, if we look at the non-native fishes' trophic niche spaces, we see that they completely overlap the two suckers, and overlap 95% of the roundtail chub niche space (Fig. 18). This shows that there is the potential for competitive interactions between the non-native fishes and the three species over limited food resources, as they all occupy similar trophic niche spaces.

Figure 18: Trophic niche space diagrams for non-native fishes on the San Rafael River.



Opportunities for Non-native Management: Recommendations

We think it is possible to minimize the negative effects of non-natives and recommend the following actions:

- Increase base flows
  - Minimize overlap (competition); more cover and habitat heterogeneity leads to more food and less predation
- Increase peak flows
  - Warmwater non-natives are poorly adapted to natural flood regime
  - Diversify habitat via geomorphic heterogeneity
- Mechanical control
  - Will not eliminate, but can aid
  - Especially big predators/competitors
- Minimize synergistic effects
  - For instance, the interactive effects of habitat degradation and exotics

Note that Oliver et al. (2010) came to slightly different conclusions (possibly because some were based on studies of the Yampa and Colorado rivers, not the Dolores)

- They hypothesized and recommended that:
  - Consecutive years of low spring flows and/or low baseflows will cause increased pops of nonnative warmwater species (Anderson and Stewart 2007)
  - Warmer water temperatures will cause upstream expansion of smallmouth bass pop (White 2010, Anderson and Stewart 2007)

- Flows between 100-1000 cfs in the 60 days before the peak will control nonnative warmwater fish pops (Anderson and Stewart 2007, Graf 2006 communication)
- Although a test flood did not decrease nonnative pops, repeating floods annually could reduce nonnatives (Valdez et al., 2001)
- Direct control of nonnatives in priority reaches will increase survival of natives (UDWR 2006, Anderson 2010)

Water Quality: Temperature and Dissolved Oxygen

From reported information about optimal temperatures for the three species (Table 3; Lamarra, 2007), we can see that the two native suckers species have an optimal temperature of 68° F (20° C) and roundtail chub has an optimal temperature of 74-75° F (23-24° C). Temperature data from four sites on the Dolores River (J. White, CDOW, unpublished data) shows that for much of the year the river is below these optimal temperatures (Fig. 19)

Table 3: Temperature tolerance limits for different life stages of the Three Species. Source: Lamarra, 2007, San Juan River Fishes Response to Thermal Modification: A White Paper Investigation.

	TEMPERATURE (°C)																												Authors
	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	
Roundtail Chub																													Bestgen 1985, Chart et al. 1999, Propst, David L. (Internet literature), Southeastern Utah's Fish Species (Internet literature), Deacon et al. 1987 - 23.8°C
Egg										X						O	O	O	O										
Larval																													
Juvenile																O													
Adult																O													
Bluehead Sucker																													Bestgen & Crist 2000, Gorman & Vanhoosen 2001, Holden & Crist 1981, Robins & Childs 2001, Valdez 1990, San Juan River <20°C
Egg													O	O					X										
Larval	X												O	O					X										
Juvenile	X																												
Adult												O	A																
Flannelmouth Sucker																													Bestgen & Crist 2000, Clarkson & Childs 2000, Deacon et al.1987, Holden & Crist 1981, Robins & Childs 2001, Valdez 1990, Word et al. 2002, Deacon et al. 1987 - 25.9°C, San Juan River 25.0°C
Egg				X																									
Larval				X									O																
Juvenile				X									O																
Adult																		A											

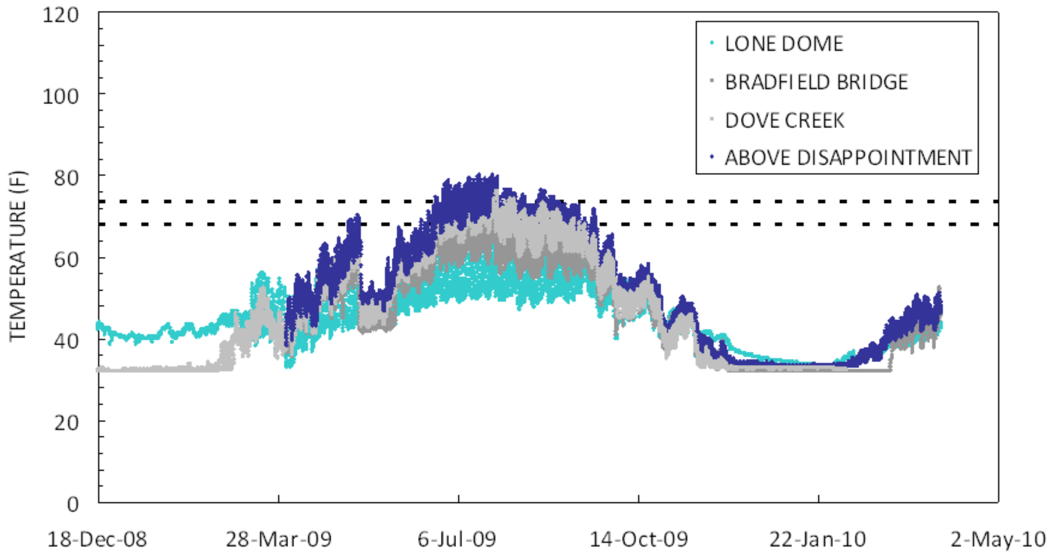
Tolerance limits

A Maximum observed summer temperatures which correspond to the maximum longitudinal fish densities

X Known minimum or maximum

O Optimum temperature compiled from various studies

Figure 19: Temperature record for four sites on the lower Dolores River from December 2008 – March 2010. Sites are listed from upstream to downstream. Dotted lines are optimal temperatures for the two native sucker species (68° F) and roundtail chub (75° F). Source: J. White, CDOW unpublished data.



Previous studies of temperature and dissolved oxygen on the Dolores River:
Valdez et al., 1992:

- Dam had negative effects on temperature and DO in early 1990s
- Low volume releases during summer caused extreme temperature variation (small thermal mass in flow), particularly in low velocity habitats (pools, backwaters), along with low DO
- Premature warming during low flows in April-May, initiated gonadal maturation and spawning by three species
  - Subsequent cold releases likely killed eggs and larvae; low flow (20 cfs) temps 16-18 C in April-May
  - Large aggregations of flannelmouths and individuals showing signs of spawning readiness observed during same period

Anderson, 2010:

- Temperature and DO problems persist today:
- Temperature exceeded CO standard for cold water fisheries at flows less than 60 cfs during summer months
- DO is less than CO standard at flows < 40 cfs during summer months

Opportunities for Improving Temperature and Dissolved Oxygen Conditions: Recommendations

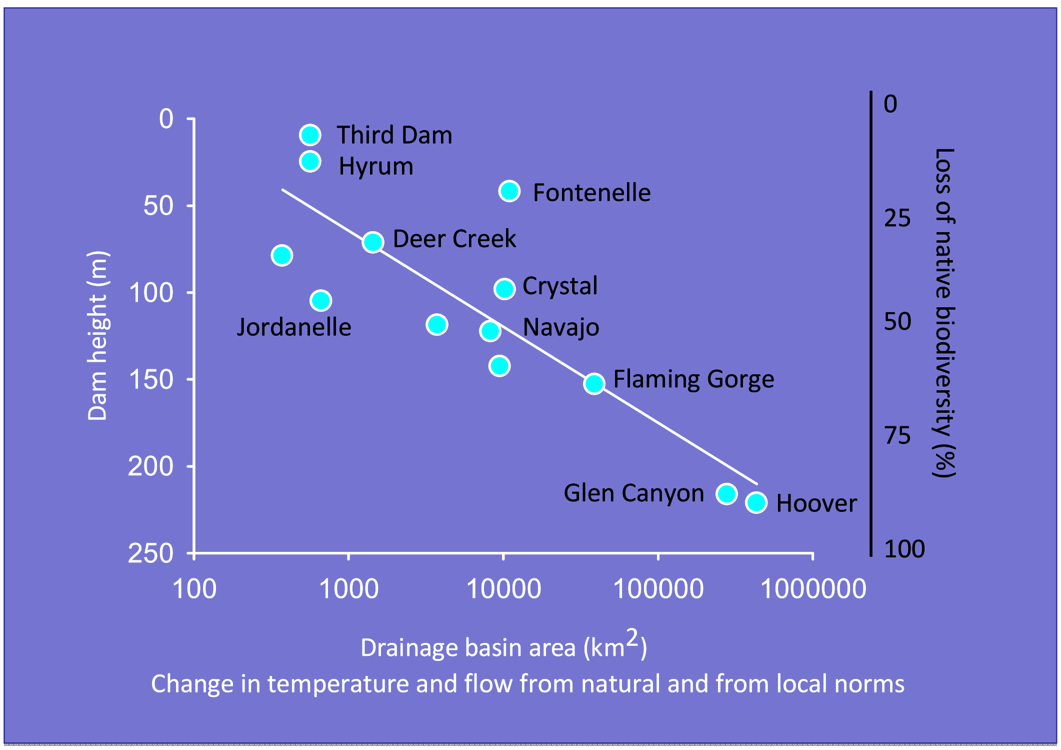
- Opportunities for improvement exist, but the magnitude and direction are uncertain and variable:
  - Using 2009 as example (Fig. 16), temperature was too cold in upper reaches, too warm in lower reaches.
  - Dissolved oxygen is limiting only when base flows are very low and water is hot and stagnant
- Mimicking the natural hydrograph (timing and base flow magnitude) should minimize or eliminate most temperature and dissolved oxygen issues
  - In general, the river has a wide temperature range
- Other water quality issues appear minor and not influential (see Valdez et al., 1992)
  - Little evidence for effects of historic pollution on biotic community of Dolores

- General improvement in water quality since 1960s
    - BCI rated "excellent" for Dolores in 1990s
    - Increasing diversity, presence of pollution intolerant species
- Although metal content in fish tissue higher of Dolores in 1991 higher than for Gunnison in 1981
  Salinity and turbidity may cause problems downstream of Disappointment Creek and Paradox Valley

Water Quality: Secondary Productivity

Vinson (2001) found an 88% decline in invertebrate diversity following construction of the Flaming Gorge Dam, and attributed it to less frequent bed movement and temperature regime change. Similar effects on biodiversity have been observed on other regulated rivers, particularly large rivers with tall dams (Fig. 20). With a height of 270 ft (82.3 m) and a drainage area of ~500 square miles (1,295 km²), the McPhee Dam on the Dolores River might be expected to result in a loss of diversity of ~30%.

Figure 20: Relationship between drainage basin area, dam height, and loss of native biodiversity for several dams throughout the southwest (from Vinson, 2001)



Riparian Ecology

- Reduced cottonwood growth in favor of hydrophytic rushes and sedges, plus reduction in frequency of overbank flooding, may reduce wood recruitment into channel, with subsequent effects on physical complexity and cover
- Vegetation establishment on bars plus reduced flooding may reduce amount of spawning habitat during high flows

- Encroachment of tamarisk and willow may be reason for channel incision at Bedrock gage (see Geomorphology section), perhaps narrowing in some places, may result in channel simplification and habitat homogenization
- Overall: not enough information and appears less important

Geomorphology

We analyzed geomorphic data from the USGS Bedrock gage station located 94 miles downstream from McPhee Dam, following the methods of Smelser and Schmidt (1998). Plots of channel bed elevation over time and channel hydraulic geometry for several time periods suggests the following geomorphic changes:

- Channel incision (bed elevation lowering) at the location of the Bedrock gage (Fig. 21), with most incision occurring between 1993 and 1996, following an extended period of drought (annual peak flows from 1988 to 1992 were only ~1000 cfs).
    - Incision occurred in the period immediately following the very high flows in 1993 (4550 cfs) and a second high flow event in 1995 (3140 cfs), with the bed dropping ~ 0.5 ft in the ~6 months following each storm
    - Although the channel incised following the drought period of 1988-1993, it remained stable (i.e., no consistent change in bed elevation) following the low flows of 2000-2004
    - Suggestion that incision may be a result of vegetation encroachment during low flows; establishment of vegetation on lateral bars during low flows can force high flows into a narrower channel, promoting incision and an increase in flow depth to maintain channel capacity.
        - The reduction in the frequency of overbank flows by McPhee Dam has led to encroachment of the channel margins by vegetation that was historically removed during large floods; this reach is described as “dominated by tamarisks”, “broad and flat”, with “high amounts of fine sediment accumulation” (DRD Core Science Report 2005).
        - During drought periods, lateral bars of fresh sediment become exposed and vegetation can establish. An extended period without overbank flows allows vegetation to grow without disturbance, reaching a density great enough to withstand higher flows and stabilize the channel margins.
        - When high flows return, as occurred in late spring of 1993, the narrower channel must accommodate the increase in discharge by incising.
- Incision is not due to alteration of sediment regime by the dam
    - The gage is located > 90 miles downstream from the dam, whereas incision is normally restricted to reaches directly downstream.
    - Furthermore, gage location is below inputs from numerous tributaries, including Disappointment Creek, which supplies large amounts of sediment to the mainstem Dolores River.
        - Basic geomorphic principles would predict that a reduction in sediment-mobilizing flows by the dam and large amounts of sediment supplied from tributaries would result in bed aggradation
- Despite evidence for incision, there are problems with this theory:
    - Time series and hydraulic geometry plots of width show channel widening, not narrowing, during this period (Figs. 22 and 23)
    - Hydraulic geometry plot shows no change in depth (so channel got lower, but not deeper) (Fig. 23)
- Additional research is needed to determine what is causing the bed lowering, if it is occurring at other locations, and what effect these geomorphic changes are having on instream habitat

  - Locate and resurvey historic channel cross-sections (e.g., old Bedrock gage location before it was moved, 1974 CDOW cross sections) to determine changes in channel shape at different locations along river
  - Complete USGS records from Bedrock station – original discharge measurement notes to verify location of all measurements, maximum depth, and actual cross-sections from different points in time to determine how shape of channel has changed, not just mean values (Smelser and Schmidt 1998 explains in detail how this data can be obtained and used)
  - Bed substrate sizes to develop estimates of discharge needed to mobilize sediment of different size fractions
  - Historical analysis of aerial photo record in relation to flow data to determine relation between geomorphic processes and high flows, history of vegetation establishment, and history of changes in channel geometry

Possible implications of geomorphic changes on fish habitat:

- We observe no changes in depth, so unlikely effects on pool habitat
- However, incision can reduce topographic variability, cause channel simplification, and lower hydraulic variability
- Vegetation encroachment may mean loss of bars used for spawning when submerged at high flows
- Channel does seem to be getting slower, which could reduce availability of fast-water refugia
- We observe apparent aggradation during high flows in post-dam era (not in pre-dam period) (see Appendix B, Geomorphology section)
  - Could reflect input from Disappointment Creek and other tributaries that might cause sedimentation problems for benthic biota
  - Evacuation during low flows, but not the same frequency of scour and fill that occurred during pre-dam period
  - Also indicates that material may be very fine, flushed during low flows

Figure 21: Bed elevation and discharge time series from the USGS gage station Dolores River at Bedrock.

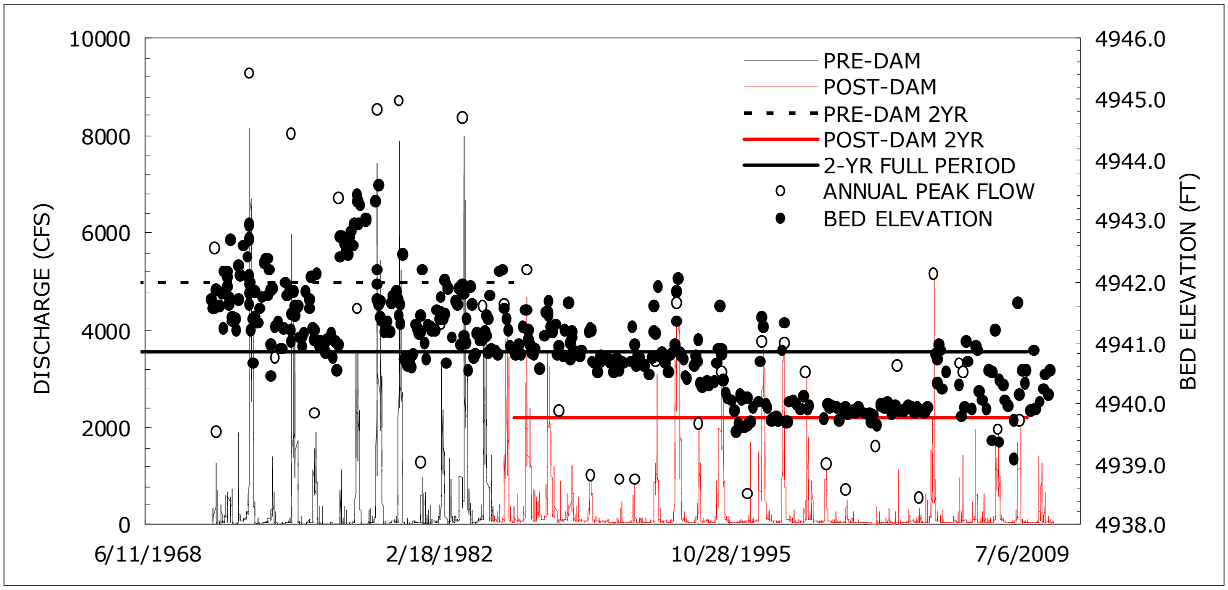


Figure 22: Time series of channel width at low to moderate discharges (30-250 cfs) at the USGS gage station Dolores River at Bedrock.

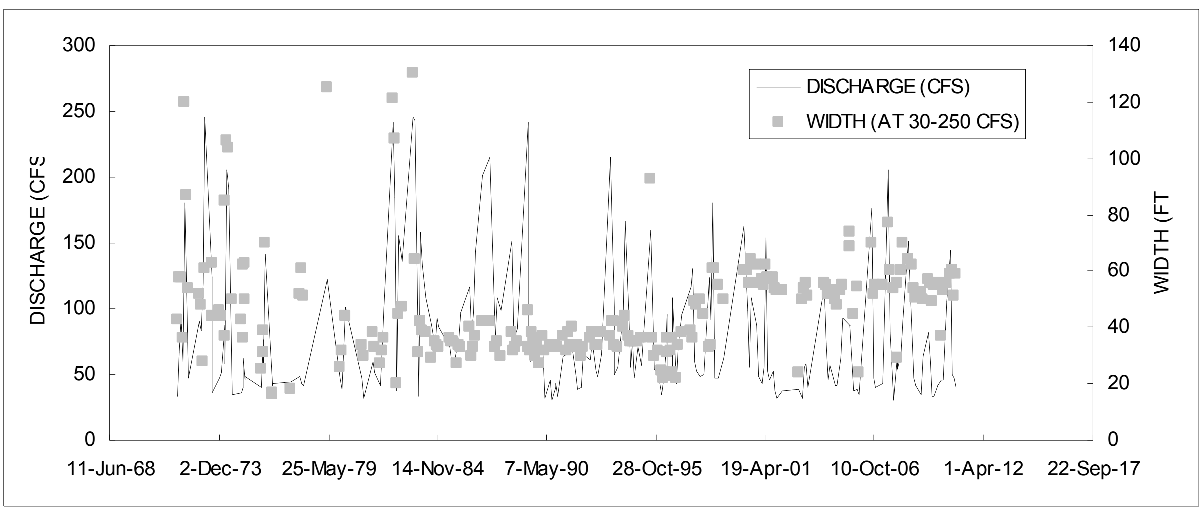
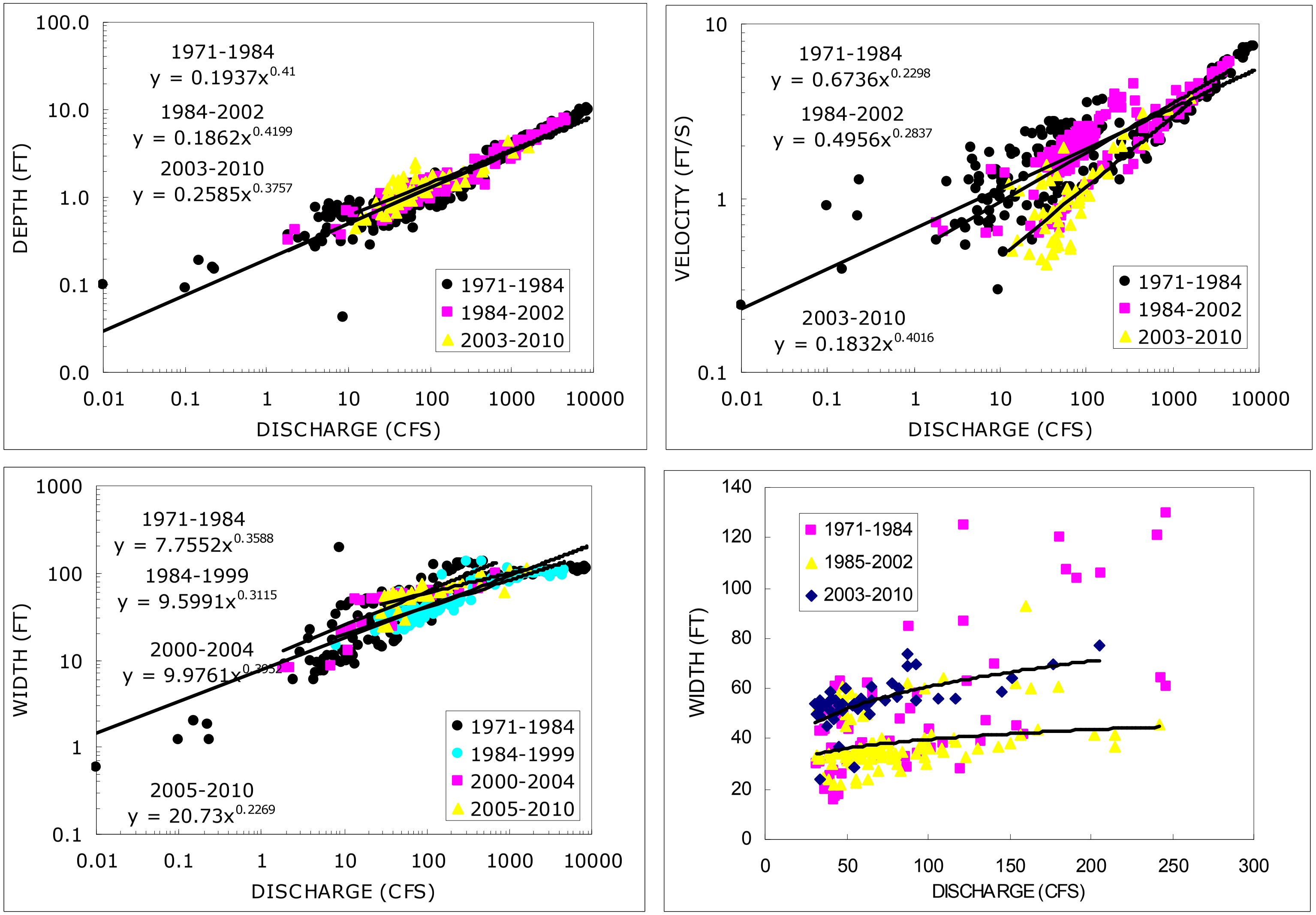


Figure 23: Hydraulic geometry plots from the USGS gage station Dolores River at Bedrock. Width is plotted against discharge for the full range of discharges and for low to moderate discharges (30-250 cfs).



Analysis of Sediment Mobilizing Flows: Recommendations

Research need:

Sediment accumulation in riffle substrates has been cited as the cause of degraded spawning habitat and reduced instream productivity in alluvial sections of the lower Dolores River (Richard and Wilcox, 2005; Anderson and Stewart, 2003). Sedimentation has likely resulted from a reduction in the duration and magnitude of peak flows since construction of the McPhee Dam in 1984 (Wilcox and Merritt, 2005; Richard and Wilcox, 2005). High flow releases from the reservoir have been proposed as a means to remove fine sediment from the channel bed. However, given the large water demands on the reservoir and limited water availability for habitat maintenance, managers need to know what magnitude and duration of flow are required to mobilize fine sediment from the channel bed.

Research questions:

What magnitude and duration of flow will flush fine sediment from the channel bed?

Most important related questions:

Sedimentation and habitat quality are a concern in what sections of river?
For these sections:
- What is the current particle size distribution of the bed?
- Is the bed armored or covered with a layer of fine sediment (e.g., sand and finer)?
- What is the bed sand content?
- What flows mobilize the surface D50, D84, and D90?
- What flows mobilize > 80% of the surface layer of bed material?
- What flows visibly remove accumulations of sand and finer sediment?

What particle sizes and bed concentrations cause degraded habitat conditions?

Other potentially useful questions:

What is the particle size distribution and load of sediment supplied to the reaches of interest?
Has the channel bed been aggrading? Is it aggrading now?
What was the frequency of bed mobilizing flows prior to dam construction?

Background:

On the Dolores River, it has been suggested that a reduction in the frequency of sediment mobilizing flows has led to the overall fining of bed sediment in alluvial reaches downstream of McPhee Dam (Richard and Wilcox, 2005; Anderson and Stewart, 2003; Richard and Anderson, 2007). Although reservoirs both store water and capture sediment, natural and anthropogenic sediment sources downstream of McPhee Dam far exceed any sediment trapped by the dam. Geology and hydrologic conditions of the basin upstream of dam result in a low rate of sediment delivery, such that minimal sediment accumulation has occurred in reservoir since construction.

Downstream of the dam, the effects of flow reduction have been exacerbated by increased sediment supply from grazed areas, banks disturbed by fishing and rafting, and roads. Sections of the river most susceptible to these impacts are the lower gradient, unconfined reaches, such as those from McPhee Dam to the top of Dolores Canyon and reaches flowing through Big Gypsum and Paradox Valleys. Other susceptible reaches are those downstream high sediment producing tributaries, such as Disappointment Creek – the largest sediment input to the mainstem Dolores River. Sediment accumulation can cause the fining of bed material, channel narrowing, and homogenization of channel morphology. Furthermore, coarse sediment contributed from side canyons are likely rarely transported under flow regulated conditions, potentially causing the steepening of channel rapids and bar growth (Richard and Anderson, 2007).

Controlled reservoir releases of flushing flows are often proposed as a way to remove accumulated fine sediments and loosen the gravel bed, in order to mitigate the effects of sedimentation on aquatic habitat (Reiser, 1998; Wu, 2000). So-called "sediment maintenance flows" are generally smaller in magnitude than "channel maintenance flows", which are intended to maintain the channel and floodplain geometry (Kondolf and Wilcock, 1996). Designing sediment maintenance flows requires specification of the magnitude, duration, and timing of flow releases. Factors to consider when choosing the timing of flow releases include the life-history requirements of the target species, historical runoff period, flow availability, and desired survival rate of incubating fish eggs (Milhous, 2000; Reiser et al., 1989; Wu, 2000).

Determining the magnitude and duration of flow requires consideration of bed sand content, water budget, and desired bed quality. However, these factors must also be balanced with potential economic and environmental costs of flow releases, including lost power generation, reduced water supply, and loss of spawning gravels (Kondolf and Wilcock, 1996; Wu and Chou, 2004). Specifying flow releases as accurately as possible can help minimize these costs, but doing so is often made difficult by the complexity of the flow and sediment transport system (for a full discussion see Wilcock et al., 1996; Wu and Chou, 2004). Sediment routing models have been developed to simulate the response to flushing flows under different flow and bed sediment conditions (i.e., the evolution of bed composition, bed elevation, and sediment transport rates) (Wilcock et al., 1996; Wu and Chou, 2003, 2004), incorporating the effects of sand content on sediment transport rates. Such can be used to evaluate flushing flow options and explore the tradeoffs associated with each.

Although sediment routing models allow for a more accurate determination of flushing flows, they require parameterization, using data on bed particle size distribution, bed sand content, and bedload transport rates at different discharges. Because of data and computational requirements, they have not been widely applied; whether they would be applicable to the Dolores River is uncertain. Alternatively, a simple assessment of the flow required to mobilize bed particles can provide insight into the required flushing flow. In theory, particle entrainment occurs when the applied shear stress exceeds the critical shear stress of each grain (i.e., the minimum force required for particle mobilization). However, in rivers with a mixture of bed particle sizes, larger grains can shield finer particles and prevent fine sediment mobilization unless the coarse fraction is entrained. As a result, the critical shear stress for gravel decreases as the proportion of fine sediment (< 2 mm) on the bed surface increases (Wilcock, 1998). For a mixed gravel-sand bed, it is helpful to know what threshold discharges mobilize the range of particle sizes on the bed, since these will differ from the minimum discharge required to entrain particles of a uniform size.

Determining the critical threshold for particle motion can be done simply and inexpensively using particle tracers (see Hassan and Ergenzinger, 2005 for a full review and discussion). Painted particle tracers are cheap and easy to use. In this method, particles from the bed are painted to stand out from the rest of the bed material. Either the entire tracer population is painted on color or different colors are used for different particle sizes. Particles may be removed and replaced with painted particles of the same size. Alternatively, seeding of tracers can be done on the bed surface in a line across the channel. In these cases, the placement of tracers is artificial and likely to influence sediment movement during at least the first transporting flow event. Alternatively, if portions of the bed become dry during low flows, the particles may be painted in-situ. Generally, the full range of particle sizes is painted. To determine the discharge required to mobilize bed particles, the bed is surveyed after each subsequent high flow event. After each event, the number and size of particles moved is recorded. Ideally, the bed would be surveyed following successively higher flow events so that critical discharges for each particle size could be determined.

On the Dolores River, Vandas et al. (1990) estimated that a discharge of 2000 cfs was required to mobilize the median particle size of riffle substrates and 7000 cfs was required to mobilize most of the bed materials in the section of river between Bradfield and Bedrock. In the post-dam period, these discharges corresponded to the 5- and 10-year recurrence interval floods, respectively. For the Big Gypsum reach, Richard and Anderson (2007) estimated a discharge of 3400 cfs for initial particle motion (return interval = 2.5 years in the post-dam regime) and 10,000 cfs for significant motion of the bed to occur (return interval > 35 years). However, both these studies estimated the threshold for particle entrainment from the Shields equation, using channel geometry and discharge to estimate average boundary shear stress and median particle size for the calculation of critical shear stress. Neither study therefore considered the effects of bed sand content and hiding effects on particle mobility.

Furthermore, it is important to differentiate between the discharge required to mobilize the bed ("sediment-maintenance flow") and the discharge required for channel maintenance. In theory, the channel-forming or dominant discharge is the flow that if maintained indefinitely would produce the same channel geometry as the natural long-term hydrograph. The concept of a channel-forming discharge is generally applicable to stable alluvial channels (i.e., those that maintain a long-term equilibrium with the imposed flow and sediment regimes), but may be less useful for rivers in arid environments characterized by localized high intensity storms and limited vegetation; under these circumstances, the channel adjusts to each major flood event. Nevertheless, characterizing the channel-forming discharge can aid management of regulated rivers by identifying how an altered hydrology might affect geomorphic conditions.

Channel-forming discharge is sometimes estimated as the effective discharge (i.e., the discharge that transports the most sediment; Wolman and Miller, 1960) or the bankfull discharge (i.e., the maximum discharge that the channel can convey without flowing onto its floodplain; Williams, 1978). For some rivers, the bankfull and effective discharges have been shown to occur with a recurrence interval of one to three years (Emmett and Wolman, 2001; Andrews, 1980; Carling, 1988; Leopold and Wolman, 1957). However, the recurrence interval of these floods can also be highly variable (Nash, 1994; Pickup and Warner, 1976). Although the discharge that entrains the bed material helps maintain the channel form (Milhous, 1982; Andrews, 1984), it is not necessarily the same as the channel-forming flow, particularly if channel morphology and bed composition are adjusting to changes in flow and sediment supply.

On the Dolores River, estimates of channel forming discharge based on modeled bankfull flow and 1.5 and 2-year recurrence interval floods for the pre-dam period have been made for several sections of river, ranging from 1000 – 3000 cfs, depending on location and method (Richard and Anderson, 2007). Although these estimates provide information about flows required for the maintenance of channel form or floodplain connectivity, they do not necessarily tell us anything about the flows required to mobilize bed material and flush fines from the current bed. Furthermore, earlier estimates of sediment mobilizing discharge may no longer be applicable if channel morph and bed conditions have changed. For instance, an increase in bed sand content over time may lower the threshold for bed mobility. Other factors such as armoring and imbrication can also affect the mobility of mixed grain size beds; these conditions are also spatially and temporally variable. Tracers offer the simplest, most straightforward means of determining the thresholds for bed mobility under present conditions.

Recommendations:

Two simple approaches to assessing bed mobility could be used in the initial stages of planning, after which more complex modeling may be considered:

(1) Painted particle tracers: seed and detect tracers following successive flow events to determine the discharge required to mobilize the range of particle sizes on the bed. See Hassan and Ergenzinger (2005) for a complete discussion of methodology; other relevant references are provided below. Ideally, flow releases from the dam would be staged to increase in regular, known intervals so that

the recovery of tracers could be done following events of specified peak flows. Tracer studies should be conducted at multiple sites along the river where sedimentation is a concern, since the flow required for bed entrainment will likely vary among sites with different morphological, bed, and sediment supply conditions.

(2) Photographs before and after flow events: set up photopoints to qualitatively document changes in alluvial features and bed conditions. Significant bed mobility should be evident in photographs and could be used to determine which flows cause sand movement.

Data have already been collected on the Dolores River that could contribute to these efforts. David Graf (CDOW Regional Water Specialist) performed painted particle studies on multiple geomorphic features at the Lone Dome site, photographing pre- and post-flood conditions (D. Graf, CDOW, personal communication). Sediment data and photographs from this site could be useful in assessing the effects of floods on bed mobility. Earlier estimates of sediment-mobilizing and channel-forming flows (c.f., Vandas et al., 1990; Richard and Anderson 2007) could be used as a reference point for the staged flow releases. We recommend implementing additional entrainment studies on other sites of the river, documenting the movement of particles following floods of progressively increasing discharge.

Simply determining the magnitude of flows needed to mobilize a significant portion of the seeded particles (e.g., > 80%) or the flow that mobilizes the coarse particles (e.g., D84) may be adequate to attempt a flushing flow release on the Dolores River, particularly if the magnitude and duration of the release are constrained by other factors (e.g., rafting schedules, water rights). However, a more complex modeling approach may be necessary if highly accurate estimates of flushing flows are required. For more information about this approach, see the references and links provided in the next section.

Other information that might be useful for addressing these research questions include: (1) repeat channel surveys at locations of interest to document channel aggradation or incision, or short-term episodes of scour and fill; (2) depth of scour and travel distance of tracer particles to estimate sediment transport rates; and (3) suspended sediment and bedload transport rate measurements at different flow levels,

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Native Fish Population Status and Trends and Opportunities for Improvement on the Lower Dolores River: Phase I Report
Appendices

Phaedra Budy and Nira L. Salant
May 2011

Table of Contents

Appendix A: Fish Population Status and Trends Supplemental Information

Additional plots

Figure A1: Percent total catch at Dove Creek Pumping Station. Non-natives sampled other than trout: green sunfish and smallmouth bass Source: CDOW unpublished data.

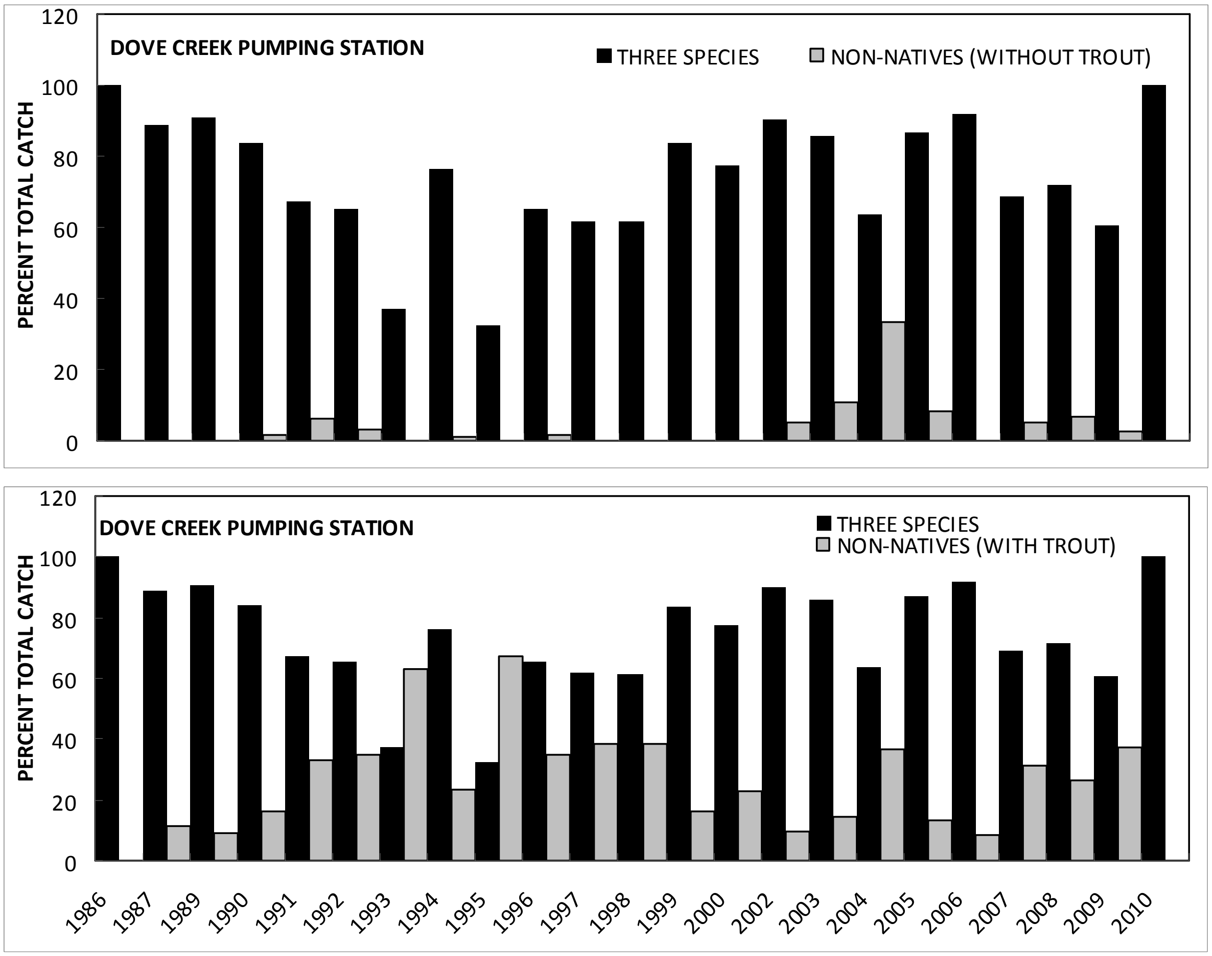
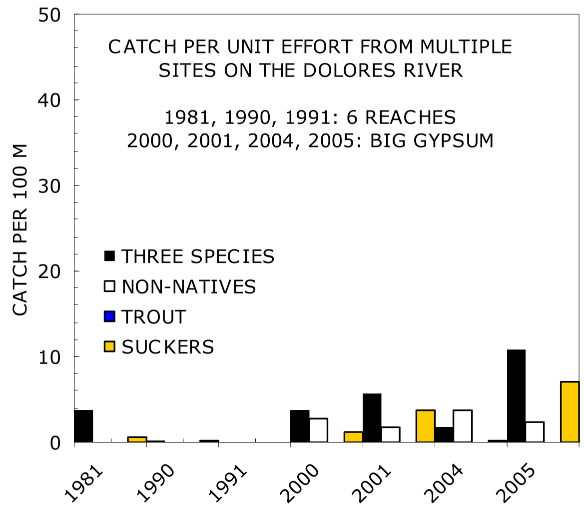


Figure A2: Catcher per unit effort from multiple sites. Sources: Valdez et al., 1992; Anderson, 2006; CDOW unpublished data.



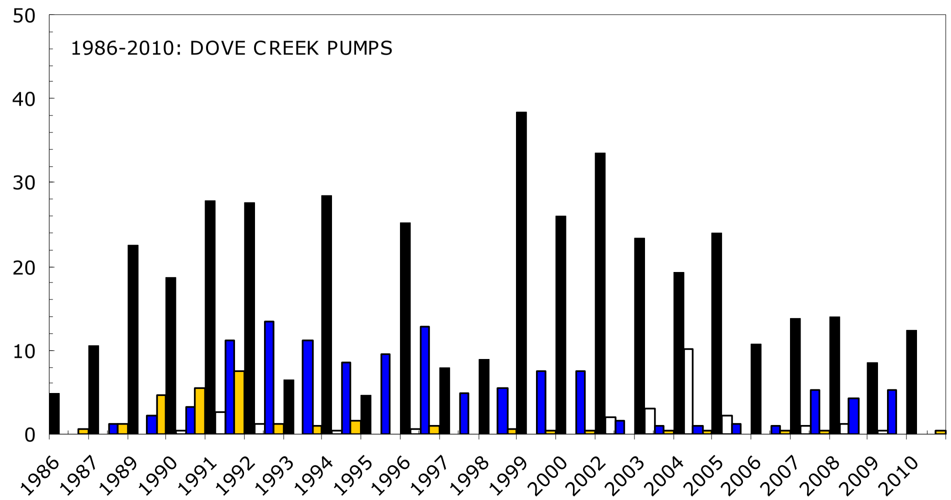
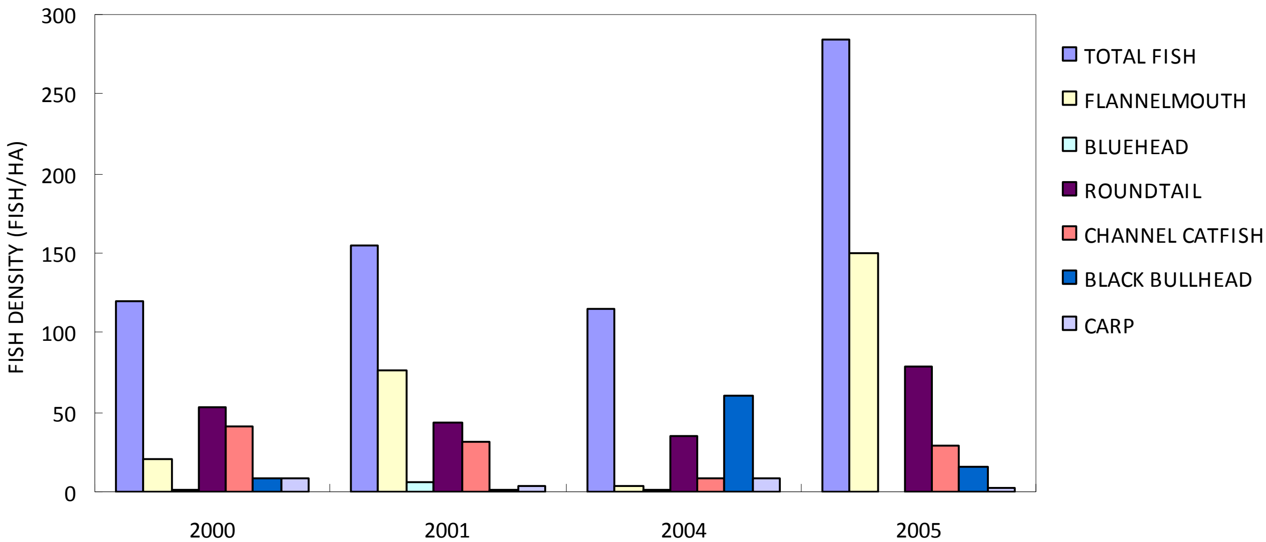


Figure A3: Fish density of native and non-native species at the Big Gypsum site (from Anderson, 2006; Table 19)



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- Sampled 6 reaches from confluence with Colorado River upstream to Bradfield Bridge; reaches 5 and 6 are within DRD study area (see table above)
- Cross-sectional surveys, habitat mapping, macroinvertebrate sampling, water quality sampling, bioassays of fish, fish surveys
- Both studies used three sampling methods that were biased towards different habitat types and fish sizes:
    - Seining: slow, shallow habitats, smaller fish
    - Gill netting: main channel habitat, deep pools, smaller and larger fish
    - Boat electrofishing
- Reaches differed in water quality, morphology, and discharge
- Found strong compositional differences between reaches
- 1982 study: 16 total spp, 4 native species (three species and speckled dace)
    - Native species composition increased upstream (Reach 1-5: 2%, 10%, 10%, 20%, 26%)
- 1992 study: 19 total spp, 6 natives (three species, speckled dace, mottled sculpin, Colorado pikeminnow)
    - Species abundance (high to low): flannelmouth, roundtail, bluehead, carp, channel catfish
    - Flannelmouth most abundant in reaches 3 and 4 (downstream of Big Gypsum) (52 and 56%); reach 2: 40%; reach 5: 45%; reach 6: 20%; reach 1: 15%

  - Roundtail chub uncommon in lower reaches; reach 4: 8%; reaches 1,2,3: < 5%;
  - Bluehead more common in lower reaches; reaches 1,2,3: 11-18%; less common in upper reaches; reaches 4,5,6: 5-8%
  - Speckled dace rare (<3%) in all reaches except reach 6 (23%)
- No significant changes in fish community composition between 1981 and 1990-91 surveys, but two notable trends
  - Except for Reach 1, lower catch rates of roundtail chub and higher catch rates of flannelmouth sucker
- Base flow releases of 20 to 40 cfs in 1990 and 1991 reduced native fish habitat through decreased fish holding areas, dewatered nursery backwaters, impeded movement, and enhanced sedimentation.
- Recommended minimum base flow releases of 50 cfs during dry and normal years and 78 cfs during wet years

Anderson, R. and G. Stewart. 2003. Riverine Fish Flow Investigations: To determine relationships between flow and habitat availability for warm-water riverine fish communities of Colorado. Federal Aid Project F-289-R6. Colorado Division of Wildlife. Denver, Colorado. http://wildlife.state.co.us/NR/rdonlyres/0BD95144-77B8-4CA1-BC4A-22F6D212A4D6/0/Anderson_Stewart2003.pdf

- Yampa, Colorado, and Dolores Rivers
- Designed a habitat instream flow method using 2D model: surveyed channel topography, developed meso-habitat suitability ratings for natives based on density and biomass population estimates; flows simulated with 2D flow model
- Studied Big Gypsum Valley reach on Dolores: 16 miles downstream of Disappointment Creek, 70 miles downstream of dam (located in Valdez et al. Reach 5)
- Mark and recapture sampling; determined density and biomass of fish > 150 mm
- Sampled in 2000 and 2001 (sampled again in 2004, see Anderson (2005) and Anderson and Stewart 2007)
- In 2000 and 2001 native species composition for fish over 15 cm was 73% and 88%, and was 80% and 65%, respectively, for total fish
- See plots for Big Gypsum site, synthesizing all studies at that site, below

Anderson, R. 2005. Riverine Fish Flow Investigations: Quantification of impacts of the 2002 drought on native fish populations in the Yampa, Colorado, Dolores and Gunnison Rivers. Federal Aid Project F-288-R8. Colorado Division of Wildlife. Denver, Colorado. http://wildlife.state.co.us/NR/rdonlyres/3247B27F-16F5-44D4-B899-DDBEFC648DF8/0/Anderson2005.pdf

- Quantification of impacts of the 2002 drought on native fish populations in the Yampa, Colorado, Dolores and Gunnison Rivers
- Sampled Big Gypsum site on Dolores in 2004
- Mark and recapture sampling; determined density and biomass of fish > 150 mm
- McPhee Reservoir captured the entire spring runoff from 2001 to 2004; peaks were determined by tributary flow, primarily Disappointment Creek
- Very low baseflows in 2002 and 2003
- Native species compositions fell to 43% (>15 cm) and 53% (total fish) in 2004; black bullhead most common species
- Comparison of fish composition, biomass, and density between 2000, 2001, and 2004 on page 25 of report

- High proportion of small fish; no natives > 20 cm; only species with fish >30 cm in the 2004 sample were carp (30) and channel catfish (11)
- Mean lengths were highest in 2000 for all species except channel catfish
- Low fish biomass compared to other rivers; total fish and three species biomass declined in 2004; only black bullhead biomass increased in 2004
- Runoff flows appear to be a primary limiting factor for native fish biomass; hypothesized that fine sediments had accumulated beyond the threshold necessary to impact invertebrate and fish productivity, due to creek inputs and reduction in peak flows by dam
- Increase in black bullhead corresponded with decline in flannelmouth sucker and roundtail chub; not efficient predator, but strongly associated with backwater habitat types
- See tables from Anderson 2006, below, for 2000, 2001, 2004, and 2005 data
- Length frequency data provided in appendix 3 of report

Anderson, R. 2006. 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. Federal Aid Project F-288-R9. Colorado Division of Wildlife. Denver, Colorado. http://wildlife.state.co.us/NR/rdonlyres/083F7AEA-266D-4482-AB58-992B9A84A7F5/0/Anderson2006PR3.pdf

- Gunnison and Dolores Rivers
- Same results as those presented in Anderson, 2005, with addition of 2005 data (see tables, below)
- Total fish relative abundance may be a better metric than fish >15 cm because a large proportion of native fish were smaller than 15 cm at Big Gypsum; total fish relative abundance includes the Non Native Cyprinids (NNC; i.e. red shiner, sand shiner and fathead minnow)
- Number of fish caught each year was highly variable
- Roundtail chub was the most common species collected in 2000 and 2004, the third most common in 2001 and ranked fifth in 2005
- Flannelmouth sucker was the second most numerous species in 2001 and 2005, years when NNC were most common.
- Bluehead sucker were common in 2001, but rare in all other years
- Low total biomass; biomass estimates for flannelmouth sucker, bluehead sucker, and roundtail chub were very low relative to other rivers.
- Total fish biomass was highest in 2000 due to more channel catfish and carp biomass
- Total biomass was lowest in 2004 for all species except black bullhead and carp (Table 19)
- Length frequency distributions (provided in appendix):
    - Flannelmouth sucker:
        - 2000: Three length frequency modes one for YOY, and one each for juvenile and adults
        - 2001: YOY mode was present but most fish were in a yearling mode, indicating good recruitment of the 2000 year-class
        - 2004: Both YOY and age 1+ flannelmouth sucker were rare, indicating poor recruitment from the 2002 and 2003 year-class
        - 2005: 13 to 18 cm numerous, indicating good recruitment from 2004, must have migrated to the area from upstream or downstream spawning sites (Dove Creek or Slick Rock Canyon)
    - Bluehead sucker:
        - No YOY collected in any year; no local reproduction
        - High number of age 1+ bluehead suckers collected in 2001, but not in 2000, 2004 and 2005
        - Strong 2000 year-class observed in 2001 must have resulted from migration

- Roundtail chub:
  - Local reproduction in all years except 2004
  - YOY and age1+ collected in both 2000 and 2001; more fish >20 cm in 2000
  - Fish <12 cm rare in 2004, likely due to a poor 2003 year-class
- Discussion of main results:
  - Effects of reduced runs and riffles due to low flows in 2002-2003
    - Most notable change: increased black bullheads and decreased flannelmouth suckers between 2000-2001 and 2004
      - Indicated increased in proportion of low velocity pools/backwaters, reduction of high velocity runs
      - 2002-2003: fewer run habitats when flows were low (2-20 cfs)
      - After 2002, fewer large flannelmouths, more small flannelmouth (12-18 cm)
    - Low numbers of bluehead suckers in 2004 and 2005
    - Reduced biomass of roundtail chub and channel catfish in 2004 (predators, forage in runs and riffles)
      - Invertebrate productivity in riffles likely reduced by siltation (accumulation of sediment between 2000-2004 (no flushing flows)
    - Degraded spawning habitat in Big Gypsum: effects on recruitment
      - Roundtail chub YOY were collected in all years except 2004, the year with the most sedimentation and also the year with the highest black bullhead density
      - No flannelmouth sucker YOY were collected in 2004 and 2005 (spawning in April, prior to high 2005 flows)
        - Age1+ flannelmouth sucker abundant in 2005 likely due to migration from upstream of Disappointment Creek or Slick Rock Canyon (downstream)
      - No bluehead sucker YOY collected at Big Gypsum in any year
        - Age1+ bluehead sucker abundant in 2001, but rare in 2004 and 2005
        - Presumed to spawn upstream of Disappointment Creek and migrate to Big Gypsum

Table 17. Density estimates for 2000, 2001, 2004 and 2005 at Big Gypsum, Dolores River.

Dolores River	Big Gypsum density fish/ha			
Species	**2000 (n)**	**2001 (n)**	**2004 (n)**	**2005 (n)**
Total fish	119.7	154.3	115.5	283.8
Flannelmouth sucker	20.0	76.	3.2	149.6
Bluehead sucker	1.6	6.5	1.0	0
Roundtail chub	53.3	43.9	34.6	78.4
Channel catfish	40.7	31.2	8.7	28.8
Black bullhead	8.1	0.9	61.0	16.1
Carp	8.7	3.2	8.3	2.9

Table 18. Significant differences (alpha = 0.05) in density estimate between years.

Dolores River	Significant difference (sd) in Big Gypsum density estimates.					
Species	**2000/2001**	**2000/2004**	**2000/2005**	**2001/2004**	**2001/2005**	**2004/2005**
Total fish	sd		sd	sd	sd	sd
Flannelmouth sucker	sd	sd	sd	sd	sd	sd
Bluehead sucker	sd		sd	sd	sd	sd
Roundtail chub		sd				
Channel catfish		sd				
Black bullhead	sd	sd		sd	sd	sd
Carp						

Table 19. 2000, 2001 2004 and 2005 biomass estimates for Big Gypsum, Dolores River.

Dolores River	Big Gypsum biomass kg/ha			
Species	2000	2001	2004	2005
Total fish	41.9	19.2	22.3	27.9
Flannelmouth sucker	4.2	3.2	0.4	6.6
Bluehead sucker	0.2	0.6	0.1	0
Roundtail chub	3.0	2.4	1.6	5.2
Channel catfish	16.3	10.3	3.2	10.9
Black bullhead	0.6	0.1	2.8	0.9
Carp	17.5	2.6	14.2	4.4

Table 20. Fish mean lengths at Big Gypsum, Dolores River.

Dolores River	Mean length in cm (n)			
Species	2000	2001	2004	2005
Flannelmouth sucker	18.8 (109)	14.2 (580)	11.1 (25)	14.9 (514)
Bluehead sucker	23.6 (11)	12.1 (343)	22.5 (5)	12.2 (4)
Roundtail chub	14.1 (552)	10.9 (512)	15.9 (228)	14.6 (224)
Carp	50.3 (18)	35.2 (11)	49.6 (30)	17.4 (40)
Channel Catfish	28.7 (87)	25.8 (62)	32.1 (22)	32.4 (24)
Black Bullhead	21.1 (27)	13.6 (14)	17.7 (197)	19.2 (46)
Green Sunfish	13.0 (43)	9.6 (42)	9.3 (27)	11.6 (27)

Dove Creek pumping station sampling reach (Mike Japhet, CDOW)

- 16 years of data from 1986-2005; located in reach 6 of Valdez et al. 1992; sampled by wade electrofishing (one or two passes) using a stationary shore shocker
- Most common: roundtail, speckled dace, mottled sculpin
- Relatively stable community composition
- Most dominant nonnative: brown and rainbow trout
- With trout excluded, natives comprised 95-100% of catch, dropped to 79 and 76% in 2002 and 2003
- Sculpin most common (~50%) until 2002, dropped to 4th most common; flannelmouth only 1.3% of catch for entire period
- Large increase in fathead minnow and green sunfish after 2002; green sunfish increased from 0-1% to 21% in 2004
- See Dove Creek fish population plots (file name: NLS_DOLORES-FISHPLOTS_15Feb11.doc)

White 2008 presentation: White, J. 2008. 2008 Dolores River update. Presentation to the Dolores River Dialogue. Colorado Division of Wildlife. http://ocs.fortlewis.edu/drd/pdf/2008%20Dolores%20River%20UpdateJIMWHITECDOW1028PP.pdf

- Trout fishery: McPhee Dam to Bradfield Bridge managed as trout fishery
  - Brown trout self-sustaining; rainbow stocked
  - Catch and release only
  - Status: sampled 1989-2008 (3 sites); general decline in trout biomass 1983-2000s; increase in 2008 (9 to 29 lb/acre)
    - Percent rainbow trout 20-23%
    - WD resistant rainbows stocked and present
    - No native suckers
  - Goal: 32 lb/acre
  - Trout biomass correlated with water deliveries from dam
  - No significant effect (yet) of stream habitat improvement on trout biomass
- Native fish
  Pyramid Mountain to James Ranch, sampled April 2008
    - Flows ~ 500 cfs (objective sample during spawning period)
    - Boat electrofishing

- Results:
- Only 9 fish collected along 14 miles: 3 LOC, 1 RBT, 2 SMB, 1 SPD, 2 RTC (67% non-native)
- No FMS or BHS
- Flow level too high, water too cold and turbid; better to sample in mid-May, 400 cfs

Dove Creek Pump Station, 1986-2008

2008 sampling:
- Increase in RTC abundance
- No native suckers
- First recorded smallmouth bass at this site

Ponderosa Canyon (Bradfield to Dove Creek station) (Nehring), 1993, 2005, and 2007
- 2 pass mark and recapture
- 20 mile reach
- Decrease in all species from 1993-2005 (LOC, RBT, CUT, FMS, BHS
- LOC most abundant in all years
- See slide 12 of presentation for plot of population estimates
- No FMS or BHS captured in 2005 or 2007

Pyramid to Slickrock, 2007
- Mostly SMB and trout
- Few native suckers
- Most bass found in "narrows" (short canyon section)

Big Gypsum Valley, 2000-2007 (Anderson, Stewart)
- 2.2 mile section below Disappointment Creek
- General decline in natives but higher numbers than reaches above creek

Slickrock Canyon, June 2007 (Kowalski)
- 32 mile reach; 1 pass effort
- Low abundance but mostly natives
- See slide 15 for plot of relative abundance of fish species (FMS, BHS, RTC, CCF, CPP, SMB, SNF, BBH)

Gateway to Stateline, June 2007 (Kowalski)
- 7 mile reach; 1 pass effort
- Only site where BHS was relatively abundant (greater CPUE than FMS, RTC, CCF, or CPP); higher CPUE than upstream
- Site is below San Miguel, which enhances baseflows

CDOW (Colorado Division of Wildlife). 2010. Dolores River native fish habitat recommendations and alternatives to Wild and Scenic designation. White paper prepared by Colorado Department of Natural Resources, Southwest Aquatic Section-DOW, Southwest Wildlife Conservation-DOW, and the DOW Water Resources Unit.

Key documents:

- 1977 Environmental Impact Statement and Definite Plan Report (EIS/DPR) for construction of Dolores Project
  - Committed to estabilishing 11 miles of good quality cold water sport fishery (downstream of project)
  - But commitment has not been met (due to water appropriations, contractual obligations, and operational mangement practices)
  - River currently support 38% of Gold Medal biomass standard
- 1996 Environmental Assessment (EA) for reoperation of project
  - Established goal of fish pool of 36,500 acre feet available for release
  - Has not occurred
  - Total downstream releases currently = 31,798 af (87% of target)

Status of fish populations below McPhee

- River supports < 1 kg/ha of natives, compared to 100-400 kg/ha in other rivers
- Range of native fish has shrunk a lot over last 27 yrs
- Native fish are smaller (average size), smaller size at maturity; poor age class representation compared to other similar rivers
- Trout populations below McPhee peaked in 1993 (above Gold Medal biomass), but have deteriorated dramatically since
- Declines due to lack of suitable habitat
  - Inadequate flows
  - Non-native interactions (primarily smallmouht bass, blackbullhead and channel catfish)
  - Water quality

Habitat modeling results:

Min streamflows needed are not being met

CWCB (CO Water Conservation Board) retains 78 cfs instream flow from McPhee to San Miguel (105 miles)

Determined as biological minimum flow

- But, instream flow water right is typically not met for most of the year
- Current downstream allocation is 46% of pool required to meet 78 cfs year-round
- Current operations annually produce baseflows of < 30 cfs
- Habitat modeling indicates 30 cfs supports < 42% of potential trout habitat and < 5% of potential native fish habitat

Status of fish populations below San Miguel confluence

- Larger native fish populations than upriver
  - o 64 native fish per mile, versus 14 fish per mile above confluence
- Other than loss of Colorado pikeminnow, native fish community is generally intact
- Character of river is different due to tributary inputs (mitigate impacts of dam)
  - o No mainstem damming
  - o Irrigation diversions do remove perennial flows from some reaches in late summer
  - o But river receives return flows and groundwater accretions
  - o Lower San Miguel has adequate baseflows
- Lower San Miguel supports all life stages of 3 native fish
- Provides flows to Dolores (below confluence), sustains native fish populations
  - o San Miguel water supply is vital to sustaining native fish populations in greater Dolores Basin
  - o Currently no instream flow appropriations protecting flows for native fish in Dolores below confluence

- Discussion

- Decline in native fish primarily related to habitat limitations
- Recommended changes in management essentially fulfilling earlier federal commitments (1977 EIS/CPR and 1996 EA)

Anderson, C. 2010. Factors affecting populations of flannelmouth suckers on the Dolores River between McPhee Dam and the San Miguel River. Technical Memo to Dolores River Dialogue Steering Committee, 4/7/2010. Watershed LLC, dba B.U.G.S. Consulting (Bioassessment Underwater, GIS and Stats).

- Brief literature review of the status and potential stressors of flannelmouth suckers in the Dolores, from McPhee to San Miguel confluence, and recommendations for addressing key data gaps
- History of flannelmouth populations in the Dolores

- 1971: Holden and Stalnaker: populations ranged from abundant to low from Cahone, CO downstream to confluence with Colorado River
- CDOW surveys:
  - DRD Reach 1: 1987-present, few large flannelmouths each year
  - DRD Reach 2 (Ponderosa Canyon): found in 1993, not in 2005 or 2007
  - DRD Reach 3 (Dove Creek Pumps): not found in annual surveys since 2004, never been abundant in annual surveys since 1989
  - DRD Reach 4 (Big Gypsum Valley): 2007, <5 per mile
  - DRD Reach 5 (Slickrock Canyon): 2007, average 2.5 per mile
  - Longitudinal survey 2008: CPUE was 2-4 times lower than in the 1990s (White et al., 2008)
- Anderson surveys:
  - DRD Reach 4 (Gypsum Valley): highly variable, 3.3% in 2004, 28% in 2005 (higher numbers likely washed downstream by spill water from more favorable upstream sites, not local recruitment) (Stewart and Anderson 2007, DRD Correlation Report, 2006)

Appendix B: Opportunities for Improvement Supplemental Information

Spill Management

Relevant references:

Anderson, R. and G. Stewart. 2003. Riverine Fish Flow Investigations: To determine relationships between flow and habitat availability for warm-water riverine fish communities of Colorado. Federal Aid Project F-289-R6. Colorado Division of Wildlife. Denver, Colorado. http://wildlife.state.co.us/NR/rdonlyres/0BD95144-77B8-4CA1-BC4A-22F6D212A4D6/0/Anderson_Stewart2003.pdf

- Lack of peak/flushing flows during study period (2000-2002)
- Severely reduced productivity because of sedimentation of riffle substrates
- Suggested runoff flow of 1200 cfs (see notes on bankfull flow and channel morphology, Richards and Anderson 2007)

Anderson, R. 2006. 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. Federal Aid Project F-288-R9. Colorado Division of Wildlife. Denver, Colorado. http://wildlife.state.co.us/NR/rdonlyres/083F7AEA-266D-4482-AB58-992B9A84A7F5/0/Anderson2006PR3.pdf

- Effects of flow on habitat availability
    - Pre-dam: high frequency of 'flushing' flows (3000-5000 cfs), low base flows (2-5 cfs); riffle/pool scour every 1-2 yrs, maintained habitats used by natives
    - Post-dam/drought years: sediment accumulation in riffles/pools, reduced habitat used by natives
    - 2005 flood: scoured pools/runs, flushed fine sediment from riffles, improved water clarity
    - Baseflows 60-70 cfs result in low total fish biomass relative to other rivers (Anderson 2005); 150 cfs needed to maintain habitat availability of CO/Gunnison (Anderson and Stewart 2003)
    - Reduced flows exacerbated native/non-native interactions
        - Increased black bullhead abundance in 2004; increased channel catfish abundance in 2005
        - Roundtail chub more drought-resistant but more vulnerable to predation by bullhead and catfish
    - Small native fish sizes in Dolores may be a consequence of long-term dewatering (since 1886)/drought-like conditions
    - Three species mature at younger ages and smaller sizes than in other systems
    - Small fish more drought resistant, large fish more flood resistant
    - Roundtail and flannelmouth can survive long-term low flows at low abundance, but bluehead suckers barely survived 2002 drought; increase in certain non-natives further threatens survival

White 2008 presentation: White, J. 2008. 2008 Dolores River update. Presentation to the Dolores River Dialogue. Colorado Division of Wildlife.
http://ocs.fortlewis.edu/drd/pdf/2008%20Dolores%20River%20UpdateJIMWHITECDOW1028PP.pdf

- Management recommendations
    - Adequate baseflows critical to native suckers; riffles for BHS, runs for FMS (Anderson and Stweart 2007)
        - Higher baseflows will also benefit trout fishery

  - Need to identify willing water leasers for dry years (work with DRD and Dolores Biology team)
- Thermal criteria could be used to evaluate effectiveness of additional water leased during critical time periods
- Continue releasing flows through bottom outlet works
- Continue fish monitoring in historic sites, as well as native longitudinal surveys in May at ~400 cfs
- Continue removing SMB
- Continue stocking WD resistant rainbow trout

Richard, G. and R. M. Anderson. 2007. Channel-forming discharge on the Dolores River and Yampa River, Colorado. Technical Publication No. 44. Colorado Division of Wildlife. Fort Collins, CO. http://wildlife.state.co.us/NR/rdonlyres/1EB6C43E-6E0C-4185-B37B-7B4595001720/0/CDOWTechReport44.pdf

- Estimated channel-forming discharge for the Yampa (2 sites) and Dolores via four methods:
  - Bankfull discharge (using GPS surveyed cross-secitons, GIS mapping and HEC-RAS modeling to determine the flow that begins to inundate the floodplain/reaches the top of the banks)
  - Effective discharge (using flow and sediment data from USGS gage to determine flood that transports the most sediment over a long period of time) (Yampa only)
  - Two year discharge (flood frequency analysis of annual peak flow data)
  - Discharge necessary to mobilize bed material and for significant motion of the bed (Shields equation and average boundary shear stress)
- On the Dolores:
  - Flow that inundates most of floodplain and flow that initiates bed mobility are 2600-3400 cfs, corresponding to 1.8-2.5 year flood frequency in post-dam regime
  - Dam reduced 2-yr flood by 27% and MAF by 50%
  - Marginal transport and significant floodplain inundation should occur ~2yr freuency in post-dam regime
  - Significant motion of bed estimated to occur at 10,000 cfs (vs. 7000 cfs estimated by Vandas et al., 1990) at frequency > 35 yrs
  - Difficult to ID current floodplains because of vegetation encroachment by tamarisk, russian olive, and willow, due to reduced flooding
  - Reduced 2-yr flood should result in smaller channel, smaller bankfull discharge; but new floodplain may not yet be evident if channel is still adjusting
  - [My note: Vegetation encroachment may be reason for incision evident in Bedrock data; forced channel to narrow, caused deepening despite reductions in flow; deepening may further reduce frequency of overbank flooding (hence, difficulty identifying floodplain, continued encroachment)]

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.

- Studied pre-dam hydrology at Bedrock gage, estimated post-dam hydrology, estimated pre- and post-dam bankfull discharges based on field data and 1.5-yr recurrence, estimated discharge required to mobilize bed (based on channel cross-sections, D50 of riffles)
- Pre-dam: 1.5-yr flow = 3068 cfs; bankfull = 2300 cfs (based on field data from site below Gypsum Valley)
- Post-dam: 1.5-yr flow = 1300 cfs
- 7000 cfs required to mobilize most of bed materials (5-yr recurrence); 7-day duration of 6641 cfs has 10-yr recurrence

- Pre-dam D50 estimated to move once every 1-2 yrs; coarser material moved once every 5-10 yrs
-

Wilcox, A. and Merritt, D.M., 2005. "Effects of modified flow regimes on the Dolores River", *Riparian Response to Altered Flow Regimes*, Proceedings of the Colorado Riparian Association, 18th annual conference, October 5-7, 2005, Durango, CO, pp. 69-83.

- Performed Indicators of Hydrologic Alteration (IHA) analysis on pre- and post-dam data at Bedrock gage
- Annual max flow decreased by ~40%
- Duration of high pulse decreased by ~60%

Richard and Wilcox, 2005. Dolores River Dialogue Geomorphology Analysis, Core Science Report, page 19.

- Effects of diversions and dam on high flows
  - Pre-dam: Reduced flow due to diversions: Mean annual flow at Dolores (above dam) = 763 cfs; at Bedrock (94 miles below dam) = 465 cfs
  - Post-dam (1984-present): Reduced annual flow by 30-69%; reduced magnitude and duration of spring peak
    - 2005 IHA:
    - Bedrock gage:
      - Annual max flows (36-41% decrease)
      - Duration of high pulse (60% decrease)
    - Cisco gage (d/s of San Miguel confluence):
      - Not as significant an impact of the dam
      - Greatest change in one and three day maximum flows (13% decrease)
- Estimates of channel-forming discharge
  - 1990 estimates of bankfull: (USDI BLM 1990)
    - Bradfield Bridge (11 miles below dam): 2000 cfs
    - Bedrock (94 miles below dam): 2500 cfs
  - 1990 estimates of 1.5-yr recurrence interval:
    - Dolores (u/s of dam): 2589 cfs
    - Bedrock (94 miles below dam): 3000 cfs
  - More recent estimates of 1.5 yr discharge: (USDI BLM 1990)
    - Dolores (u/s of dam): 2200 cfs
    - Below McPhee dam: 1000 cfs
  - 1990 estimates of flow needed to mobilize bed material (between Bradfield and Bedrock)
    - 2000 cfs required to mobilize D50
    - 7000 cfs required to move most of bed
    - Pre-dam: D50 moved every 1-2 yrs, larger particles moved every 5-10 yrs
  - More recent estimates of bankfull (Big Gypsum)
    - HEC-RAS modeling
    - 25 cross-sections, 1.9 mile reach
    - Combined model results with DEM to show areas inundated at different flows
    - 2000 cfs needed to inundate floodplain
    - 1000 cfs does not inundate floodplain
- Sediment dynamics
  - Small effect of dam on sediment supply
    - Geology and climate of basin upstream of dam result in low rate of sediment delivery

- Minimal sediment accumulation has occurred in reservoir since construction (no formal measurements)
- Natural and anthropogenic sediment delivery d/s of dam is large, outweighs trapping effects

- Therefore, reduction in frequency of sediment mobilizing flows likely resulted in overall fining of bed sediment
  - Coarser sediment from side canyons for tributary bars
  - Likely rarely transported under regulated conditions, potentially causes steepening of rapids, bar growth
  - Analogous to situation on CO river in Grand Canyon due to reductions in peak flows by Glen Canyon Dam
  - Effects of flow reduction exacerbated by increased sediment supply (erosion) due to grazing, slow rate of vegetation recovery, bank disturbance by fishing and rafting, roads)

- Magnitude of effect varies among reaches depending on gradient, confinement, and trib inputs
  - Most susceptible to change: lower gradient, unconfined reaches; fining of bed material, channel narrowing, channel simplification
    - McPhee Dam to top of Dolores Canyon (3-4 miles d/s of Bradfield Bridge)
    - Portions flowing through Big Gypsum and Paradox Valleys
  - Also susceptible: reaches d/s of sediment producing tributaries
    - Disappointment Valley: Largest sediment input to mainstem (perennial flow in Disappointment Creek), river mile 124 near Slickrock; drainage underlain by Mancos Shale, mantled by shallow soils (USDA 1972)
  - High gradient, confined, bedrock controlled reaches less susceptible but likely also narrowed due to bar growth and vegetation encroachment

Effects of changes in hydrologic regime on native fish spawning

- Changes in hydrograph (magnitude, timing, duration of peak) affects spawning/migration cues (Muth et al. 2000)
- Brouder 2001
  - Upper Verde River in AZ, 11 years
  - Roundtail catch rate increased in years with floods, decreased when no flood
  - Recruitment of roundtail yound dependant on flooding flows
  - Reduction in flood frequency could cause roundtail pops to decline
  - See also Bryan and Hyatt (2004): lack of peak flows over 5 years preceding study may have caused low survival of young roundtails
- Temperatures
  - Spawning begins when temps reach 14-24 degrees C (Bezzerides and Bestgen 2002)
  - Temp increase typically coincides with decrease in runoff after spring peak
  - Eggs hatch after 4-7 days at 19 degrees C
  - Successful spawn every year may not be necessary to sustain population (long-lived fish)
  - But long periods of low to no peak flow may result in aging populations
- Recommendations (Oliver et al., 2010):
  - Release 100-1000 cfs in the 60 days before peak to keep temperatures low, will cue spawning
  - In spill year, ramp down from peak flows slowly to allow greater survival of eggs and larvae (avoid stranding in dry sites, reduce efficiency of predators)
- Data needs:
  - What is role of tributaries in supplementing flows; what impact of tribs on native fish spawning success?

- What is importance of high spring flows/spill flows to native fish reproduction and recruitment?

Bottom line:

CDOW recommends using existing stream flow forecasts to provide adequate hydrograph for native fish (strategy used for other federal reservoirs, e.g., Flaming Gorge, Aspinall Unit on Gunnison). Use April 1st runoff forecast to plan for managed spill. Minimize debts to fish pool by declaring spill earlier and start low volume spills (mimic pre-dam hydrograph).

Current operations: spill is only declared when reservoir is assuredly going to fill. Usually, spill declaration occurs late in runoff season, leads to abrupt increase in flows and an unnatural hydrograph pattern (no gradual rising limb). This is in turn leads to cold water thermal shock to native fish when they are preparing to spawn. Also increases amount of time when d/s releases are debited against fish pool account. These changes would require some stakeholder interactions with boating community and a formal agreement with BoR.

Reduction in peak flows in the post-dam regime has altered geomorphic processes, with subsequent effects on channel morphology and in-channel habitat that have been exacerbated by vegetation encroachment in the reaches downstream of Disappointment Creek (reaches 4b-6). Sediment accumulation in riffle substrates due to lack of flushing flows reduced quality of spawning habitat and instream productivity (Richard and Wilcox, 2005; Anderson and Stewart, 2003)

Base Pool Management

Relevant references:

Valdez, R., A. Masslich, W.J. & Wasowicz, A. (1992) Dolores River native fish habitat suitability study. UDWR Contract No. 90-2559. Prepared for: Utah Division of Wildlife Resource, Salt Lake City, UT. 111pp

- Base flow releases of 20 to 40 cfs in 1990 and 1991 reduced native fish habitat through decreased fish holding areas, dewatered nursery backwaters, impeded movement, and enhanced sedimentation.
- Recommended minimum base flow releases of 50 cfs during dry and normal years and 78 cfs during wet years

Kowalski, D., R. Anderson, J. White and B. Nehring. 2010. Native fish of the lower Dolores River:status, trends, and recommendations. Presentation to the Dolores River Dialogue. Colorado Division of Wildlife. http://ocs.fortlewis.edu/drd/pdf/Dolores%20Native%20Fish%20Status%20and%20Trends%202010danmarch2010.pdf

Summary of flow recommendations:

Source	Flow (cfs)	Location	Release required (cfs)	Volume (af)	% Max BHS biomass
CWCB Instream Flow	78	McPhee-San Miguel	94	68,037	22
Nehring 1985 (Trout)	150	Below McPhee	150	108,569	33
Anderson 2007 (w/ spill)	60	Big Gypsum	72	52,113	12
Anderson 2007 (no spill)	80	Big Gypsum	96	69,484	22
Current fish pool	41	Below McPhee	41	29,300	3

- Current pool is 43% of minimum flow necessary to protect trout fishery; protects <5% of native fish habitat
- But habitat-flow relationship is steep: small increase in flow leads to large increase in biomass (based on flow-biomass relationships from HSMs)

CDOW (Colorado Division of Wildlife). 2010. Dolores River native fish habitat recommendations and alternatives to Wild and Scenic designation. White paper prepared by Colorado Department of Natural Resources, Southwest Aquatic Section-DOW, Southwest Wildlife Conservation-DOW, and the DOW Water Resources Unit.

- Recommendations

Two broad objectives:

New management strategies (alter current water release patterns) to ensure persistence of native fish in river (McPhee to San Miguel)

Current conditions below San Miguel confluence should be protected from future alterations and depletions

Recommended minimum strategies

Five major strategies to meet minmum flow (78 cfs) more often and protect against future depletions on San Miguel and Dolores d/s of confluence

1. Guarantee annual increase to fish pool

Increase pool to 36,500 af (at least)

Lease and/or purchase of water supplies

Would provide enough water for minimum flow of 50 cfs

Periodic spills would increase flow to 78 more often

2. Improve reservoir operation to benefit natives

Use existing stream flow forecasts to provide adequate hydrograph for native fish

Similar strategy to other federal reservoirs (e.g., Flaming Gorge, Aspinall Unit on Gunnison)

April 1st runoff forecast used to plan for managed spill

Minimize depts to fish pool by declaring spill earlier and start low volume spills (mimic pre-dam hydrograph)

Current operations: spill is only declared when reservoir is assuredly going to fill

Usually, spill declaration occurs late in runoff season, leads to abrupt increase in flows

Unnatural hydrograph pattern (no gradual rising limb)

Leads to cold water thermal shock to native fish when they are preparing to spawn

Increases amount of time when d/s releases are debited against fish pool account

Would require some stakeholder interactions with boating community

Would require formal agreement with BoR

3. Adaptive spill management oversight by Dolores Biological Team

Dolores Biology Team designated by the 1996 EA, with input from water managers from MVIC and DWCD

4. Establish instream flow protection for native fish pops and stream flows on the San Miguel and Dolores below confluence

A. File 2 new CWCB instream flow water rights:

On the San Miguel from Calamity Draw (location of irrigation return flows) to Dolores confluence

On theDolores below San Miguel confluence

B. File new CWCB instream flows to protect trib flows to the Dolores, both perennial and ephemeral

Tribs provide seasonal water

Glade Creek

5. Potential increase of water to fish pool through lease via the CWCB

Leasing is only temporary solution and can be more costly

Anderson, R. and G. Stewart. 2007. 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. Colorado Division of Wildlife. Denver, Colorado. http://wildlife.state.co.us/NR/rdonlyres/778159B8-1EA2-443C-A0AF-A8DAB3F41473/0/SpecialReportpart2.pdf

- 2D habitat modeling for natives: modeled habitat availability at micro and meso habitat levels
- Used research grade sonar and total station GPS to survey habitat variables (depth, velocity)
- Developed habitat suitability models with site specific electrofishing samples:
  - Distribution of habitat types (optimal, unsuitable, etc.) based on fish biomass
  - Biomass-flow relationships for FMS and BHS
- Determined that a flow of 300 cfs maximizes BHS and FMS habitat
- Inadequate riffle quantity and quality limits fish habitat and invertebrate productivity
  - Deeper, higher velocity riffles were rare at discharges < 60 cfs
  - Low flows resulted in too little velocity and depth in the majority of riffle and run habitats for FMS and BHS
  - Poor invertebrate production due to lack of quality riffles limit food resources for RTC

- 80 cfs (60 cfs with spill) minimum flow recommendation at Big Gypsum would rpotect 12-22% of maximum native fish habitat
- Lack of high peak flows have resulted in bank encroachment, decreased width:depth, increased pool frequency
- Non-natives:
  - Impact is less than habitat problems
  - Control efforts not likely to be effective because of species present and available access
  - Improving/maintaining fish habitat is key to discouraging non-native fish expansion

Anderson, C. 2010. Factors affecting populations of flannelmouth suckers on the Dolores River between McPhee Dam and the San Miguel River. Technical Memo to Dolores River Dialogue Steering Committee, 4/7/2010. Watershed LLC, dba B.U.G.S. Consulting (Bioassessment Underwater, GIS and Stats).

- Q: Why would greater perennial baseflows be effective at conserving flannelmouth populations?
- Q: Why are flannelmouth populations in a precarious state despite an apparent increase in baseflow post dam construction?

- Habitat preferences:
  - Adults most commonly found in fast water runs and riffle habitats (Stewart and Anderson 2007); less susceptible to predators than young
  - Disperse large numbers of eggs over gravel/cobble substrate during spring; adhere to rocks or settle into interstitial spaces; may need habitat clean of mud and silt (Anderson 2005)
  - Young fish drift to slower waters (eddies, shoreline habitats) to mature, require refuge from visual predators (smallmouth bass, green sunfish, trout) – murky or fast water
  - Not restricted to warmwater habitats
- Base flows: Higher baseflows → more refuge habitat and lower density of predators
- Historic hydrology (DRD Hydrology Report 2005)
  - Diversions began in late 1880s

- Flows were intermittent during late summer months (disconnected pools) in Reaches 1 - 5 (USGS McPhee gage)
- Flows have been perennial since construction of dam (1984) but peak flows decreased by ~50% and June flows decreased by order of magnitude
- Resulting changes in instream habitat (David Graf personal communication)
  1. Fine sediment deposition and accumulation
  2. Shallower pools
  3. Channel encroachment by vegetation
  4. Habitat modeling (Stewart and Anderson 2007)
  5. Baseflow of 300 cfs necessary to maintain flannelmouth population in Big Gypsum comparable to populations of Yampa, Gunnison, and Colorado
  6. Minimum baseflow of 50-60 cfs during spill years and 80 cfs during non-spill years to support 'modest' population
  7. Current baseflow of 30 cfs during winter and 78 during summer during non-shortage years
     - But 2002 (drought year) summer flows were as low as 15 cfs
     - 2003 peak flow was 41 cfs, ~40 cfs for a few weeks, dropped to 20 cfs until May 4th when flows increased slightly
     - 2004 peak flow was 92 cfs for one day

- Comparisons with other river systems:
  - Strawberry River, Utah: 32 mile section, altered hydrograph, confined by reservoirs; peak flows <200 cfs, minimum flows 31 cfs (Jan), 41 cfs (Aug); 4 tributaries available for flannelmouth spawning; brown trout only non-native (upstream reaches) = healthy flannelmouth population (Breen and Hedrick 2009)
  - Upper Muddy Creek, WY: intermittent reaches during late summer months due to irrigation diversions, no dams (natural peak flows); non-native white suckers and creek chubs = stable flannelmouth population until recently (hypothesis: competition and interbreeding with white suckers) (Bower and HUbert 2008)
  - Colorado River, below Davis Dam: channelized, armored; non-native predators (smallmouth bass, striped bass, bluegills); minimum flows ~2000 cfs, maximum > 20,000 cfs, daily fluctuations of several thousand cfs; refuge in fast flowing waters, unknown mechanisms for spawning success; breeding congregations ~1.5 km below dam

Bottom line:

Current pool of 31,798 af is only 87% of target recommended pool (CDOW 2010). Current pool is 43% of minimum flow necessary to protect trout fishery; protects <5% of native fish habitat (Kowalski et al., 2010)

CWCB (CO Water Conservation Board) retains 78 cfs instream flow from McPhee to San Miguel (105 miles) - determined as biological minimum flow, but instream flow water right is typically not met for most of the year. Current downstream allocation is 46% of pool required to meet 78 cfs year-round and current operations annually produce baseflows of < 30 cfs. Habitat modeling indicates 30 cfs supports < 42% of potential trout habitat and < 5% of potential native fish habitat (CDOW 2010).

Increasing pool to 36,500 af (at least) by leasing and/or purchasing water supplies would provide enough water for minimum flow of 50 cfs, while periodic spills would increase flow to 78 more often (CDOW 2010)

Reduced Predation and/or Competition from Non-Native Fish

Relevant references:

Anderson, R. and G. Stewart. 2007. 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. Colorado Division of Wildlife. Denver, Colorado. http://wildlife.state.co.us/NR/rdonlyres/778159B8-1EA2-443C-A0AF-A8DAB3F41473/0/SpecialReportpart2.pdf

Anderson, R. 2005. Riverine Fish Flow Investigations: Quantification of impacts of the 2002 drought on native fish populations in the Yampa, Colorado, Dolores and Gunnison Rivers. Federal Aid Project F-288-R8. Colorado Division of Wildlife. Denver, Colorado. http://wildlife.state.co.us/NR/rdonlyres/3247B27F-16F5-44D4-B899-DDBEFC648DF8/0/Anderson2005.pdf

Anderson, C. 2010. Factors affecting populations of flannelmouth suckers on the Dolores River between McPhee Dam and the San Miguel River. Technical Memo to Dolores River Dialogue Steering Committee, 4/7/2010. Watershed LLC, dba B.U.G.S. Consulting (Bioassessment Underwater, GIS and Stats).

- Non-native predators:
  - Predation by non-natives likely plays significant role in reducing survival of young flannelmouths and recruitment to spawning age (Rees et al., 2005; Bezzerides and Bestgen 2002)
  - Since 1987:
    - Non-native populations have increased in Reaches 1-4 (rainbow, brown, smallmouth bass, green sunfish)
    - CDOW has stocked Reach 1 with thousands of fingerling trout annually(Nehring 1991, DRD Correlation Report 2006)
    - Trout populations peaked in 1993 in Reach 1 due to spill from reservoir (along with Kokanee salmon and smallmouth bass)
  - 2006 CDOW survey between Pyramid and Disappointment Creek: > 80 smallmouth bass found (feed heavily on small fish)
  - Green sunfish
    - Present in river since before dam construction
    - Occasionally caught in slower waters of Reach 1 and 2
    - Dove Creek site, 21% of catch in 2004
- Factors affecting population stability:
  - Require successful spawn followed by 2+ years of adequate refuge for young (Rees et al. 2005); successful spawn not required every year (Mueller and Wydoski 2004)
    - Three ways to increase survival
      1. Decrease density of predators (increase baseflows, remove predators)
      2. Increase amount of refuge habitat (increase baseflows, ensure high power spill releases)
      3. Both
         - Best spawning habitat is in Reaches 1-3 and upper portions of Reach 4 (upstream of Disappointment Creek) (run habitat free of mud and silt) (Anderson 2005, large aggregations of spawning flannelmouth observed in 2006)

- Non-natives present in these spawning areas: rainbow and brown (reaches 1-3), smallmouth bass (reaches 3-4), occasional green sunfish (reach 1)
- Below Disappointment Creek, silted bed unsuitable for spawning, but murky water provides refuge, non-native competitors (carp, channel catfish, black bullhead)

- Methods for removing non-native predators implemented elsewhere in CO River basin, being assessed for Dolores
  1. Efforts to remove smallmouth bass in Yampa and Green (2007 and 2008) had limited success
  2. Strong reproduction in 2006 and 2007
  3. Higher and cooler flows in 2008 led to lower smallmouth reproduction
  4. For effective control of smallmouth bass, critical to allocate water for sampling and non-native fish abatement

- Examples of other rivers with altered baseflows and healthy flannelmouth populations, therefore other factors need to be considered:
  - Altered spring flows (reducing spawning success and habitat availability)
  - Relationship between temperature and spawning cues
  - Loss of access to upstream habitat and tributaries
  - Significant numbers of non-native predators
- Recommendations:
  - More through literature review
  - Participation in meetings regarding native fisheries
  - Consult with investigators conducting this research
  - Cooperate with CDOW fishery biologists
- Data needs:
  - Current status of native fish populations
  - Impacts of non-native fish (including trout)
  - Methods of non-native fish removal
  - Conditions that lead to successful spawning and survival
  - Potential to use Selective Level Outlet Works at McPhee Dam to expand native fish habitat upstream (recognizing risk of expanding non-native habitat into Lower Dolores)

Bryan, S. and M. Hyatt. 2004. Roundtail Chub Population Assessment in the Lower Salt and Verde Rivers, Arizona.State Wildlife Grant Final Report. Arizona Game and Fish Department, Phoenix, AZ 85023 19pp.

- Lower Salt and Verde Rivers
- Rapidly declining roundtail chub population
- Concluded that low survival of young fish likely due to non-native sport fish and sustained lack of high peak flows

Oliver, A., C. Anderson and R. Anderson. 2010. Baseline field investigations, science-based opportunities and potential tools for improvement of the downstream environment on the lower Dolores River. Report Submitted to the Colorado Water Conservation Board in Fulfillment of the 2008/2009 Severance Tax Trust Fund Grant Awarded to the Dolores River Dialogue. http://ocs.fortlewis.edu/drd/pdf/DRD%20Big%20Gypsum%20Monitoring%20Site%20Grant%20Report.pdf

Utah Division of Wildlife Resources. 2006. Range-Wide Conservation Agreement and Strategy For Roundtail Chub Gila Robusta, Bluehead Sucker Catostomus discobolus, and Flannelmouth Sucker Catostomus Latipinnis. Prepared for Colorado River Fish and Wildlife Council. Publication Number 06-18. Salt Lake City, UT. 59pp. http://wildlife.state.co.us/NR/rdonlyres/C0157052-214D-4E9D-B9C3CCCE989EE715/0/ChubSuckerRangewideConservationAgreementandStrategy010407.pdf

Valdez, R., T. Hoffnagle, C.McIvor, T. McKinney, W. Leibfried (2001) Effects of A Test Flood On Fishes Of The Colorado River In Grand Canyon, Arizona. Ecological Applications: Vol. 11: 686-700.

Bottom line:

Percentage of non-native species has increased since first documented in 1971 (Holden and Stalnaker 1971); 13 non-native species documented today (Anderson, 2005; Anderson, 2006), although the species composition varies by reach.

Anderson (2005, 2006) found that an Increase in black bullhead corresponded with decline in flannelmouth sucker and roundtail chub following a period of drought (Big Gypsum site). Although not efficient predator, black bullhead is strongly associated with backwater habitat types which were more prevalent during low flow years. Anderson and Stewart (2007) concluded that the impact of non-natives was less than habitat problems and that control efforts were not likely to be effective because of species present and available access. Rather, improving and maintaining fish habitat is critical to discouraging non-native fish expansion.

Note that the review by Oliver et al. (2010) came to slightly different conclusions (possibly because some were based on studies of the Yampa and Colorado rivers, not the Dolores). They hypothesized and recommended that:

- Consecutive years of low spring flows and/or low baseflows will cause increased pops of nonnative warmwater species (Anderson and Stewart 2007)
- Warmer water temperatures will cause upstream expansion of smallmouth bass pop (White 2010, Anderson and Stewart 2007
- Flows between 100-1000 cfs in the 60 days before the peak will control nonnative warmwater fish pops (Anderson and Stewart 2007, Graf 2006 communication)
- Although a test flood did not decrease nonnative pops, repeating floods annually could reduce nonnatives (Valdez et al., 2001)
- Direct control of nonnatives in priority reaches will increase survival of natives (UDWR 2006, Anderson 2010)

Water quality

Relevant data:

CDOW Temperature Data, 2005-2010, 4 sites:

- Bradfield Bridge
- Dove Creek Pumps
- Above Disappointment
- Lone Dome Headgate

2010-2011 data are available from from Jim White

USGS gage at Bedrock temperature data, 1985-present

Figure B1: Temperature record (minimum and maximum daily) from the USGS gage station, Dolores River at Bedrock, 1990-2011

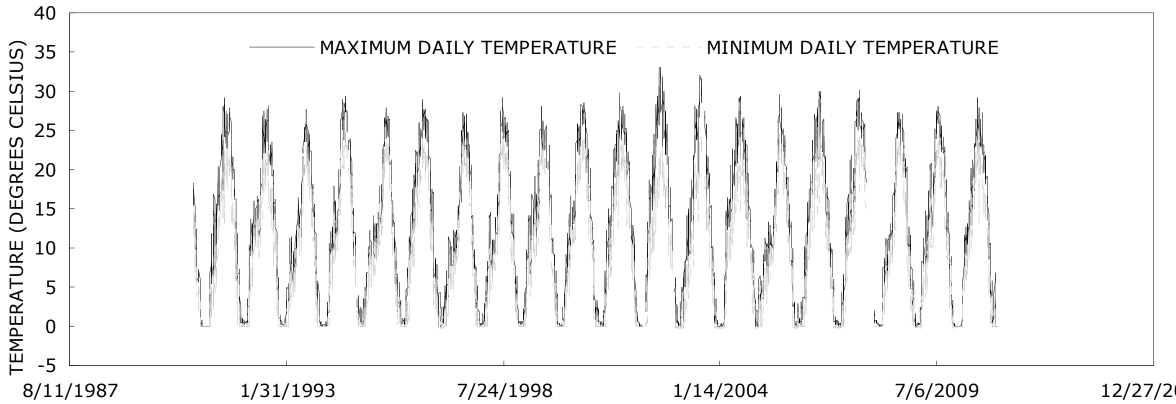
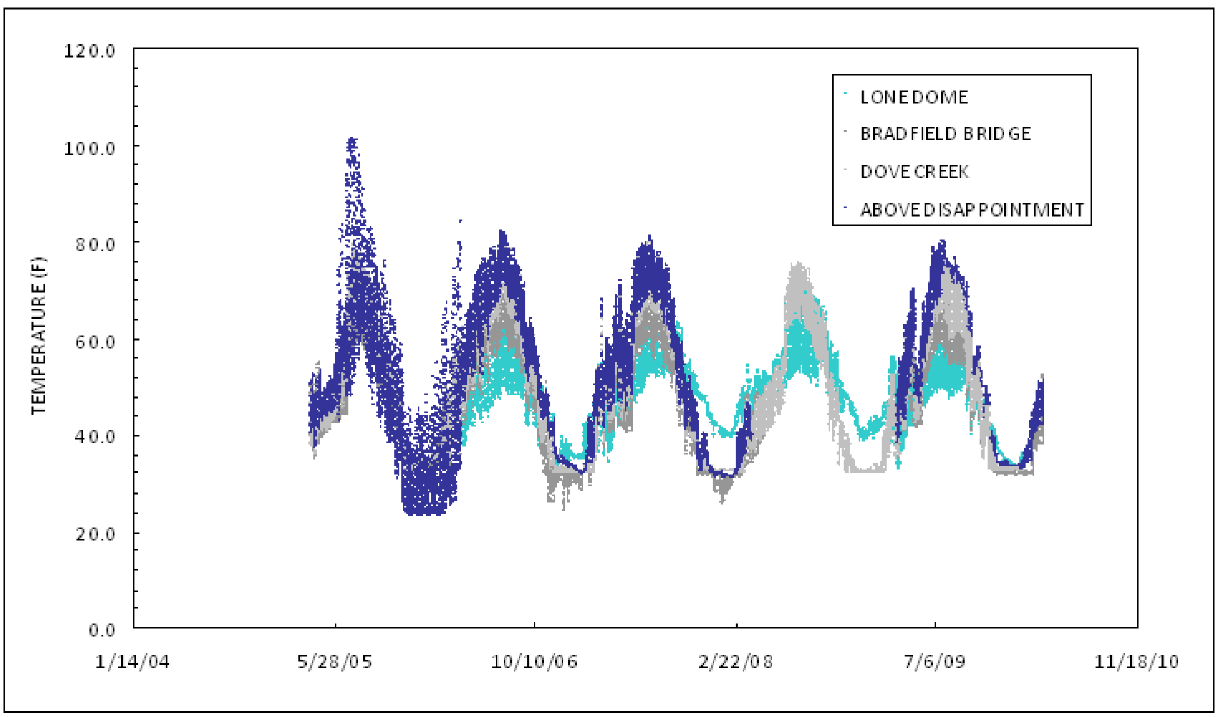


Figure B2: Temperature record (continuous) from four sites downstream from McPhee Dam on the Dolores River, listed from upstream to downstream, 2005-2010. Source: Jim White, CDOW, unpublished data.



Relevant references:

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.

- Table 35, page 61-65: Temperature and water quality (conductivity, salinity, DO, alkalinity, pH, Secchi depth) data recorded for three Dolores River field trips in 1990 and three in 1991 (March – October), numerous river miles from Colorado River confluence upstream through Big Gypsum Valley

- Table 36, page 66: Summary of water quality data for Field Trip 1 of the 1990 Dolores River study
  - Above and below San Miguel confluence, near confluence with Colorado River
  - Alkalinity, pH, TDS, ammonia, nitrate, phosphate, copper, iron, zinc, lead, oil, TSS
- Table 37, page 67: Summary of water quality for Field Trip 2 of the 1990 Dolores River Study.
  - Near Slickrock, Above and below San Miguel confluence, near confluence with Colorado River
  - Alkalinity, pH, TDS, ammonia, nitrate, phosphate, copper, iron, zinc, lead, oil, TSS
- Table 38, page 68: Summary of water quality for Field Trip 3 of the 1990 Dolores River Study.
  - Near Slickrock, near Bedrock, Above and below San Miguel confluence, near confluence with Colorado River, San Miguel above confluence with Dolores
  - Alkalinity, pH, TDS, ammonia, nitrate, phosphate, copper, iron, zinc, lead, oil, TSS
- Tables 39-41, pages 69-73: Summaries of water quality for additional field trips in 1990 and 1991 for all sites (Slickrock, Bedrock, above and below San Miguel, CO River confluence, San Miguel); additional elements (aluminum, cadmium, silver)
- Table 42, page 74-75: Historical summary of water chemistry in the Dolores (DO) and San Miguel (SM) Rivers (ten studies from 1960-1990)
- Table 43, page 76: Radium-226in Dolores and San Miguel River bottom sediments,1991
- Table 44, page 77: Historical comparison of Radium-226in Dolores and San Miguel River bottom sediments at five sample sites (1960-1990)
- Tables 45-47, pages 78-79: Heavy metal content of liver and/or kidney tissue for fish from Dolores (1991) and Gunnison (1981), for individual sites and summarized
- Tables 48-54, pages 80-92: Invertebrate data from trips 1-4 on the Dolores, 1990-1991, 3-5 sites (note: first pages of Tables 52-54 are missing)
- Main results:
  - Temperature:
    - Above confluence with San Miguel to Bradfield Bridge:
    - Ranged from 0-30 C, highs in July and August, lows in winter
    - Dam releases had large effect on both diel and annual patterns
      1. Diel: low volume releases during summer caused extreme temperature variation (small thermal mass in flow), particularly in low velocity habitats (pools, backwaters), along with low DO
      2. Annual: premature warming during low flows in April-May, initiated gonadal maturation and spawning by three species; subsequent cold releases likely killed eggs and larvae; low flow (20 cfs) temps 16-18 C in April-May; large aggregations of flannelmouths and individuals showing signs of spawning readiness observed during same period
    - Distinct temperature break at Disappointment Creek (difference up to 4 C during summer)
      1. Above creek: cool, clear (flow through extensive canyons)
      2. Below creek: warmer, more turbid (due to less confined, open water and erodible shales and sandstones)
    - Below confluence with San Miguel

- Primarily influenced by San Miguel; moderated by large volumes of water from San Miguel
    - Ranged from 3.5 C to 28.5 C (March – August)
- USGS gage at Bedrock (upstream of San Miguel): 0-30 C (winter – July); maximum = 33.5 C
- USGS gage at Cisco (9.5 miles upstream of Colorado): maximum = 20 C
- Comparison of mean monthly temperatures from gages near Cisco on Dolores vs. Colorado:
    1. Lower volume and earlier runoff → earlier warming on Dolores (by ~10-20 days)
    2. Consistently higher temperatures on Dolores than Colorado except during November – January

- Water chemistry, pages 15-20
    - DO: Above EPA standards for non-salmonid fisheries
    - Salinity: highest when flows were lowest; increased at Paradox Valley downstream to San Miguel, where dilution occurred
    - Sulfate: substantially lower than in 1986
    - TSS: ranged 14-18,600 mg/l; highest after high intensity storms (runoff)
    - Oil and grease: generally low
    - Phosphate: lowest near Slickrock and highest at the station above the confluence of the San Miguel River, indicating inputs from Paradox Valley; Mackenthun (1973) set the desired goal for the prevention of plant nuisances at 0.1 mg/l for flowing waters not directly discharging into lakes or impoundments.
    - Orthophosphate: low
    - Heavy metals:
        - Note: historical comparison of metal concentrations should be viewed cautiously because of inherent differences in sample sites, collecting and measurement techniques, and variability in related physical parameters such as flow, pH, and water hardness.

- Fish tissue and sediment analysis, pages 20-22
    - Radium concentrations in sediments declined since 1950s due to closure of Uravan Mill in 1970 and Superfund clean up program in 1988
        - No longitudinal trends in 1991
    - Average metal content in RTC tissue from Dolores in 1991 significantly greater than in RBT and white sucker tissue from Gunnison in 1981
    - Flannelmouth suckers in Dolores (1991) had significantly higher concentrations for 4 of 5 metals than white suckers in Gunnison (1981)
- Macroinvertebrates, page 22
    - Difficult to make historical comparisons because of differences in techniques, season, flows
    - Little macroinvertebrate data from Dolores or San Miguel prior to 1980; available data indicates low species diversity in 1970s and 80s
    - Indicator taxa:
        - 1960: pollution intolerant Plecoptera absent in San Miguel samples
        - 1980s and 90s: pollution intolerant Plecoptera present in San Miguel samples

- 1990s: Pollution intolerant Trichoptera present in Dolores and San Miguel, but not found historically
- Biotic Condition Index (USFS 1985) values calculated in 1991 (based on stream gradient, substrate, alkalinity, sulfate, and tolerance quotients for individual taxa)
  Dolores BCI = 108 ("Excellent")
  San Miguel BCI = 56 ("Fair to poor")
- Indicates improvement in water quality since 1960s

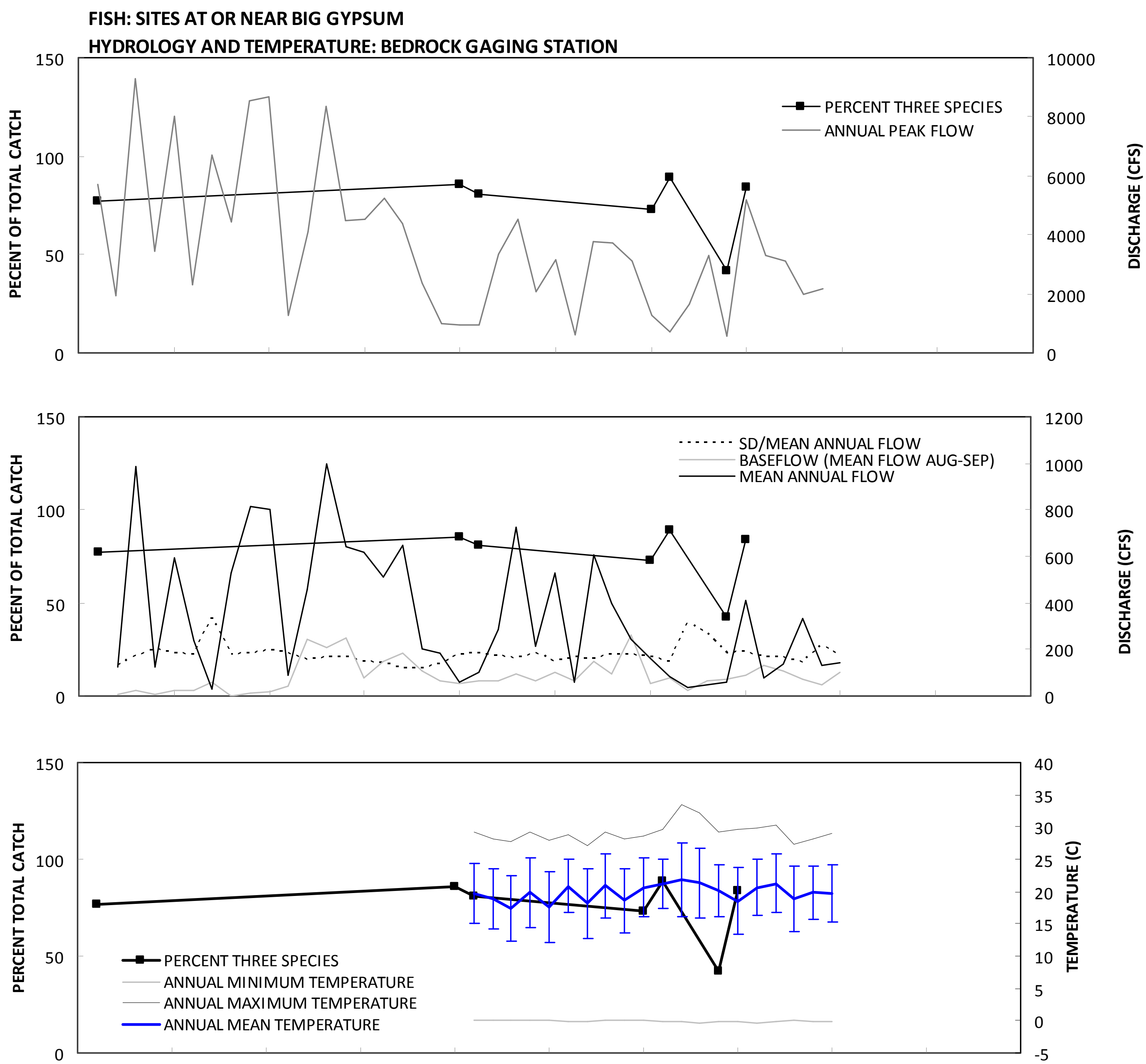
Anderson, C. 2010. Selective level outlet works, downstream water temperature and dissolved oxygen. Presentation to the Dolores River Dialogue. B.U.G.S. Consulting

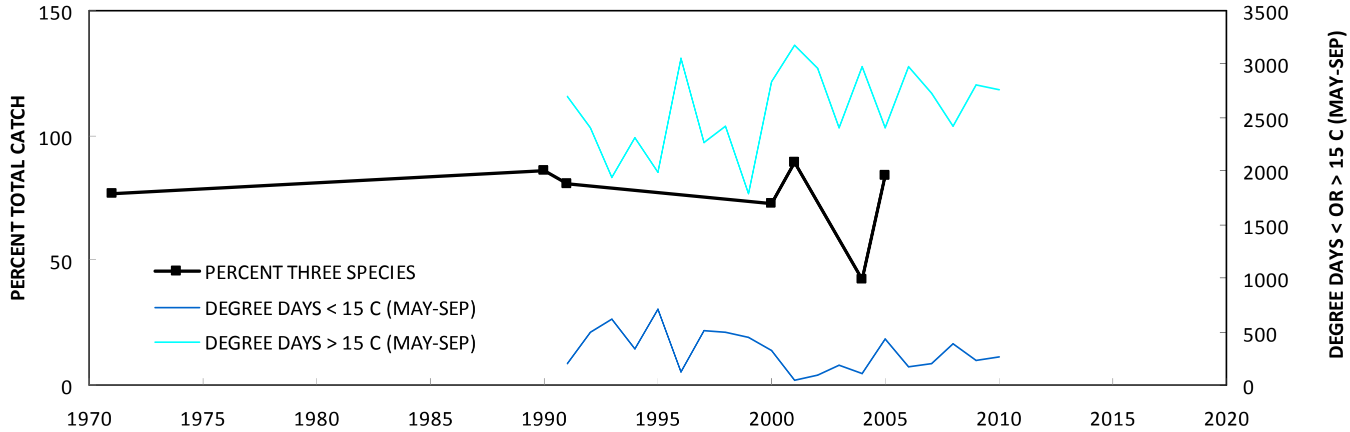
- Temperature exceeded CO standard for cold water fisheries at flows less than 60 cfs during summer months
- DO is less than CO standard at flows less than 40 cfs during summer months
- Baseflows greater than 60 cfs (McPhee to Bradfield Bridge) will maintain temps below CO standard for coldwater fisheries

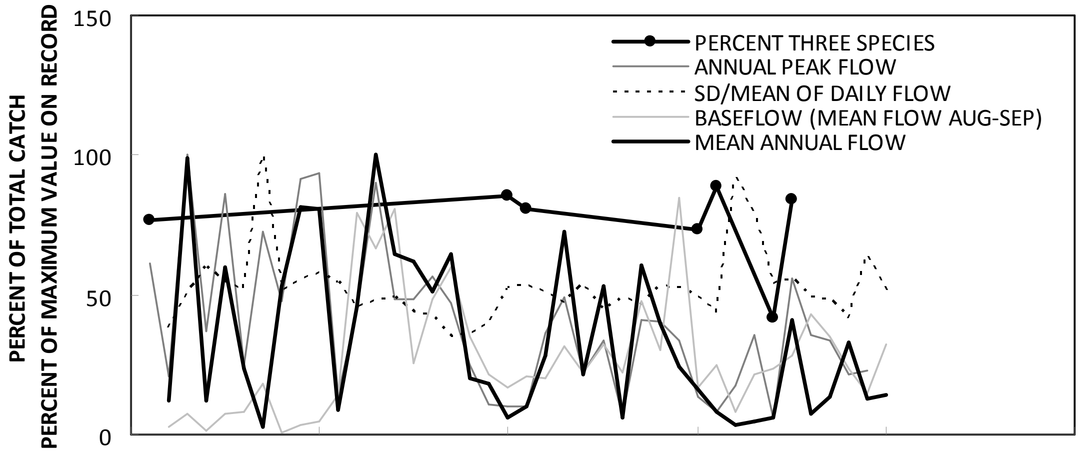
Bottom line:

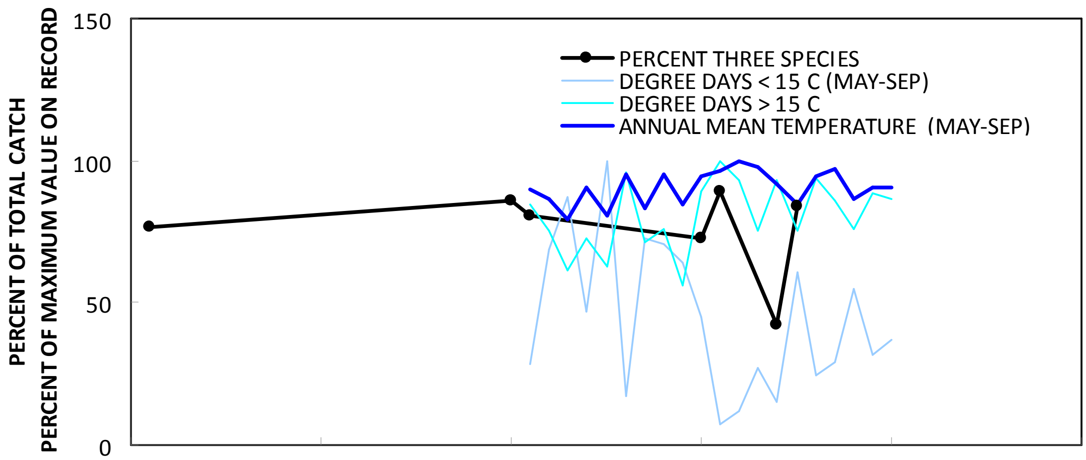
Dam was shown to have negative effects on temperature and DO in early 1990s:
Low volume releases during summer caused extreme temperature variation (small thermal mass in flow), particularly in low velocity habitats (pools, backwaters), along with low DO
Premature warming during low flows in April-May, initiated gonadal maturation and spawning by three species; subsequent cold releases likely killed eggs and larvae; low flow (20 cfs) temps 16-18 C in April-May; large aggregations of flannelmouths and individuals showing signs of spawning readiness observed during same period
Temperature and DO problems persist today:
Temperature exceeded CO standard for cold water fisheries at flows less than 60 cfs during summer months
DO is less than CO standard at flows less than 40 cfs during summer months
Salinity and turbidity may cause problems downstream of Disappointment Creek and Paradox Valley
Little evidence for effects of historic pollution on biotic community of Dolores; general improvement in water quality since 1960s (BCI rated "excellent" for Dolores in 1990s; increasing diversity, presence of pollution intolerant species), although metal content in fish tissue higher of Dolores in 1991 higher than for Gunnison in 1981

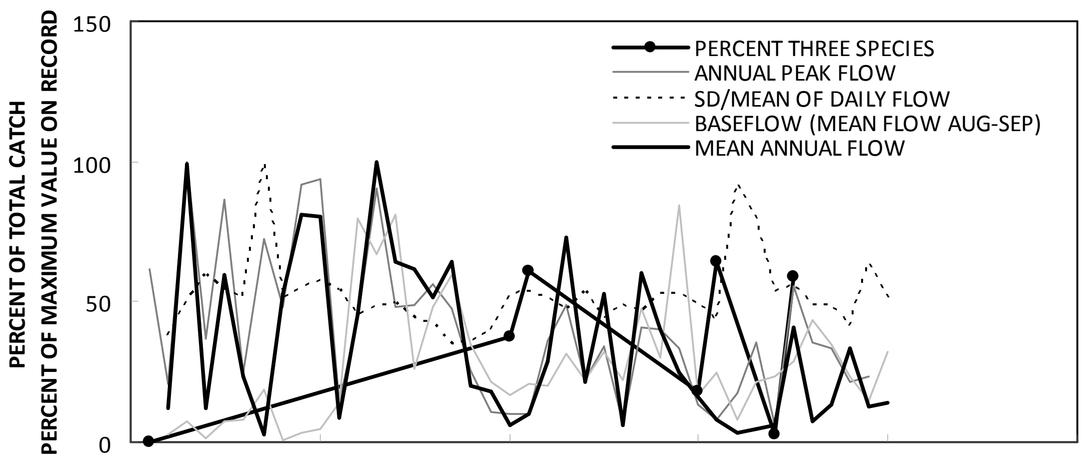
Figure B3: Three species population trends of sites at or near Big Gypsum with hydrology and temperature record of Bedrock gage station.


FISH: SITES AT OR NEAR BIG GYPSUM
HYDROLOGY AND TEMPERATURE: BEDROCK GAGING STATION
PECENT OF TOTAL CATCH
DISCHARGE (CFS)
PERCENT THREE SPECIES
ANNUAL PEAK FLOW
150
100
50
0
10000
8000
6000
4000
2000
0
PECENT OF TOTAL CATCH
DISCHARGE (CFS)
SD/MEAN ANNUAL FLOW
BASEFLOW (MEAN FLOW AUG-SEP)
MEAN ANNUAL FLOW
1200
1000
800
600
400
200
PERCENT TOTAL CATCH
TEMPERATURE (C)
PERCENT THREE SPECIES
ANNUAL MINIMUM TEMPERATURE
ANNUAL MAXIMUM TEMPERATURE
ANNUAL MEAN TEMPERATURE
40
35
30
25
20
15
10
5
-5


150
100
50
0
PERCENT TOTAL CATCH
3500
3000
2500
2000
1500
1000
500
0
DEGREE DAYS < OR > 15 C (MAY-SEP)
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
PERCENT THREE SPECIES
DEGREE DAYS < 15 C (MAY-SEP)
DEGREE DAYS > 15 C (MAY-SEP)


PERCENT OF TOTAL CATCH
PERCENT OF MAXIMUM VALUE ON RECORD
0
50
100
150
PERCENT THREE SPECIES
ANNUAL PEAK FLOW
SD/MEAN OF DAILY FLOW
BASEFLOW (MEAN FLOW AUG-SEP)
MEAN ANNUAL FLOW


PERCENT OF TOTAL CATCH
PERCENT OF MAXIMUM VALUE ON RECORD
0
50
100
150
PERCENT THREE SPECIES
DEGREE DAYS < 15 C (MAY-SEP)
DEGREE DAYS > 15 C
ANNUAL MEAN TEMPERATURE (MAY-SEP)


PERCENT OF TOTAL CATCH
PERCENT OF MAXIMUM VALUE ON RECORD
0
50
100
150
PERCENT THREE SPECIES
ANNUAL PEAK FLOW
SD/MEAN OF DAILY FLOW
BASEFLOW (MEAN FLOW AUG-SEP)
MEAN ANNUAL FLOW

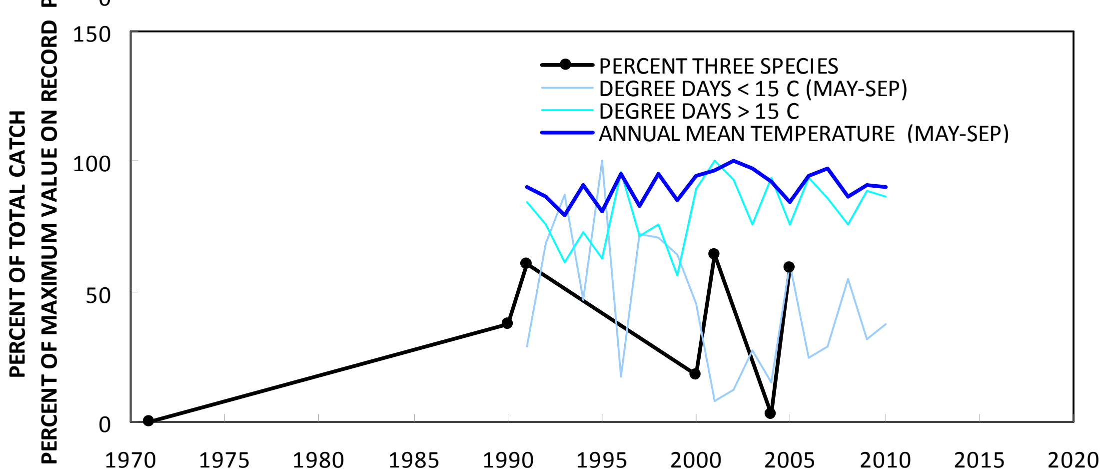
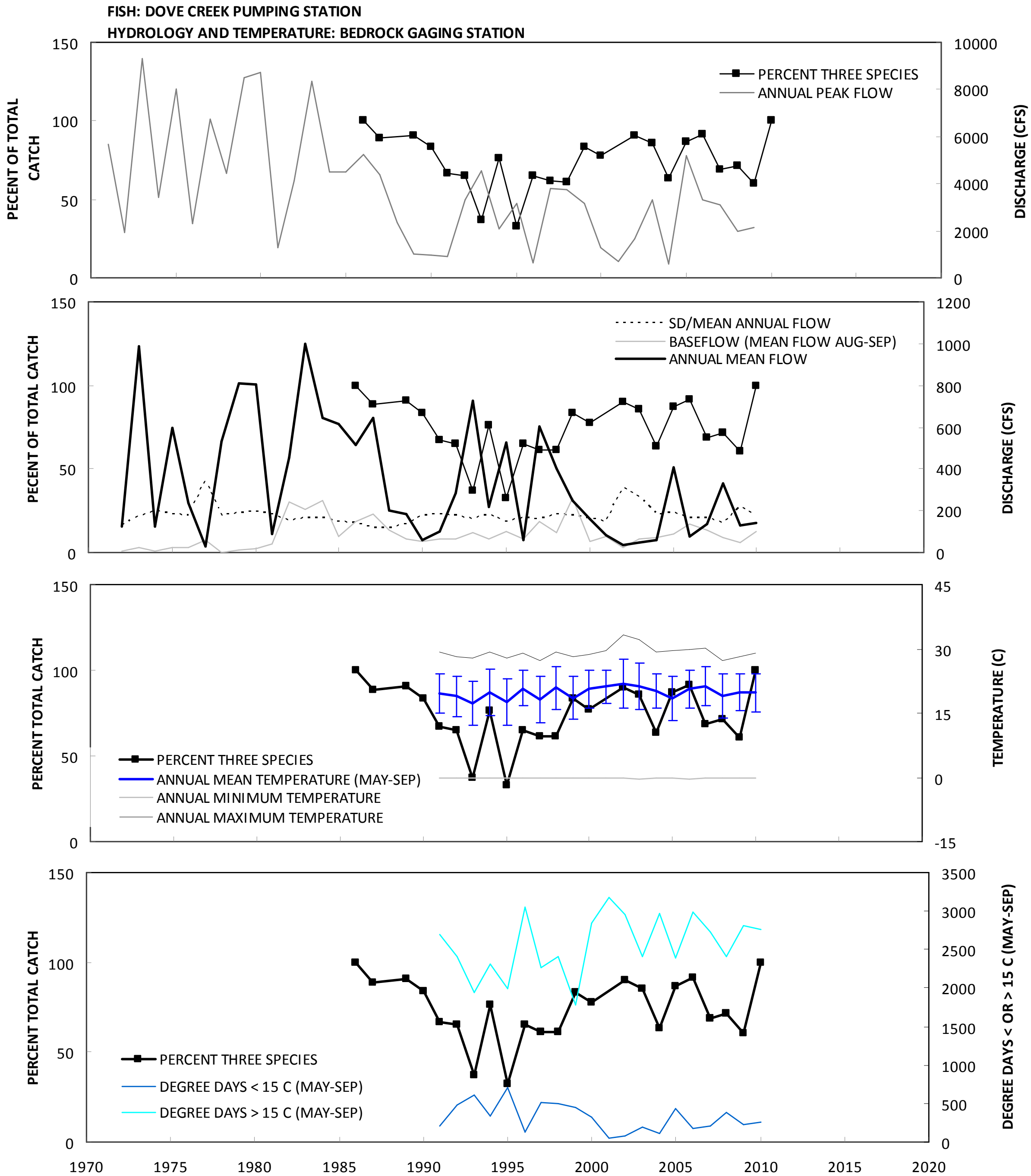
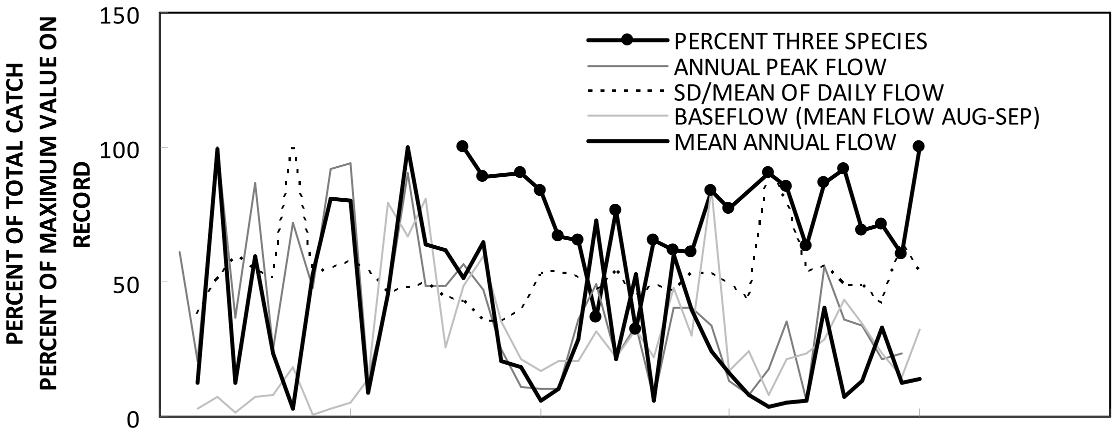
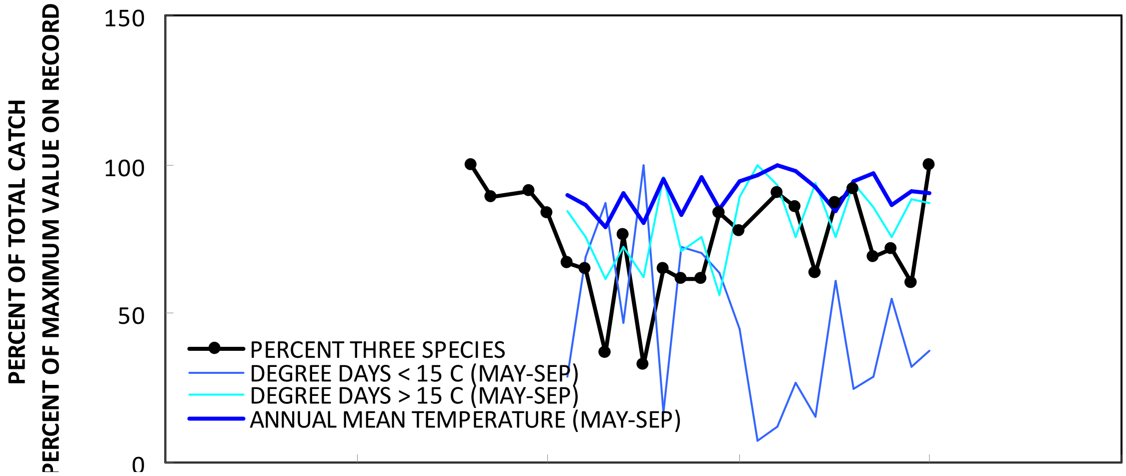

PERCENT OF TOTAL CATCH
PERCENT OF MAXIMUM VALUE ON RECORD
0
50
100
150
PERCENT THREE SPECIES
DEGREE DAYS < 15 C (MAY-SEP)
DEGREE DAYS > 15 C
ANNUAL MEAN TEMPERATURE (MAY-SEP)
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020

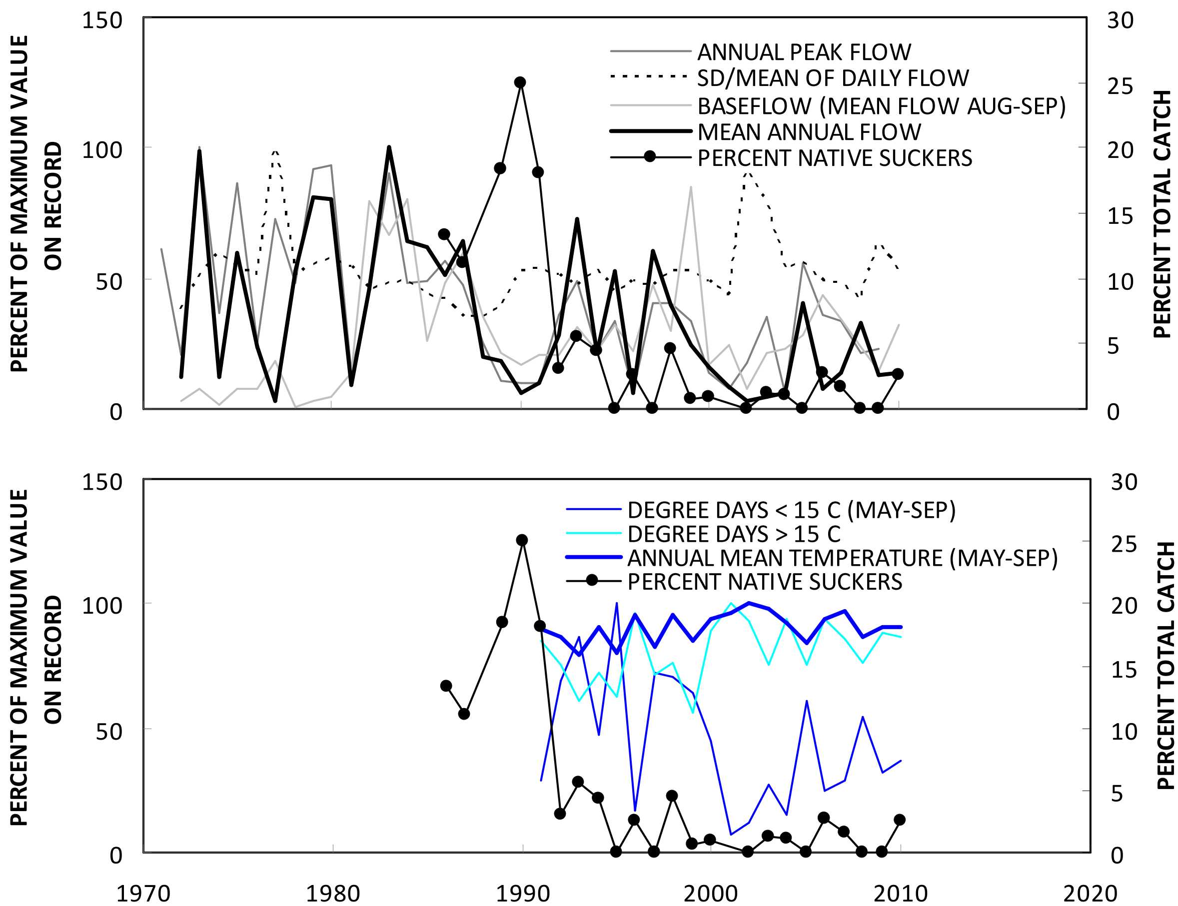
Figure B4: Three species population trends of Dove Creek Pumping Station with hydrology and temperature record of Bedrock gage station.



*Error bars are standard deviation around the annual mean


150
100
50
0
PERCENT OF TOTAL CATCH
PERCENT OF MAXIMUM VALUE ON
RECORD
PERCENT THREE SPECIES
ANNUAL PEAK FLOW
SD/MEAN OF DAILY FLOW
BASEFLOW (MEAN FLOW AUG-SEP)
MEAN ANNUAL FLOW


150
100
50
0
PERCENT OF TOTAL CATCH
PERCENT OF MAXIMUM VALUE ON RECORD
PERCENT THREE SPECIES
DEGREE DAYS < 15 C (MAY-SEP)
DEGREE DAYS > 15 C (MAY-SEP)
ANNUAL MEAN TEMPERATURE (MAY-SEP)



ANNUAL PEAK FLOW
SD/MEAN OF DAILY FLOW
BASEFLOW (MEAN FLOW AUG-SEP)
MEAN ANNUAL FLOW
PERCENT NATIVE SUCKERS
PERCENT OF MAXIMUM VALUE ON RECORD
PERCENT TOTAL CATCH
DEGREE DAYS < 15 C (MAY-SEP)
DEGREE DAYS > 15 C
ANNUAL MEAN TEMPERATURE (MAY-SEP)
PERCENT NATIVE SUCKERS
PERCENT OF MAXIMUM VALUE ON RECORD
PERCENT TOTAL CATCH
150
100
50
0
30
25
20
15
10
5
0
1970
1980
1990
2000
2010
2020

Riparian Ecology

Relevant references:

Merritt, D. 2005. Dolores River Dialogue Riparian Vegetation Analysis. Core Science Report, pp. 42-59

- Four sections:
  - 1) Concepts that relate plant life history to hydrologic regime
  - 2) Reviews the few studies from Dolores that described changes in plant communities over past couple decades
  - 3) Discusses considerations for developing vegetation inventory for Dolores to monitor community over time
  - 4) Discusses biologically relevant changes in flow regime since McPhee Dam construction and likely resulting changes in riparian communities along Dolores

Sections 2 and 4 summarized:

- 2) Riparian vegetation of the Dolores River
  - Transitional between lower montane and Colorado Plateau desert:
  - Woody riparian vegetation (e.g., sandbar willow, river birch, box elder)
  - Herbaceous riparian vegetation
  - Terrace vegetation (e.g., Ponderosa pine, Gambel oak, rabbitbrush, sage)
  - Upland vegetation (e.g., Pinion pine, juniper, Gambel oak, sage, saltbrush)
    - Narrow canyons: best suited for shrub and dwarf tree communities
    - Wider valley segments: more conducive to extensive cottonwood forests
  - Few published studies of Dolores River vegetation; difficult to draw strong conclusions
    - National Park Service wild and scenic river study in late 1970s (USDI 1979)
  - Upstream from Bradfield Bridge: tamarisk not dominant; likely limited by elevation (abundant only below 7000 ft)
  - Downstream from Bradfield Bridge: "near natural", sandbar willow and extensive cottonwood
  - Downstream from Disappointment Creek: tamarisk abundant, increasingly dominant downstream
    - Gypsum Valley: extensive groves of cottonwood
  - Today:
    - Tamarisk still limited upstream from Bradfield Bridge due to frost impact
    - Tamarisk common in low-lying alluvial reaches (e.g., Big Gypsum, Paradox Valley)
    - Few old cottonwood in Gypsum Valley, tamarisk is abundant, monotypic stands are extensive
    - Highly saline soils due to runoff/tributary inputs draining shale formations; further concentrated due to evaporation from shallow water tables; lack of overbank flows allows salt to accumulate
      = Favorable conditions for tamarisk
      = Inhibited germination, survival, and growth of cottonwoods (Shafroth et al. 1995)
      = Increased vulnerability of plants to moisture stress
- Kriegshauser and Sommers (2004):
  - Measured vegetation along reach of Dolores near Lone Dome, 1988-2001 (longest study, 14 years)
  - Recorded:
    1. Significant increase in sandbar willow cover/number:
       a. Not surprising: willow can spread by root sprouts, therefore not as dependent on flooding for asexual reproduction; absence of overbank

flows allowed willow to encroach on channel, particularly along gaining reaches or reaches with stable baseflow
    b. Provides valuable habitat and is native, but encroachment may reduce channel capacity or cause incision
2. No significant change in cottonwood cover/number
3. Decline in silverberry
    a. Possibly related top increases in soil salinity
    b. Can tolerate occasional flooding and fire; often located in transitional area between frequently flooded sandbars and upland areas
4. Streamside meadows became dominated by xeric species
5. Meadows historically flooded at 8000 cfs were rarely flooded post-dam
    - Colorado Natural Heritage Program:
        - Seven sites from McPhee to downstream of San Miguel confluence, late 1990s
        - > 50 species, 7 plant associations
        - Cottonwood not dominant in any sampled stands along Dolores (not likely representative)
        - Cottonwood was dominant in 6 of 7 sites sampled along lower San Miguel
- San Miguel is unregulated, could be example of "natural" plant community
    - General conclusions regarding current state and trends:
- Note: difficult to draw clear conclusions given that studies came from different segments and occurred over several decades
- Cottonwood forests are less frequent and less extensive than historically
- Silverberry may be declining along some reaches
- Tamarisk has increased in abundance and extent
- Sandbar willow is more abundant than historically
    - Data needs:
- Current vegetation inventory of Dolores River, will provide:
    1. Baseline for future monitoring
    2. Basis for determining management goals, accounting for physical and hydrologic constraints
    3. Information on most effective way to restore system
        Well-established tamarisk unlikely to be removed by large overbank flood
        Mechanical removal may be necessary prior to large spill
        Erode banks and create new sites for cottonwood establishment
    4. "Pre-restoration" condition to assess vegetative response to management activities (e.g., flooding, mechanical removal, baseflow changes)

- 4) Biologically relevant changes in flow regime on Dolores
- Indicators of hydrologic alteration analysis and flood frequency analysis (USGS Bedrock, CO gage and Cisco, UT gage)
    - Changes in high flows:
        - Average instantaneous peak flow reduced by 48% at Bedrock
        - Lowest instantaneous peak flow was an order-of-magnitude larger in pre-dam period than post-dam at Bedrock
        - Reductions at Cisco gage not as extreme
        - Average flow during the month of May decreased by 40% at Bedrock but stayed about the same (+1.5%) at Cisco.
        - Average June flow in the decreased by 54% and 18% at Bedrock and Cisco, respectively.

    - 10 year recurrence interval flood decreased from 9,040 cfs to 5,500 cfs (-39%) at Bedrock and from 13,500 cfs to 10,000 cfs (-26%) at Cisco
- Likely effects of changes in high flows:
    - Shifts in community composition and vegetation encroachment
    - Reduced frequency and extent of floodplain inundation → increased microbial activity → potentially increased salt concentrations in soils
    - Smaller annual floods → stable bars and islands → higher vegetation cover, more perennial species, more obgligate wetland species (Merritt and Cooper 2000), decreased abundance of disturbance-vulnerable species (e.g., narrowleaf cottonwood)
    - Decrease in magnitude of 10-yr recurrence interval flood → less cottonwood recruitment (recruitment linked to 10-yr flood; Scott et al. 1997) → senescing stands of cottonwood, few younger age classes (D. Graf, pers. comm.)
        - Recommendation: release appropriately timed, high magnitude (i.e., overbank) flows from McPhee dam in high snowpack years to benefit disturbance tolerant species (e.g., cottonwood)
- Changes in low flows:
    - 1, 3, and 7 day minimums have increased at Bedrock from 230-590% (<10 cfs to >30 cfs)
    - Similar pattern, smaller magnitude change at Cisco
- Likely effects of changes in low flows:
    - Increase in hydrophytic vegetation along channel margins (e.g., rushes, sedges)
    - Increase in extent of fluvial wetlands; increased diversity, productivity, forage, and habitat for insects, birds, mammals
    - In conjunction with decreased high flows, facilitated encroachment of sandbar willow
    - Increased water table → reduced water stress in phreatophytes farther from channel (cottonwood, willow, tamarisk)
        - Recommendation: do not reduce low flows unless high flows are restored; would cause reductions in the extent of wetland communities (shift towards channel or replacement by drought tolerant species)
- Changes in timing and rate of change in flows:
    - Most of peak flows have been inappropriately timed for coinciding with cottonwood seed release (late May – early June), most peaks occurred in April (all except 1967 and 1987, which occurred in early to late May)
        - Recommendation: time peak to be within the window of historic peak flows (median pre-dam peak = May 18); rate of stage decline should not be > 2.5 cm per day during and after period of cottonwood seed release (Rood et al. 2005); finer sediments can withstand higher rates of drawdown, coarser sediments require lower rates of drawdown; should calculate stage decline for areas of likely cottonwood recruitment (i.e., areas with bare alluvial patches)

Oliver, A., C. Anderson and R. Anderson. 2010. Baseline field investigations, science-base opportunities and potential tools for improvement of the downstream environment on the lower Dolores River. Report Submitted to the Colorado Water Conservation Board in Fulfillment of the 2008/2009 Severance Tax Trust Fund Grant Awarded to the Dolores River Dialogue. http://ocs.fortlewis.edu/drd/pdf/DRD%20Big%20Gypsum%20Monitoring%20Site%20Grant%20Report.pdf

- Review of Adam Coble masters thesis (study from 2008-2010)
        - Radial growth rates of narrowleaf cottonwoods has decreased since 1985
        - Invasive species increase downstream

        - See Table 3, Tamarisk Coalition field inventory sampling data (2010): Mcphee to Colorado River confluence
        - Focus on cottonwoods
- Floods play large role in establishment and survival of cottonwoods
- Riparian specialists: dependent on flows, more sensitive to changes in flows than other species
- Limited cottonwood seedling establishment and survival since dam construction, due to
- Availability of areas of bare moist sediment (Need to germinate; timing of seed release coincide with snowmelt and overbank flows)
- Levels of salinity in sediments
- Rate of soil moisture recession
- Subsequent scouring
- Competition
- Flow hypotheses:
        - 1) Peak flows > 2000 cfs for > 7 days every 1-2 yrs or on a 10 yr recurrence interval (Richard and Anderson 2007)
    - Will support cottonwood establishment and maintain riparian diversity
        - 2) In yrs when peak > 2600 cfs, spill drawdown rate below threshold for cottonwood establishment will improve seedling survival
        - 3) Channel and floodplain resetting flows > 5000 cfs at a 20-yr recurrence (or more frequent)
    - Will create new sites for colonization, reducing channel narrowing and armoring, recharge and rinse floodplain soils, promote riparian diversity
        - 4) Timing peak release within range of historic peak flows
    - Will support cottonwood establishment and reduce comptetion from Tamarisk

- Management hypotheses:Active and passive control of tamarisk
    - Will open up new regeneration sites for riparian species
    - Will reduce competition for regeneration sites

Bottom line (possible relevance to native fish)

Encroachment of tamarisk and willow may be reason for channel incision at Bedrock gage, perhaps narrowing in some places, may result in channel simplification and habitat homogenization

Reduced cottonwood growth in favor of hydrophytic rushes and sedges, plus reduction in frequency of overbank flooding, may reduce wood recruitment into channel, with subsequent effects on physical complexity and cover

Vegetation establishment on bars plus reduced flooding may reduce amount of spawning habitat during high flows

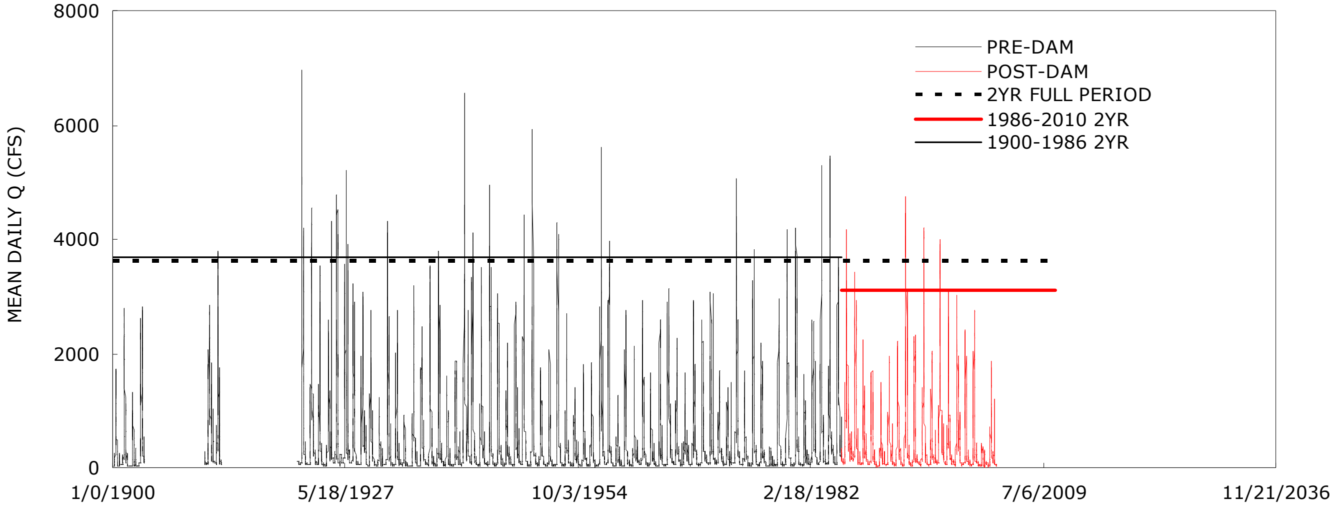
Geomorphology

Additional plots

Hydrologic records demonstrating changes in peak flows, baseflows, flood frequency, and flow duration
Bedrock gage data illustrates trends, plots from Dolores, McPhee and Slickrock gages show lack of change upstream of dam and changes closer to the dam.

Figure B4: Mean daily discharge for gages on the Dolores River. Horizontal lines are the 2-year flood discharges for the two gages/periods

Dolores River near Dolores (upstream from McPhee Reservoir)



Dolores River near McPhee (1938-1952) and Slickrock (1997-2011), downstream from McPhee Dam. Discharge is normalized by drainage area at each gage.

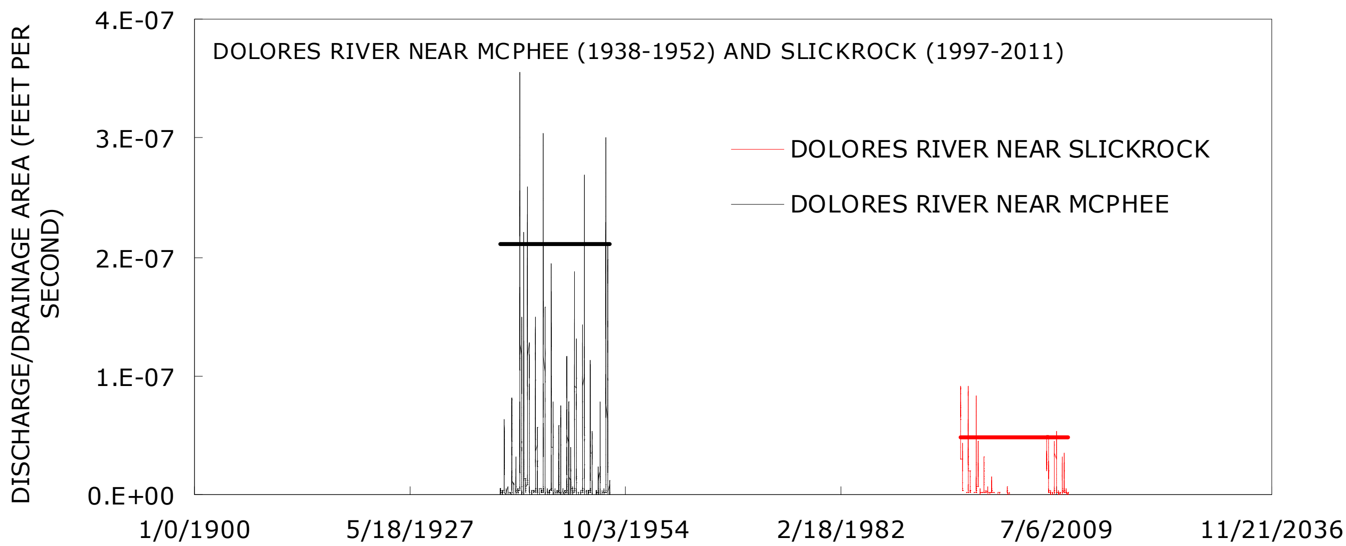
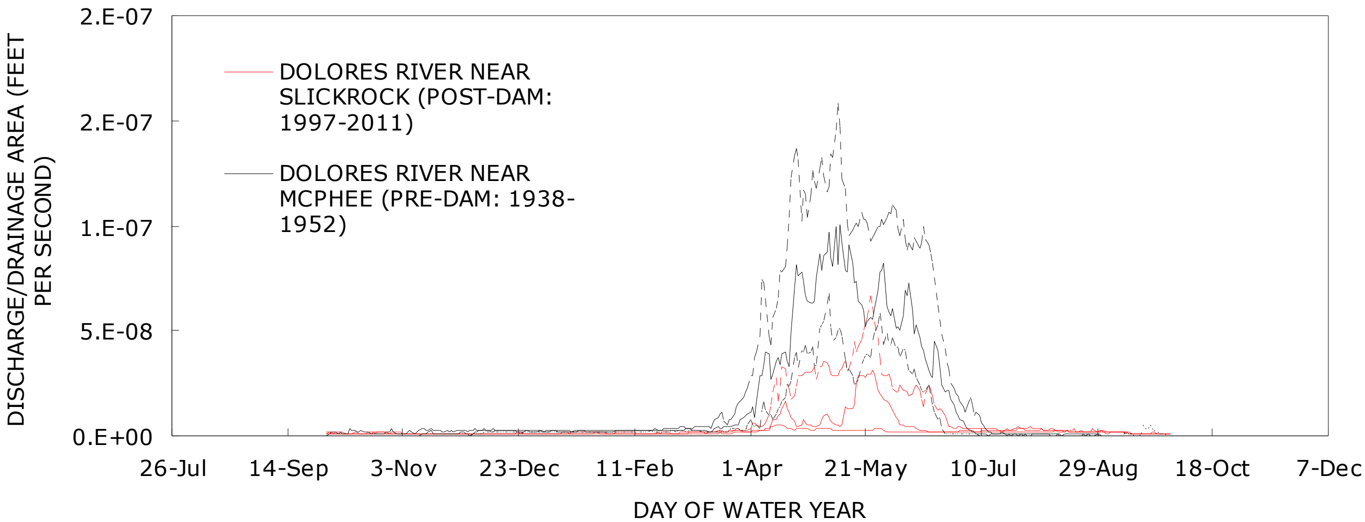


Figure B5: Median annual hydrographs for gages on he Dolores River, for pre- and post-dam periods. Dotted lines are 25th and 75th percentiles.

Dolores River near McPhee (1938-1952) and Slickrock (1971-2011). Discharge is normalized by drainage area at each gage. Second plot has smaller scale on y-axis to show differences in base flow between periods.



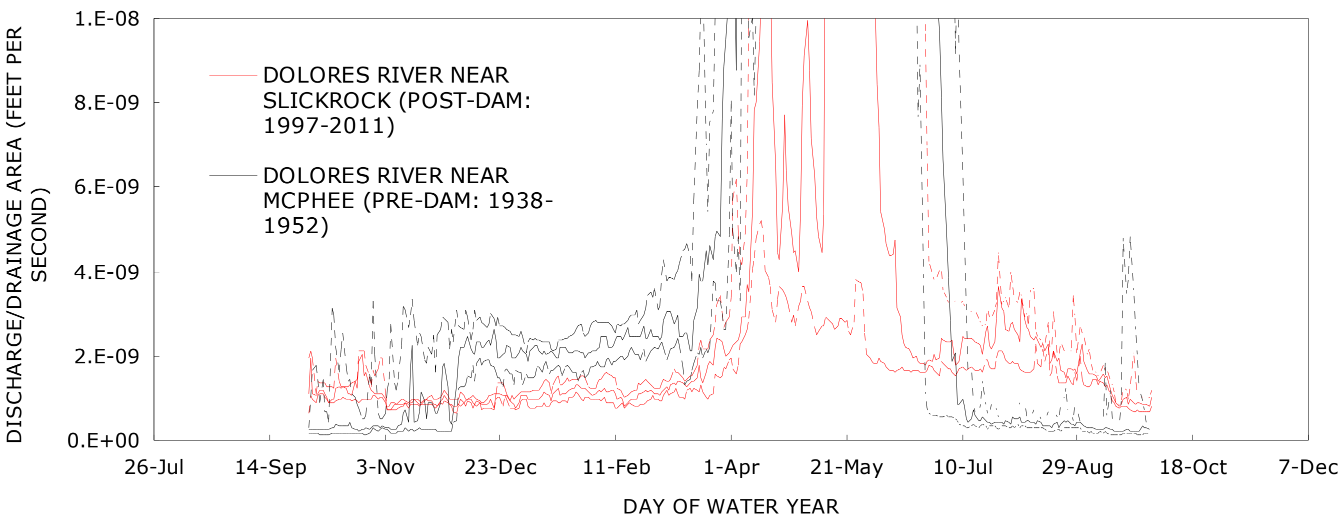
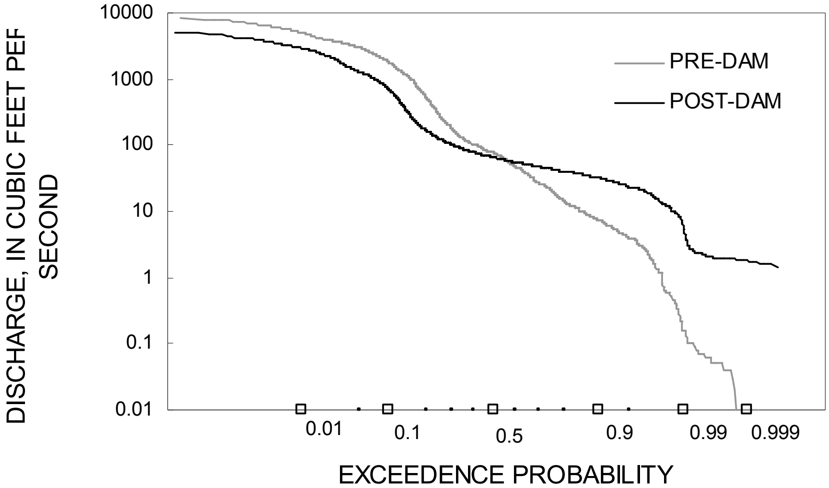
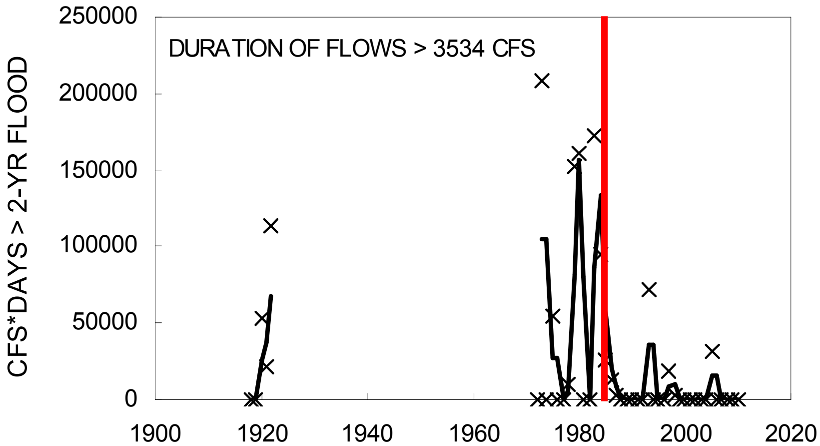


Figure B6: Flow duration curves for Dolores River at Bedrock gage: A) Proportion of time that a given flow is equaled or exceeded; B) number of days multiplied by the mean daily flow on each day that flows exceeded the 2-year flood discharge (3534 ft^3/s) in a given year. Trendline is moving average with 2-year period; vertical red line indicates year of completion of the McPhee Reservoir (1985).





Geomorphic data from Bedrock gaging station (bed elevation time series and hydraulic geometry plots)

- Evidence that the channel has incised since construction of McPhee Dam at Bedrock gage location (bed elevation time series)
    - Incision not due to alteration of sediment regime by the dam; the gage is located > 50 miles downstream from the dam, whereas incision is normally restricted to reaches directly downstream).
    - Furthermore, gage location is below inputs from numerous tributaries, including Disappointment Creek, which supplies large amounts of sediment to the mainstem Dolores River.
    - Basic geomorphic principles would predict that a reduction in sediment-mobilizing flows by the dam and large amounts of sediment supplied from tributaries would result in bed aggradation
    - However, the reduction in the frequency of overbank flows by the dam has led to encroachment of the channel margins by vegetation that was historically removed during large floods. Reach is described as "dominated by tamarisks", "broad and flat", with "high amounts of fine sediment accumulation" (DRD Core Science Report 2005). Establishment of vegetation on lateral bars during low flows can force high flows into a narrower channel, promoting incision and an increase in flow depth to maintain channel capacity.
    - An indication of this pattern of vegetation establishment followed by bed incision can be seen in the time series of bed elevation and daily flows; the most significant period of incision occurred between 1993 and 1996, following an extended period of drought (annual peak flows from 1988 to 1992 were only ~1000 cfs). During drought periods, lateral bars of fresh sediment become exposed and vegetation can establish. An extended period without overbank flows allows vegetation to grow without disturbance, reaching a density great enough to withstand higher flows and stabilize the channel margins. When high flows return, as occurred in late spring of 1993, the narrower channel must accommodate the increase in discharge by incising.
    - Incision occurred in the period following very high flows in 1993 (4550 cfs) and a second high flow event in 1995 (3140 cfs), with the bed dropping ~ 0.5 ft in the ~6 months following each storm
    - Channel incised following drought of 1988-1993, but was stable following low flows of 2000-2004, possibly because vegetation had fully established
    - Although this is a great theory, we need additional information about the history of vegetation encroachment at this and other locations. An aerial photograph record could be used to evaluate changes in vegetative cover and channel width.
    - Current description of cross-section (from USGS station description): "Both the right and left banks are moderately steep and brush lined and act as the high flow control and contain the flow to high stages. Banks are not subject to overflow except under extreme flooding conditions and the highway bridge may act as the control under these circumstances. The river bottom in the pool has several large boulders, but most of the cross section is faced with gravels, sands, and silts."
    - Problems with theory:
        1. Time series and hydraulic geometry plots of width show channel widening, not narrowing, during this period
        2. Hydraulic geometry plot shows no change in depth (so channel got lower, but not deeper)
        3. Odd how in the post-dam period of incision, the bed actually aggraded during the storm and incised in the 6 month period following the storm, whereas in the pre-dam period the bed scoured and filled more regularly and not in direct relation to flow (scour generally during the flood, aggradation during low flows or on the falling limb of a flood)

- Note that we don't observe long-term changes in bed elevation or hydraulic geometry at the USGS Slickrock gage (1997-2003; 2008-present) or the CDWR gage at McPhee 2000-2009), but this may be due to the incompleteness or shortness of the records. Neither gage was in operation immediately following dam construction or during the period when incision occurred at the Bedrock gage (1993-1995). We therefore cannot determine whether the bed adjusted to changes in flow and sediment prior to installation of the gages. We might expect incision to occur immediately downstream of the dam, due to the trapping of sediment by the dam. Farther downstream, sediment supply increases due to tributary inputs, such that the bed would likely aggrade due to the reduction in sediment-mobilizing flows by the dam.

Figure B7: Time series of bed elevation plotted with (a) mean daily discharge and annual peak flow and (b) flood duration at Bedrock gage.

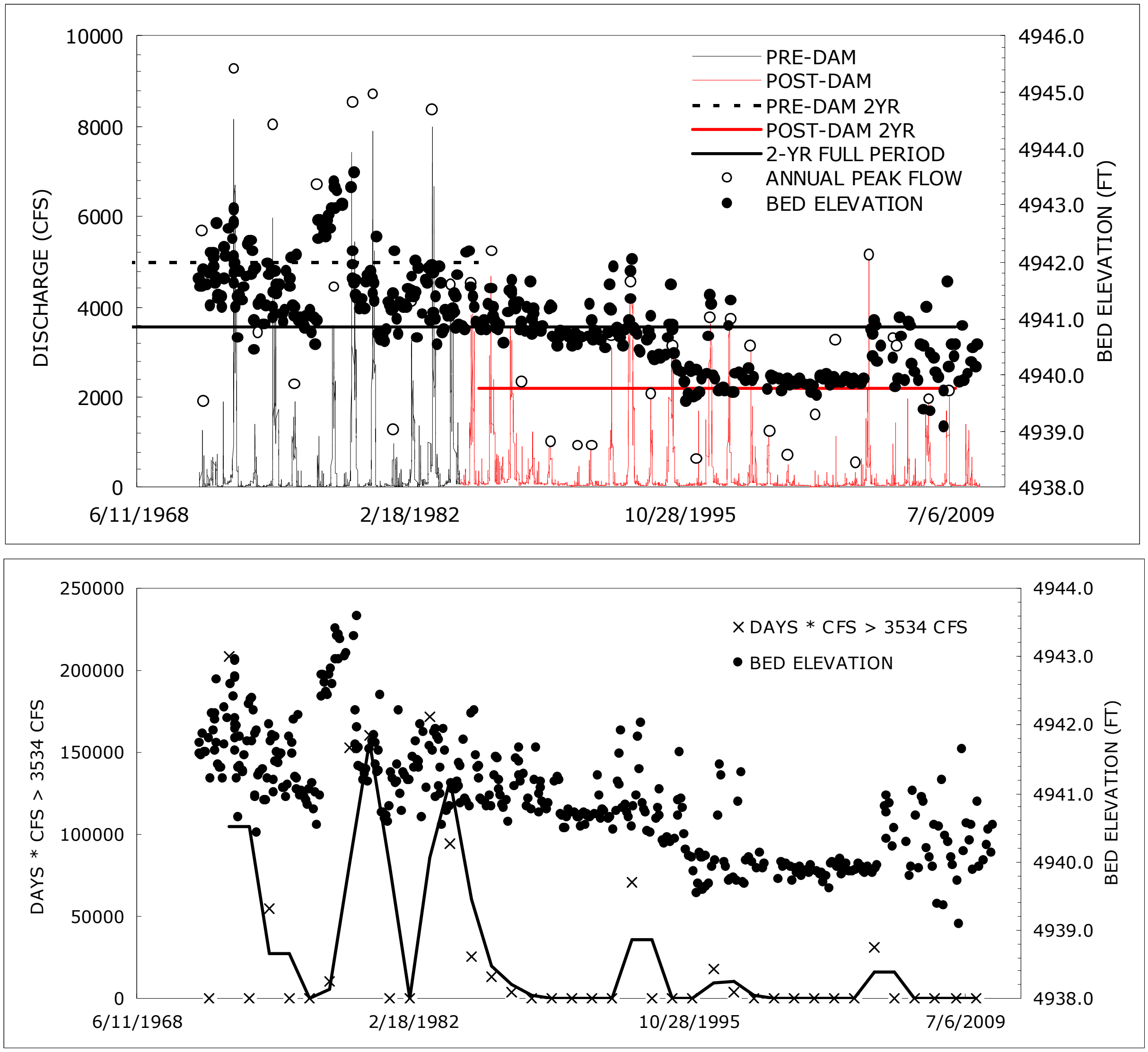
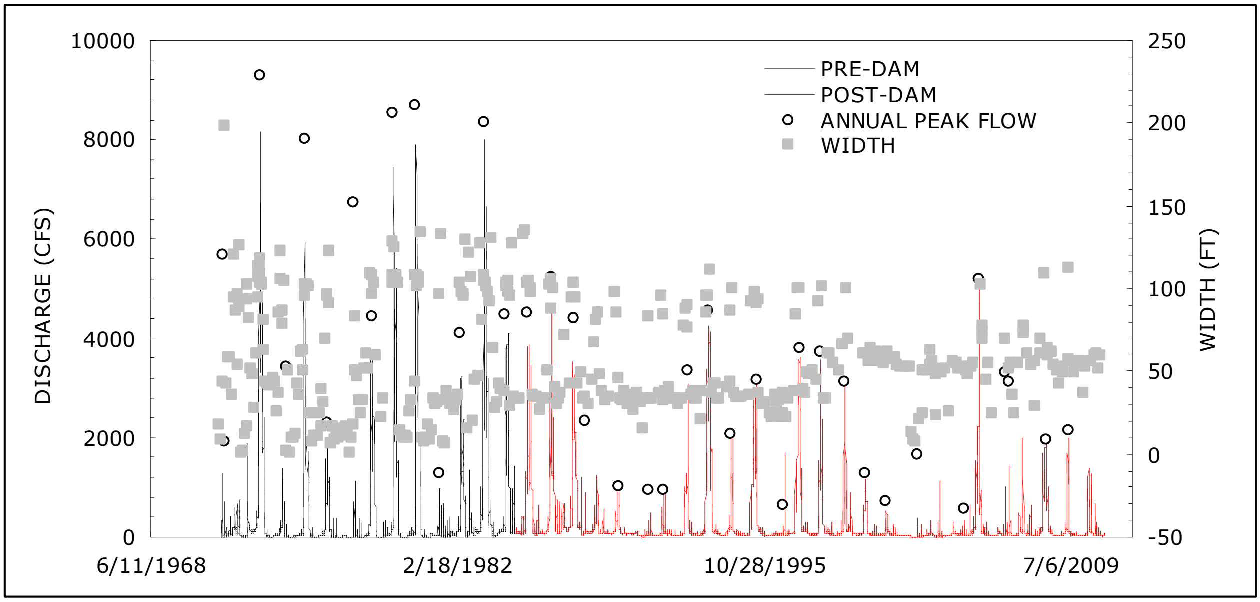


Figure B8: Time series of channel width plotted with mean daily discharge and annual peak flow at Bedrock gage. Second plot shows widths only for discharges between 30 and 250 cfs.



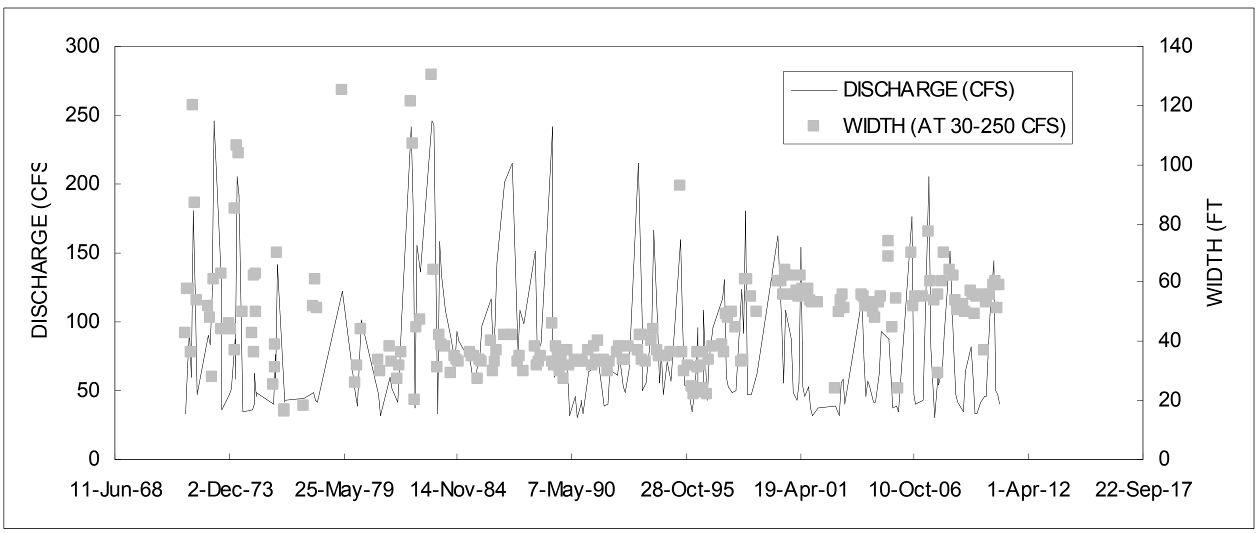


Figure B9: Plot of bed elevation, mean daily discharge, and annual peak flow for a six year period in the post-dam era, showing aggradation during high flows.

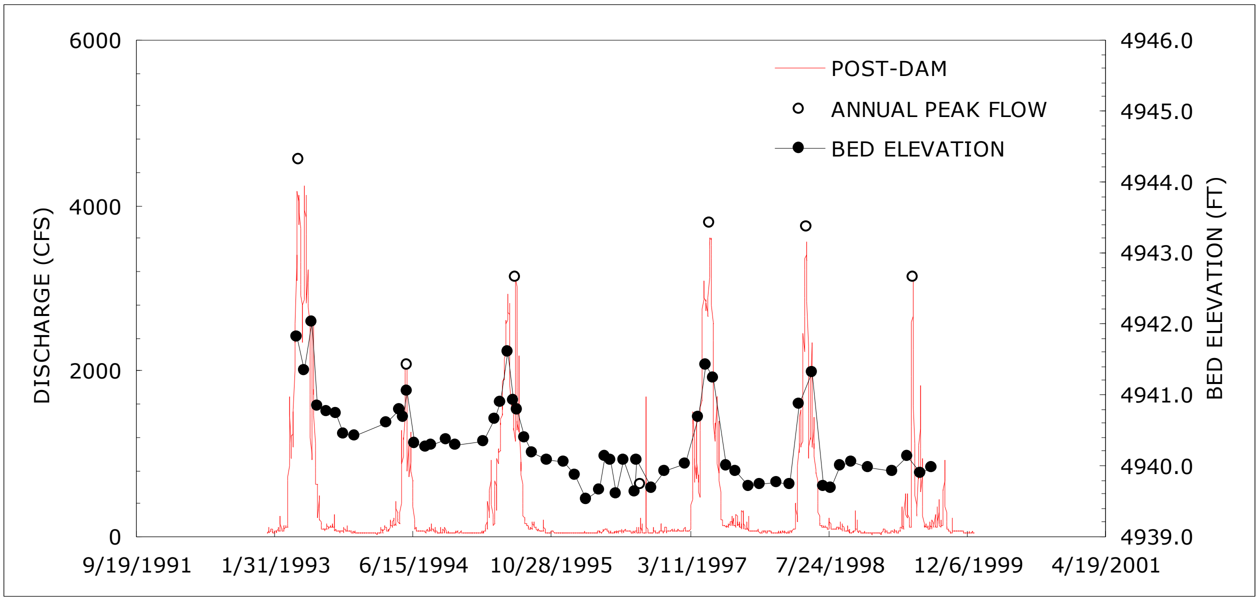
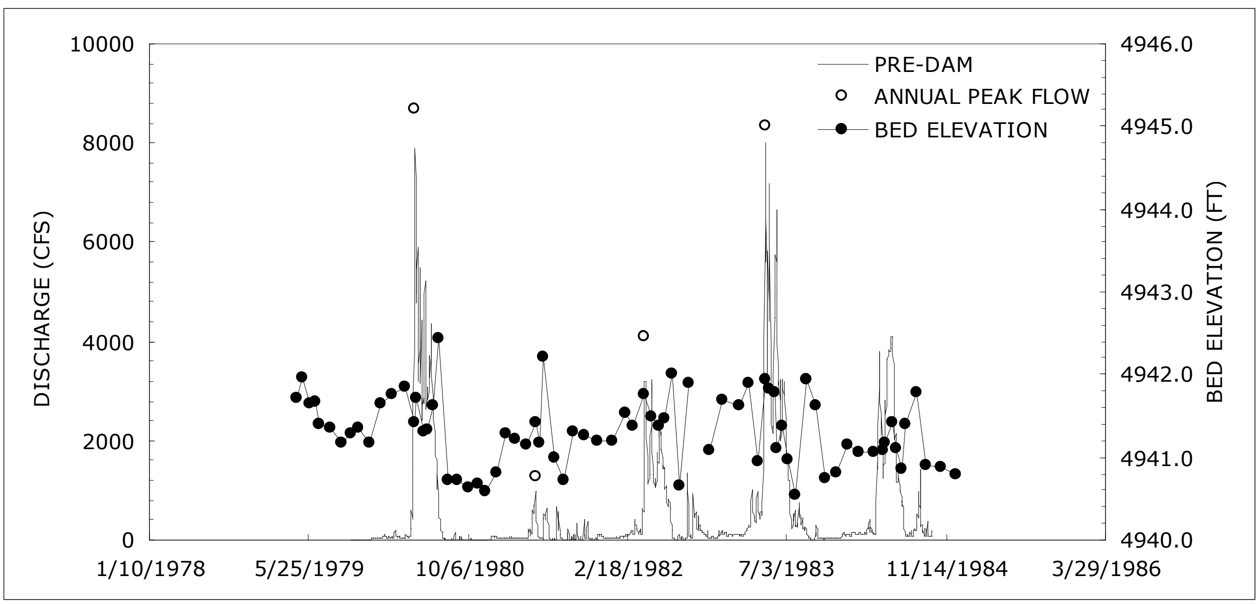


Figure B10: Plot of bed elevation, mean daily discharge, and annual peak flow for a six year period in the pre-dam era, showing no relation between flow level and bed elevation. only



Appendix C: Summary of life history requirements for native and trout species

Table C1: Flannelmouth sucker life history characteristics

	Spawning[1,2]	Larva	Juvenile	Adult[3,4]
Substrate	Sand to gravel		Silt to gravel	Suitable: Sand to coarse gravel Preferred: Coarse substrates
Depth	Shallow			61-80 cm*
Velocity			Lower velocity than adults	> 0.81 m/s*
Habitat	Sand-gravel bars	Backwater and shoreline habitats	Backwaters, eddies, side channels, and shallow riffles	Moderate to deep areas with cover (pools, lower parts of glide or pool)[5]
Temperature	Suitable: 6-18.5 °C[6]			Suitable: 10-27 °C Preferred: 25.9 °C[7±]
Diet[8]	----	Chironomids, copepods, phytoplankton, organic detritus	Terrestrial seeds and plant debris, algae, aquatic invertebrates, phytoplankton, organic detritus	
Migration	May or may not migrate to spawn depending on habitat availability and homing behavior; only use limited number of sites; may move long distances to find suitable habitat	Drift along shoreline adjacent to swift areas or congregating along edges of shallow pools Drift during night	Long distance movements (up to 230 km) documented but not widespread. Generally center around home range (mainstem and tributary habitats);small localized movements during day and night[9] Larger individuals more sedentary	
Non-natives	----	Predation by red shiners in shoreline and backwater areas~	Predation by northern pike, channel catfish, and smallmouth bass~ Competition with white sucker~	
Hybridization[10]	Adults hybridize with five other spp. (including non-native white sucker); some evidence for fertile hybrids			

Notes:

[1]Spawning: Typically in May-June (in UCRB); may also spawn in late summer or fall; 6-week or longer period
[2]Incubation: 6-7 days at 15.5-17.8 C
[3]Maturation: 4-6 yrs; 400-500 mm; 1.5 kg
[4]Life span: 15 yrs or more
[5]Adults can also be found in fast currents (riffles, runs)
[6]Temperature is primary spawning cue; examples of spawning in tributary mouths during high flows because of warm, ponded conditions
[7]Cold waters limit distribution at high elevations†
[8]Omnivorous; diet depends on life stage and food availability
[9]Long migrations not common but may be important for maintenance of isolated headwater populations
[10]Impact of hybridization unknown

Table C2: Bluehead sucker life history characteristics

	Spawning[1,2,3]	Larva	Juvenile	Adult[4]
Substrate	Gravel beds; shallow redd excavated in gravel			Coarse gravel to small cobble[*]
Depth	Shallow water	Shallower than adults		1-20 cm[*] Large adults: Up to 2-3 m
Velocity		Low velocity		> 0.81 m/s[*] Moderate to fast current
Habitat		Shoreline and backwater habitats		Shallow, fast Large adults: Deep cover, undercut banks
Temperature	15.6-24.6 °C		Preference: large, cool streams (< 20 °C) Tolerate: warm, small creeks (up to 29 °C)	
Diet		Dipteran larvae, diatoms, zooplankton	Benthic algivores or facultative herbivore (algae, organic and inorganic debris, small aquatic insects from rocks and boulders)	Benthic algivores or facultative herbivore (algae, organic and inorganic debris, small aquatic insects from rocks and boulders)
Migration		Drift in current		Limited movement; small, localized movement during day and night (maximum recorded = 35 km)
Non-natives	----	Predation by red shiners in shoreline and backwater areas[Φ]	Predation by northern pike, channel catfish, and smallmouth bass [Φ] Competition with white sucker [Φ]	
Hybridization[5]	Adults hybridize with 3 other spp.; bluehead-white sucker (non-native) hybrids common			

Notes:

[1]Typically spawn in spring and early summer (low elevations) and mid-late summer (high elevations); in some rivers (e.g., Colorado) there is a protracted spawning season from February to October
[2]Fecundity: varies with fish size and environmental conditions (5,000-20,000 eggs)
[3]Incubation: 7-8 days at 15.6-17.7 °C
[4]Maturation: size varies with stream size; 90-200 mm standard length
[5]Impact of hybridization unknown

Table C3: Roundtail chub life history characteristics

	Spawning[1]	Larva	Young-of-year	Juvenile	Adult[2,3]
Substrate	Gravel			Found: fine sand to boulders; most often: sand-gravel	Prefer: Sand to coarse gravel[*] Tolerate: fine sand to boulders and bedrock[§]
Depth	31.6 cm (average)[≈]				61-80 cm[*]
Velocity	0.44 m/s (average)[≈]		< 0.61 m/s	< 0.61 m/s	0-0.2 m/s[*]
Habitat	Deep pools and runs	Low velocity backwaters	Shallow, low velocity	Pools, below riffles or formed by debris on margins[¥]	Deep, slow pools[*], with access to feeding areas
Temperature	Tolerate: 14-24°C Prefer: 18-20 °C[4,5]		Critical thermal maxima: 30.5-39.5 °C Critical thermal minima: 7.7-<1 °C Prefer: 20-24 °C (for fish acclimated at 8, 24, and 30 °C)[¢]		Tolerate: up to 32 °C
Diet	Omnivorous: diet depends on life stage and food availability	Diatoms and filamentous algae[¤]		Chironomid larvae and ephemeroptera nymphs; but may also include algae[6], tricpterans, and ostracods	Opportunistic predator[7] (aquatic insects, crustaceans, fish, plant matter, snails, ants, beetles, crickets, grasshoppers, lizards)
Migration	Spawning movements of 5-80 km reported	Drift in current or move to backwater areas to feed			Small, localized movements during day and more extensive movements at night Seasonal movements to new habitat in some systems, not all
Non-natives	---		Predation by red shiners[¦]	Competition with virile crayfish[»] and channel catfish[£]	Predation by channel catfish[**]
Hybridization[8]	Strong evidence for hybridization among Gila spp.: Spatio-temporal overlap of spawning Occurrence of mature fish with characteristics intermediate between species Hybrid crosses produced in hatchery				

Notes:

[1]Fecundity: varies with fish and stream size
[2]Maturation: 3-5 yrs, 150-300 mm length
[3]Life span: 8-10 yrs (larger systems); less in smaller tributaries
[4]Temperature most significant factor associated with onset of spawning
[5]Incubation: 4-7 days at 19 °C
[6]Plant matter generally consumed for epiphytic organisms
[7]Average gut length: standard length = 0.99:1; suggests largely carnivorous diet[#]
[8]Strong evidence for hybridization among Gila spp., but still some debate over factors responsible for morphologic intergrades

Citations: All information from Bezzerides and Bestgen (2002) unless otherwise indicated

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Table C4: Comparison of habitat, flow, and temperature needs for trout and native fish in the Dolores River.

	Spawning	Adult	Source
Trout			
Habitat characteristics	Head of riffle or downstream edge of pool Clean gravel 1.5-5 cm particles, 0-20% fines	Slow, deep pools with cover (logs, boulders) Optimal depth: 45 cm	Raleigh et al. (1984) Raleigh et al. (1986)
Base flows	----	40 to 80 cfs (Dry/wet years)	Nehring (1992) Dolores River Biology Team (1993)
Peak flows	125 cfs (Rainbow/spring) 65 cfs (Brown/fall-winter)	----	Nehring (1992)
Temperature	Suitable: 12-17 °C[1] Optimal 12 °C	Suitable 3-25 °C[2] Optimal 12-18 °C Growth ceases at 19°C	Raleigh et al. (1984) Raleigh et al. (1986)
Three species			
Habitat characteristics	Flannelmouth: Shallow, sand-gravel bars Bluehead: Shallow, gravel bed Roundtail: Deep pools and runs; gravel	Flannelmouth: Moderate to deep areas with cover (pools, lower parts of glide or pool); can be found in riffles and runs Bluehead: Moderate to fast current; coarse substrates Roundtail: Deep, slow pools with cover; sand to gravel	Bezzerides and Bestgen (2002)
Base flows	----	All: 50/78 cfs (dry/spill years) Flannelmouth: 60/80 cfs (dry/spill years)	Valdez et al. (1992) CDOW (2010) Oliver et al. (2010)
Peak flows	Simulate pre-dam hydrograph (gradual rising and falling limb) Declare spill earlier and start low volume spills 100-1000 cfs in 60 days before spawning Ramp down from peak flows slowly	----	Valdez et al. (1992) CDOW (2010) Oliver et al. (2010)
Temperature	Flannelmouth: 6-18.5 °C Bluehead: 15.6-24.6 °C Roundtail: Suitable: 14-24 C; Prefer: 18-20 °C	Flannelmouth: Suitable: 10-27 °C; Prefer: 25.9 °C Bluehead: Prefer: < 20 °C; Tolerate: up to 29 °C Roundtail: up to 32 °C	Bezzerides and Bestgen (2002)

Notes: [1]Average maximum water temperature during embryo development; [2]Average maximum water temperature during warmest part of year

Appendix D: Characteristics of DRD reaches on the Lower Dolores River

Reach	Morphology	Riparian vegetation	Notes
(1) McPhee Dam to Bradfield Bridge	12 miles Low gradient, wide valley, meandering pool-riffle sequences	Mixed deciduous: cottonwood, box elder, willow	"Catch and release" area, focus of baseflow management
(2) Bradfield Bridge to Dove Creek Pumps	19 miles Steeper gradient, bedrock outcrops and boulders (colluvial)	Ponderosa pine woodland, willows and oaks along stream	Naturally reproducing brown trout population; no native suckers in 2005
(3) Dove Creek Pumps to Joe Davis Hill (9 miles)	9 miles Steep gradient, confined, large boulders; valley broadens downstream	Ponderosa pine/box elder, old cottonwood stands on terraces; downstream change to willow and sedge along river, pinion-juniper upland	Sampled since 1986: declining suckers, variable roundtail, recently increasing green sunfish
(4) Joe Davis Hill through Big Gypsum Valley	38 miles Relatively flat	Sage, rabbitbrush, greasewood in stream corridor, increasing tamarisk downstream; riparian willow-sedge, increasing phragmites sp. Downstream; occasional silver buffaloberry (native)	
Three subreaches:			
(4a) Joe Davis Hill to Disappointment Creek	Confined, colluvial and bedrock controls		
(4b) Disappointment Creek to Big Gypsum Valley	Confined, but high sediment load from Disappointment Creek		
(4c) Through Big Gypsum Valley	Alluvial, narrowing and incision due to vegetation establishment on fresh sediment	Tamarisk, willow, phragmites	No trout, not considered cold water fishery
(5) Big Gypsum Valley to Wild Steer Canyon: Slickrock Canyon	42 miles Low gradient, high sinuosity, confined	Distinct shift from box elder, New Mexico privet and willow to tamarisk-dominance; few spring-fed cottonwoods	Not sampled since 1992, when relatively complete native fish assemblage existed
(6) Wild Steer Canyon to San Miguel River: Paradox Valley	12 miles to Saucer Basin Flat and wide, high salt concentrations and fine sediment accumulations; last few miles upstream of San Miguel: broad, but confined, increased gradient, channel complexity	Dominated by tamarisk	Poor native fish habitat, except in last few miles

Notes: from DRD Correlation Report, 2006

Phase I Report

Status and Trends of Native Roundtail chub (*Gila robusta*), Flannelmouth sucker (*Catostomus latipinnus*), and Bluehead Sucker (*Catastomus discobolus*) in the Dolores River downstream from McPhee Dam.

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Lower Dolores Plan Working Group – Legislative Committee

May, 2011

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Executive Summary

The main objective of this report was to determine the status and trends of three native species in the Dolores River downstream of McPhee Dam. These species are roundtail chub (*Gila robusta*), flannelmouth sucker (*Catostomus latipinnus*), and bluehead sucker (*Catastomus discobolus*). There were two main questions posed for the review. These were:
1) What is the current status and trend of each species of Native Fish?
2) How can the status of each Native Fish be improved?

The response to the first question includes a description of my recommendations for what is needed to improve the status of each species. In addition, opportunities for improvement were identified for various management options including: spill management, base flow management, thermal regime, and reduction of competition and predation from non-native species.

I reviewed and borrowed heavily from existing reports, publications, unpublished data and analyses from a variety of sources including but not limited to: Dolores River Dialogue, United States Geological Survey, and Colorado Division of Wildlife. These reports and data included material on hydrology, geomorphology, fish sampling, water quality, water temperature and habitat for the Dolores River. In addition, materials from other studies in the species range were consulted.

The three species were common to rare prior to construction of McPHee Reservoir. The native suckers were present after closure of the dam but limited to large adult size classes. The roundtail chub has persisted but at low levels. All three native species have declined over the past 25 – 40 years. The sharpest decline has occurred in the past 20 years. Reasons for the decline potentially include:

- Changes to peak flow timing, magnitude and duration
- Changes to the thermal regime which changed a warm water habitat to a cold water habitat and possibly truncated the species range
- Habitat fragmentation and isolation of individual populations that once may have functioned as a meta-population in the Dolores River.
- Habitat loss due to increased sediment deposition without adequate flows for sediment transport and channel maintenance.
- Competition and predation from non native cold water and warm water fish species

Opportunities for improvement of native fish populations and persistence of native species would depend on several factors. These include:

- Successful reproduction on an annual basis
- Successful recruitment from larval and juvenile age classes to successive age classes at a rate higher than natural mortality and predation.
- Demonstration of successful recruitment would be stable or increasing native fish populations.

Alternatives for improvement include:

1) A peak flow regime that more closely mimics a natural pattern as seen upstream of McPhee Reservoir. This could include:
    - An earlier peak release such as early May.
    - Sufficient peak flow magnitude for sediment transport and habitat maintenance.

2) Base flow enhancement that mimics upstream base flow conditions and follows the recommendations from earlier studies. Base flow alternation may not be as limiting as the lack of peak flows.

3) A thermal regime that provides warmer water downstream of the dam. This would provide several benefits:
    - It would provide the natural cues for native fish.
    - It would disadvantage the non native cold water fish and could reduce competition and predation on native fish.
    - Provide better conditions for growth of native warm water fish.

4) Removal of both cold water and warm water non native fishes. This would reduce competition and predation on native fishes. The removal may include mechanical, chemical or management (removal of harvest limits and actively encourageing harvest).

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Introduction

The main objective of this report is to determine the status and trends of three native species in the Dolores River downstream of McPhee Dam. These species are roundtail chub (*Gila robusta*), flannelmouth sucker (*Catostomus latipinnus*), and bluehead sucker (*Catastomus discobolus*). The Scientific and Water User Panel (the Panel) generated a list of questions to be addressed in this review. In addition, the Panel provided access to a body of information on the Dolores River. This body of information was supplemented with other information researched or identified by myself. This Phase I report documents my findings on the status of the Native Fish in the Lower Dolores River (Reaches 1-6) and opportunities to improve their status.

These findings were presented orally on April 6th and April 7th, 2011 in a meeting with the Panel in Cortez, Colorado. This Phase I report will be used to develop a range of alternatives to improve the status of the native fish and coordinate with the other Science Contractors to develop a joint report. The joint report will be presented to the Panel on June 7th, 2011.

Priority Inquiry Questions to Address

The following list of questions and topics are the focus of this review. The study area of interest for this report is in Reaches 1 through Reach 6 as defined by Dolores River Dialogue (DRD) (Figure 1). The question list was cited in the original "A Way Forward" Work Plan. In some cases, the questions were expanded upon to provide more detail.

Native Fish Status:

1) What is the current status and trend of each species of Native Fish?

- Roundtail Chub, specific to reaches 1 through 6
- Bluehead Sucker, specific to reaches 1 through 6
- Flannelmouth Sucker, specific to reaches 1 through 6

· Describe what status would be needed to ensure the Native Fishes persistent presence in the river?

2) How can the status of each Native Fish be improved? What are the best management options and do-able alternatives?

Opportunities for Improvement:

Opportunities for improvement in the status of the native fish were addressed using the available information provided by the Legislative Subcommittee along several fronts including but not limited to the following:

- · Spill management
- · Base pool management at different levels
- · Reduced predation and/or competition from non-Native Fish
- · Water quality
- · Riparian ecology
- · Identification of Dolores River reaches where improvement opportunities are most desirable and most feasible

Methods

I reviewed and borrowed heavily from existing reports, publications, unpublished data and analyses from a variety of sources including but not limited to: Dolores River Dialogue, United States Geological Survey, and Colorado Division of Wildlife. These reports and data included material on hydrology, geomorphology, fish sampling, water quality, water temperature and habitat for the Dolores River. In addition, materials from other studies in the species range were consulted.

Results

Fish populations are highly dependent on both the physical processes and biological responses to those processes for their persistence. The physical environment; channel characteristics, substrate, stream slope, and discharge together provide the boundary space for the animals that live within that environment. By first understanding the limits of the physical environment within the river, one can better determine the potential factors that limit fish populations. An understanding of the current physical environment in the Dolores River is important in answering the two primary questions for this review. The physical environment discussed here includes geomorphology, hydrology, and water quality (chemical and temperature).

Geomorphology

The river segment of interest for this review is from McPhee Dam downstream to the confluence with the San Miguel River (Figure 1). This river segment was divided into six separate reaches (DRD 2006), which are:

Reach 1 – Dam to Bradfield Bridge (12 miles). This reach is relatively low gradient with pool riffle sequences and is typical of alluvial rivers.
Reach 2 – Bradfield Bridge to Dove Creek Pumps (19 miles). This reach has a steeper gradient and bedrock and boulders control much of the channel.
Reach 3 – Dove Creek pumps to Joe Davis Hill (9 miles). This is also a steep reach confined by canyon and boulders.
Reach 4 – Joe Davis Hill to Big Gypsum (38 miles). This is a lower gradient reach with several different characteristics from bedrock controls in the upper portion to alluvial in the lower portion.
Reach 5 – Big Gypsum to Wild Steer Canyon (42 miles). This is a low gradient, highly sinuous reach but controlled by canyon walls.
Reach 6 – Wild Steer Canyon to Saucer Basin (12 miles). This is a low gradient reach that crosses Paradox Valley and has high concentrations of salts.

The total river distance for these six reaches is approximately 132 miles. Most of the river channel from the dam downstream to the San Miguel River confluence is confined by canyon or steep topography. Some of the reaches exhibit characteristics of low gradient alluvial streams with some potential to move laterally on the flood plain but most reaches are either controlled by bedrock, large boulders or canyons (Table 1). Lateral movement in these confined reaches would not be likely.

Channel and sediment movement are important components of creating, providing and maintaining habitat for riverine species. Regular sediment transport is necessary to provide habitat for periphyton and macroinvertebrates, which are food web resources relied upon by fish. Sediment transport also removes fine material that can be detrimental to spawning habitat of both cold water and warm water species.

Hydrology

McPhee Reservoir was constructed during 1983 through 1984 and began full operation in 1986 (Voggesser 2001). Prior to the construction of the reservoir, the peak flows during runoff were a function of each year's snowmelt conditions. Dolores River discharge at Dolores are regularly 3000 cfs and higher with average daily peak flows of approximately 5,000 cfs (Figure 2).

The reservoir storage and controlled releases from the dam are evident in the records for the Bedrock gage. Prior to construction of McPhee dam, the peak discharges regularly exceeded 6,000 cfs with peak flows exceeding 8,000 cfs (Figure 3). After construction and operation of McPhee dam, peak flows only occasionally exceed 4,000 cfs. The reductions in peak flow occurrence and duration have a direct impact on the ability to transport sediment and create and maintain riverine habitat. The estimated bankfull discharge at the Bedrock gage site is estimated at 3,058 cfs (Richard and Wilcox 2005).

The main changes in the average daily flows occur during the runoff period. The runoff is truncated with storage and the peak release shifted to later in the runoff (Figure 4). Late summer base flows are higher since the operation of the dam began than prior to the dam. Dolores River flow prior to construction of the dam could be at or near zero due to direct diversions for irrigation.

The shift in peak flow timing is also evident in the annual pre dam hydrographs, which show the higher flow years have earlier peak flows (Figure 5). The post dam hydrographs show that the peaks are more evenly distributed or later in runoff than pre dam (Figure 6). Timing of peak flow can be an important spawning cue for fish. Flannelmouth suckers and bluehead suckers generally spawn in late April or early May with the larvae hatching in early to mid May (Brandenburg and Farrington, 2011). The increase in flow and warming water temperatures are cues for spawning. The native sucker species spawn when water temperatures exceed 12° – 13° C. Data from the San Juan River has shown that the native suckers will either cease spawning or not have viable eggs when water temperatures are less than 12° C.

Several release scenarios have been developed for the Dolores River. These release scenarios cover a range of hydrologic conditions from base flow to a large spill. The spill discharges are focused on a particular peak flow value; however, they do not have the duration of the natural peak flows. Further, the release timing is shifted to late May and early June, which is later than natural peak flows (Figure 7) (DRD 2006).

Daily flow exceedance also has changed with operation of the dam. The post dam low flows are higher than pre dam while the peak flows are reduced (Figure 8). As would be expected with reservoir storage, the peak flows are substantially lower and less frequent than pre dam (Figure 9).

Water Quality

Temperature

A major change that can occur with reservoir operations is a shift in the thermal regime. Prior to construction of the reservoir, the water temperatures were controlled by atmospheric conditions. USGS records show that water temperature reached 25° C at Dolores, which would be suitable for warm water fish and near the upper limit for cold water species, in particular, native Colorado River cutthroat trout. This suggests that the Dolores River currently occupied by the reservoir may have been a transition zone from cold water to warm water species.

Since the reservoir has been in operation, cold water is released from the dam. This change in thermal regime has suppressed the natural warming and results in cooler water temperature farther downstream than under pre dam conditions. Current average daily water temperatures upstream of Disappointment Creek are usually less than 25° C (Figure 10). Maximum water temperatures at the USGS Bedrock gage are usually higher than 25° C and occasionally higher than 30° C (Figure 11). There appears to be no influence of the cold-water release in the lower Dolores near Cisco, Utah (Figure 12).

The effect of cold-water release can be seen in the water temperature data monitored by CDOW in 2005, 2006 and 2007. Water temperature decreases slightly in 2005 during the high peak release (Figure 13). There is no apparent effect during 2006 when flows were low except for a few days (Figure 14). There is a substantial effect in 2007 that shows water temperatures decrease when discharges increase during May and June (Figure 15).

Chemistry

The water chemistry data for the Dolores River does not include long term continuous monitoring. Most of the available data is in the form of spot measurements. Previous studies have shown elevated levels of metals in Reach 6 (Valdez et al. 1992). The presence of heavy metals is also reflected by metal intolerant macroinvertebrate species in the lower river (Anderson 2007). Metal intolerant heptageniid mayflies are present in upstream river sections but absent from downstream sections including downstream of the San Miguel.

USGS (2000) studied water quality in Paradox Valley. The study reported elevated levels of salts, especially at lower flows. In addition, the Total Dissolved Solids are approximately 10,000 ppm at lower flows. This level of TDS can cause reproductive failure in some cyprinid species. The elevated levels for salts and TDS may be a deterrent to fish migration through this section of river, especially at low flows.

Biology

Invertebrates

There are sporadic data on macroinvertebrate communities in the Dolores River. Macroinvertebrates are a major food component of the native species. Both sucker species feed on invertebrates. Macroinvertebrate collections were a component of the studies conducted in the early 1990's (Valdez et al. 1992). Nehring (1993) collected invertebrate data during winter trout studies in Reach 1. Anderson (2007) collected invertebrates at multiple locations downstream from the dam. The Valdez et al. (1992) and Anderson (2007) studies provide the most complete descriptions of the macroinvertebrate community. All the studies differed in the levels of taxonomic identification. The difference in taxanomic level limits the comparisons that can be made between studies. None of the studies included a measurement of biomass.

Most rivers downstream of coldwater release dams exhibit a shift in invertebrate taxa. Generally, stoneflies and mayflies are reduced in number or absent due to the lack of seasonal fluctuation in thermal regime and the dominant invertebrate taxa are caddis flies and midges. The change in species composition may not impact the food base for fish since the productivity for these rivers sections is usually elevated by nutrients released from the reservoir. A more diverse macroinvertebrate community could provide a broader feeding opportunity for higher trophic levels.

Fish

Historically warm water fish would have dominated the Dolores River in Reaches 1 – 6. The presence of native warm water fish in Plateau Creek upstream of the dam and records of warm water temperatures support this conclusion. There may have been seasonal use by native cold-water fish.

Native fish in the Dolores River likely moved in and out of some sections of the river and possibly into the Colorado River. The native sucker species are known to have seasonal movements within rivers of many miles (Miller et al. 1995). The upper limits of use by warm water species was likely determined by the tolerance of thermal regimes. The upstream movement of these native fish may have been blocked when diversions were built for irrigation, however, the downstream migration would have continued.

Non-native warm water fish can compete with native species for resources (e.g. habitat and food) or be predators or both. The first reports of non-native warm water fish are from collections made in the 1950s (Nolting, 1959). Nolting reported channel catfish and carp present in both the Dolores and San Miguel rivers. Holden and Stalnaker (1975) collected four native (flannelmouth sucker, bluehead sucker, roundtail chub and speckled dace) and seven non-native species. Valdez et al. (1982) collected the same four native species and 12 non-native species. Valdez et al. (1992) sampled after the dam was completed and collected six native species (mottled sculpin and Colorado pikeminnow, in addition to the previous four species) and 13 non-native species. The mottled sculpin were collected in the section from Bradfield Bridge to Disappointment Creek. The Colorado pikeminnow were collected near the confluence with the Colorado River.

Valdez et al. (1992) was the most comprehensive of the early studies and employed a variety of sampling gear and was the most wide-ranging sampling up to that time. The study area for that project extended from the Bradfield Bridge downstream to the confluence with the Colorado River.

Roundtail chub were common in DRD reaches 2-6. Bluehead sucker were common downstream of the San Miguel River but less abundant in DRD Reaches 2-6 comprising 5% to 8% of the fish captured (Valdez et al. 1992). Flannelmouth sucker were most abundant in DRD Reach 6 and decreased in abundance progressing upstream through DRD Reaches 5 – 2.

Colorado Division of Wildlife (CDOW) has a long term monitoring site at the Dove Creek Pumps on the Dolores River. Data for this location extends from 1986 through 2007. The site has non-native and native fish species. Non-native smallmouth bass were first captured at this site in 2006 (CDOW data). Roundtail chub have been the dominant species captured at this site (Figure 16).

A comprehensive longitudinal survey in 2007 documented the presence of both native and non-native species in lower DRD Reach 3. This section of river is dominated by brown trout in the upper half and smallmouth bass in the lower half (Figure 17) collectively making up 97% of the fish captured. Native fishes were 3% of the catch (White et al. 2007).

The dominant species in the DRD Reaches 1 and 2 are non-native trout. Brown, rainbow and cutthroat trout were stocked from 1984 through 1988 (Japhet 1988). Brown trout stocking was discontinued in 1988 when natural reproducing populations established. CDOW continues to stock rainbow and cutthroat trout at some times. DRD Reach 1 is managed as a cold-water fishery by CDOW. The cold water species extend into Reaches 2 and 3 with brown trout occurrence extending the farthest downstream.

Native species were the relatively abundant in Reach 2 in surveys in 1993. Flannelmouth sucker populations were estimated at 1,610±1,460 in upper Reach 2. No flannelmouth suckers were captured in 2007 (White et al. 2007). Bluehead sucker population estimates were 132±172 in 1993 and one bluehead sucker captured in 2007.

Roundtail chub were 72% of the fish collected at the Dove Creek pump site in 2007. Only one bluehead sucker was captured and no flannelmouth suckers were captured. Green sunfish were present at this site.

Upper DRD Reach 3 was dominated by smallmouth bass and brown trout in 2007. There were multiple age classes of smallmouth bass collected in 2007 (White et al. 2007). One bluehead sucker and five flannelmouth sucker were collected in 2007. Six roundtail chubs were collected in this reach.

Upper DRD Reach 5 at Big Gypsum was sampled from 2000 to 2005 and in 2007. The Slickrock Canyon portion of DRD Reach 5 was sampled in 1991 by Valdez et al. (1992) and in 2007 by CDOW. Native fish abundance at Big Gypsum has declined from 2000 to 2007. Non-native white suckers and smallmouth bass are present at this site. Flannelmouth sucker abundance in 2001 was 193 per pass and in 2007 was 10 per pass.

Bluehead sucker had a similar decline. Roundtail chub abundance has been relatively stable since 2001 (White et al. 2007).

The Slickrock Canyon section of Reach 5 had relatively high numbers of flannelmouth sucker and roundtail chub. Non-native species captured in this reach include smallmouth bass, channel catfish, common carp, green sunfish and black bullhead.

The lower Dolores River (downstream of the San Miguel River) is dominated by native species. Flannelmouth sucker and bluehead sucker comprised 60% of the fish captured and include multiple age classes. Non-native fish included channel catfish and common carp.

Status and Trends

The native fish community has declined in most of the river from McPhee Dam downstream to the San Miguel River since 1993. Flannelmouth sucker and bluehead sucker appear to be gone from Reaches 1 and 2. These species are present in some portions of Reach 3 but in low numbers. Several factors may be responsible for this trend.

Reach 1 and Reach 2 have high populations of trout, in particular, brown trout. Large brown trout can feed almost exclusively on fish. Trophic studies in the San Juan River show that brown trout rank the highest on stable isotope analysis indicating a large proportion of their diet is derived from fish (Miller and Lamarra 2006). Most predatory species require an annual ration of 4 to 5 times their body weight in food to grow. Smallmouth bass require 200 grams of food to grow from 40 grams to 85 grams (Miller and Lamarra 2006). These two species could be eating the smaller native fish and be part of the cause for the decline in the native fish populations.

The flow regime in the river has changed since dam operation began in 1986. The current flows regime has peak flows that are lower and occur later in the summer. The native species generally spawn on the ascending limb of the hydrograph in late April and early May. The change in peak flow timing may be impacting the spawning cues needed by the native species. The lower peak flows may also be changing habitat characteristics in the channel. Lower flows likely do not have the same capacity to transport sediment and create and maintain habitat. Accumulation of sediment can reduce the habitat quality for macroinvertebrates and spawning fish. Large peak flows in confined river channels can scour fine material from riffles, runs and some pool habitats.

The dam has also caused a change to the thermal regime in the river. The cold-water portion of the river has effectively moved downstream, which may limit suitable areas for warm water species. In addition, the natural salt dome in Paradox Valley may be the effective lower limit of suitable water quality for native fish. The elevated salts could pose a natural barrier to movement when concentrations are high. The combination of cold water in the upper river with the natural occurrence of poor water quality could reduce the overall length of river that is suitable for native warm water fish.

The dam also creates an upstream and downstream passage block for native fish. The occurrence of native fish in tributaries that drain into McPhee Reservoir documents that native fish were present prior to the dam. These tributary populations may be an important source of fish to recolonize sections of the Dolores River. Historically, the Dolores River may have been a large metapopulation of native fish with exchange between the tributaries and the mainstem. The populations of native fish in tributaries like the San Miguel River and Disappointment Creek may still function in that manner.

In addition to the lower number of native fish, the size distributions show that some cohorts (year classes) are absent as well. The San Miguel River has a good composition of year classes for ages from one year old to adult. In contrast, the size classes in the Dolores River are very truncated with some year classes not present (Figure 18).

The presence of non-native species is likely impacting the native fish community. The Dolores River non-native fish community has increased in size and diversity since 1971. Non-native predators include trout, smallmouth bass, green sunfish, and channel catfish. Native predators would have included mainly roundtail chub, occasionally Colorado pikeminnow and cutthroat trout. The non-native predators impose an additional stressor on the native fish populations that was not present In their native environment.

Conclusions

The three species were common to rare prior to construction of McPHee Reservoir. The native suckers were present after closure of the dam but limited to large adult size classes. The roundtail chub has persisted but at low levels. All three native species have declined over the past 25 – 40 years. The sharpest decline has occurred in the past 20 years.

Reasons for the decline include:

- Changes to peak flow timing, magnitude and duration
- Changes to the thermal regime which changed a warm water habitat to a cold water habitat and possibly truncated the species range
- Habitat fragmentation and isolation of individual populations that once may have functioned as a meta population in the Dolores River.
- Habitat loss due to increased sediment deposition without adequate flows for sediment transport and channel maintenance.

- Competition and predation from non native cold water and warm water fish species

Opportunities for improvement of native fish populations

Persistence of native species will depend on several factors. These include:

- Successful reproduction on an annual basis
- Successful recruitment from larval and juvenile age classes to successive age classes at a rate higher than natural mortality and predation.
- Demonstration of successful recruitment would be stable or increasing native fish populations.

Alternatives for improvement include:

1) A peak flow regime that more closely mimics a natural pattern as seen upstream of McPhee Reservoir. This could include:
- An earlier peak release such as early May.
- Sufficient peak flow magnitude for sediment transport and habitat maintenance.

2) Base flow enhancement that mimics upstream base flow conditions and follows the recommendations from earlier studies. Base flow alternation may not be as limiting as the lack of peak flows.

3) A thermal regime that provides warmer water downstream of the dam. This would provide several benefits:
- It would provide the natural cues for native fish.
- It would disadvantage the non-native cold water fish and could reduce competition and predation on native fish.
- Provide better conditions for growth of native warm water fish.

4) Removal of both cold water and warm water non-native fishes. This would reduce competition and predation on native fishes. The removal may include mechanical, chemical or management (removal of harvest limits and actively encouraging harvest).

Water quality conditions other than water temperature may have an impact on the native fish in the Paradox Valley section of the river. This is a natural condition and may not be feasible to correct. The impacts from mining (metals and uranium) could be remediated with mine cleanup. The current conditions from these impacts seem to be much lower than 40-50 years ago. The clean up that has taken place seems to be beneficial to the fish community.

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Tables

Table 1. Dolores River reach length and slope.

	Distance (miles)	Upper Elevation (ft)	Lower Elevation (ft)	Slope (ft/ft)	Slope (%)	Channel Type
Reach 1	12	6650	6500	0.0024	0.24	Alluvial
Reach 2	19	6500	6100	0.0040	0.40	Bedrock and Boulder controlled
Reach 3	9	6100	5800	0.0063	0.63	Canyon and boulder controlled
Reach 4	38	5800	5340	0.0023	0.23	Bedrock controls transitioning to alluvial
Reach 5	42	5340	5000	0.0015	0.15	Canyon controlled
Reach 6	12	5000	4880	0.0019	0.19	Low gradient entrenched

Table 2. Fish abundance in Dolores River – 1993 to 2007 (White et al. 2007).

Reach	Species	1993	2007
DRD Reach 1	Trout	920/mile	210/mile
	Flannelmouth sucker	0	0
	Bluehead sucker	0	0
	Roundtail chub	0	0
DRD Reach 2	Trout	5095$\pm$5,546	852$\pm$20
	Flannelmouth sucker	1610$\pm$1410	0
	Bluehead sucker	132+172	0
	Roundtail chub	58	31
	Smallmouth bass	0	84
DRD Reach 3	Flannelmouth sucker	NA	
	Bluehead sucker		
	Roundtail chub		
DRD Reach 4	Trout		
	Flannelmouth sucker		
	Bluehead sucker		
	Roundtail chub		
DRD Reach 5	Trout		
	Flannelmouth sucker		
	Bluehead sucker		
	Roundtail chub		

Figures

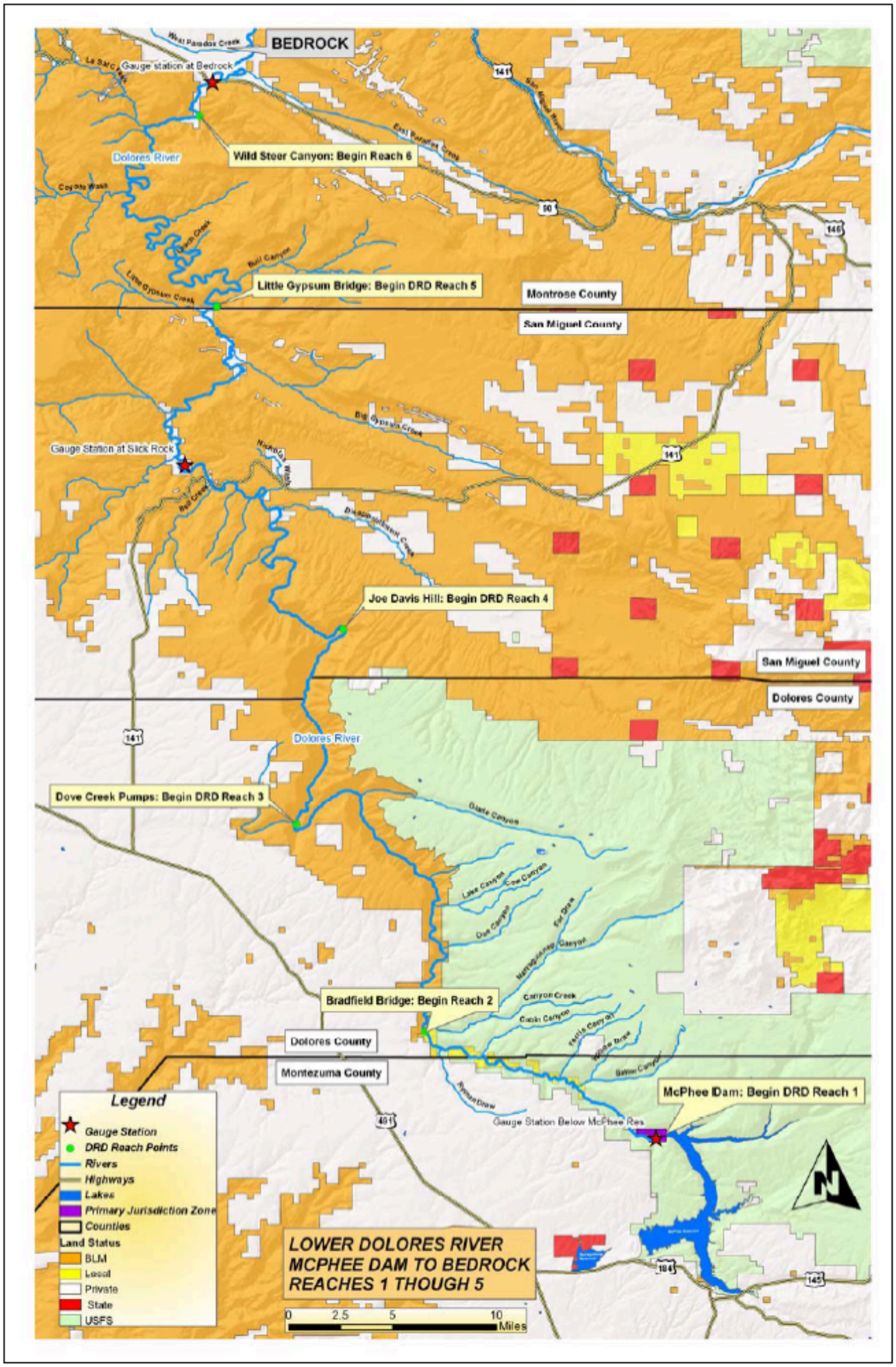

Figure 1. Map of study area Reaches 1-5 and upper Reach 6 (Source: DRD).

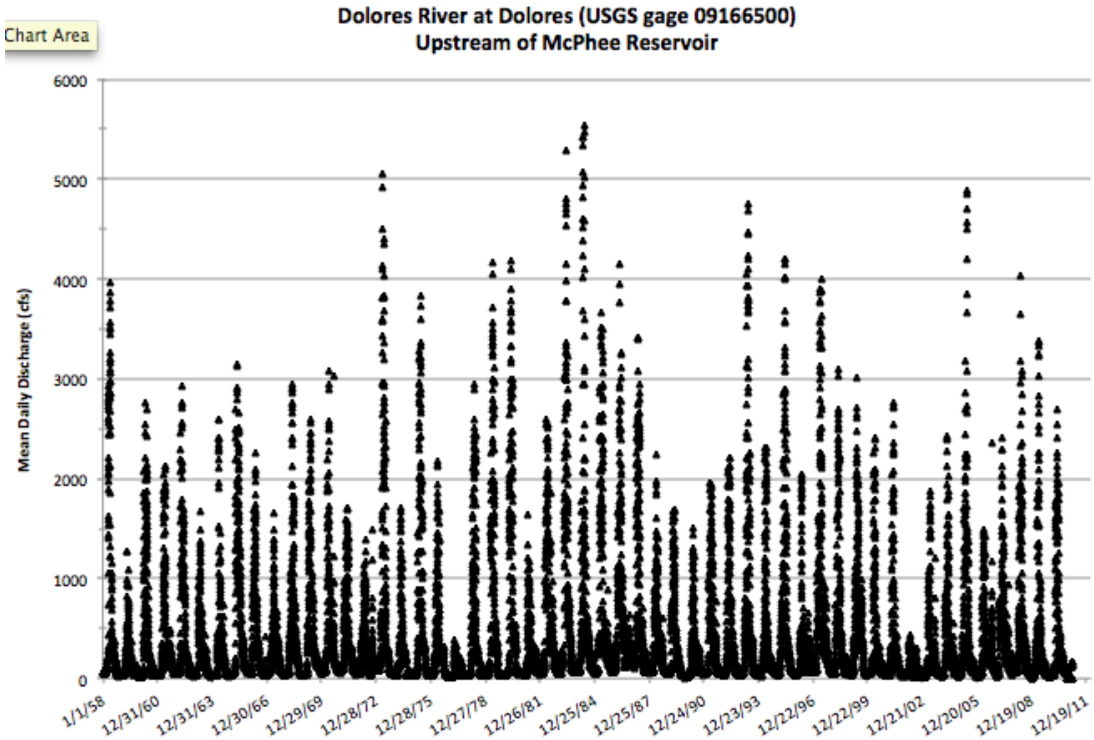

Figure 2. Dolores River discharge at Dolores (USGS gage 09166500) from 1958 to 2011.

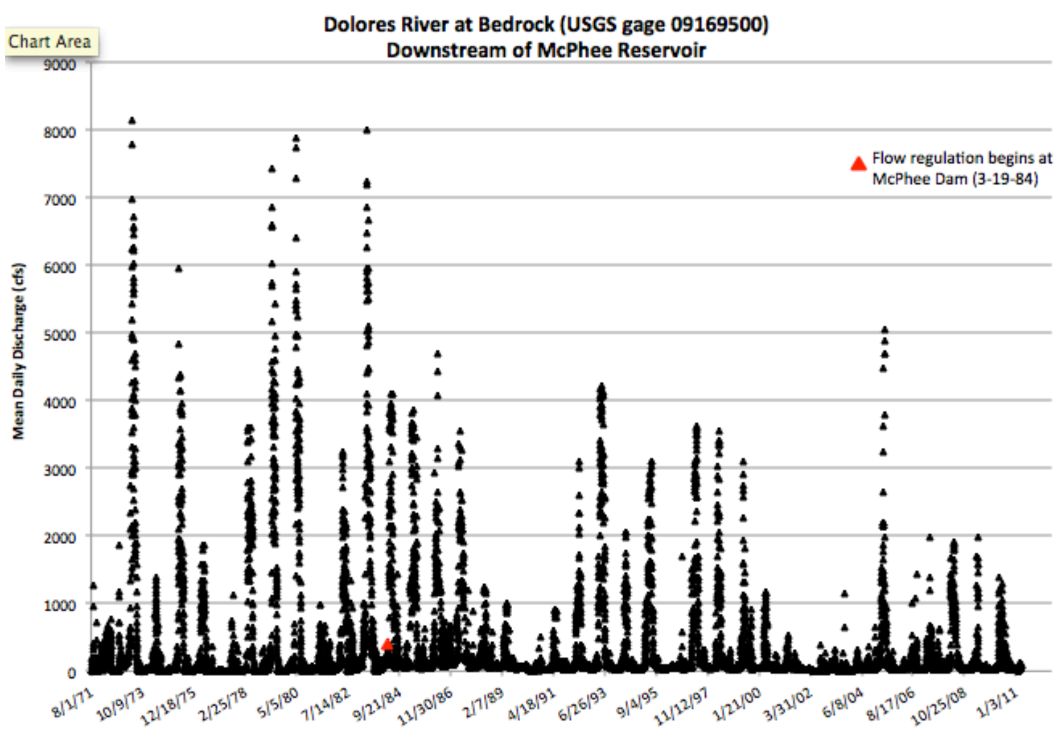

Figure 3. Dolores River discharge at Bedrock (USGS gage 09169500) from 1971 to 2011.

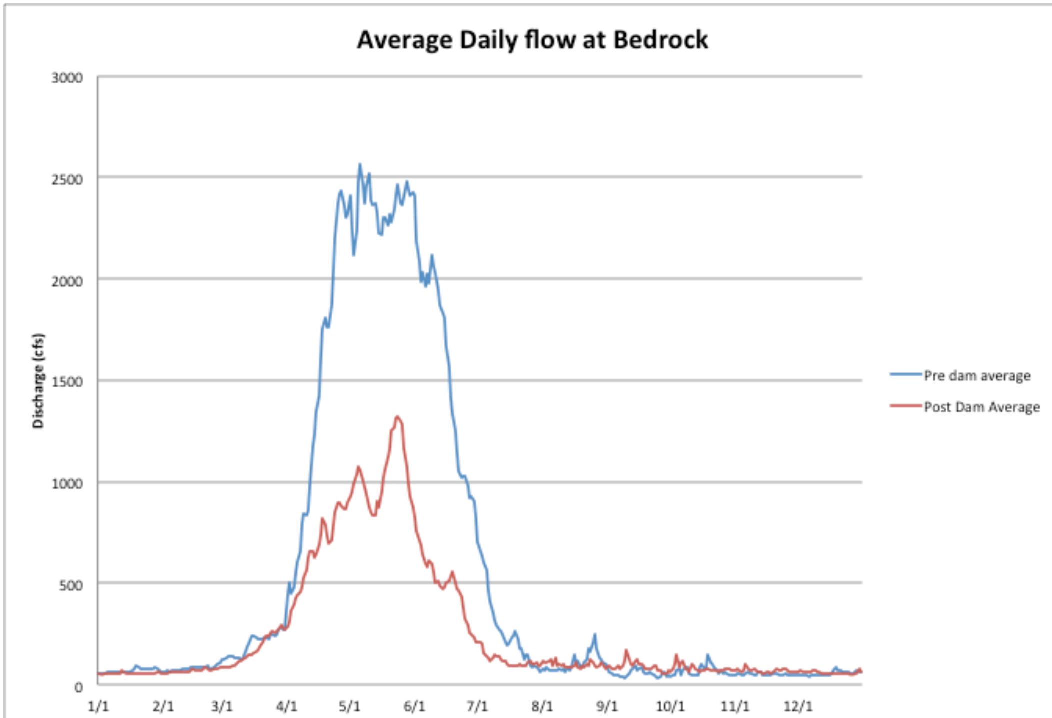

Figure 4. Comparison of average daily pre dam and post dam flow for the Dolores River at Bedrock.

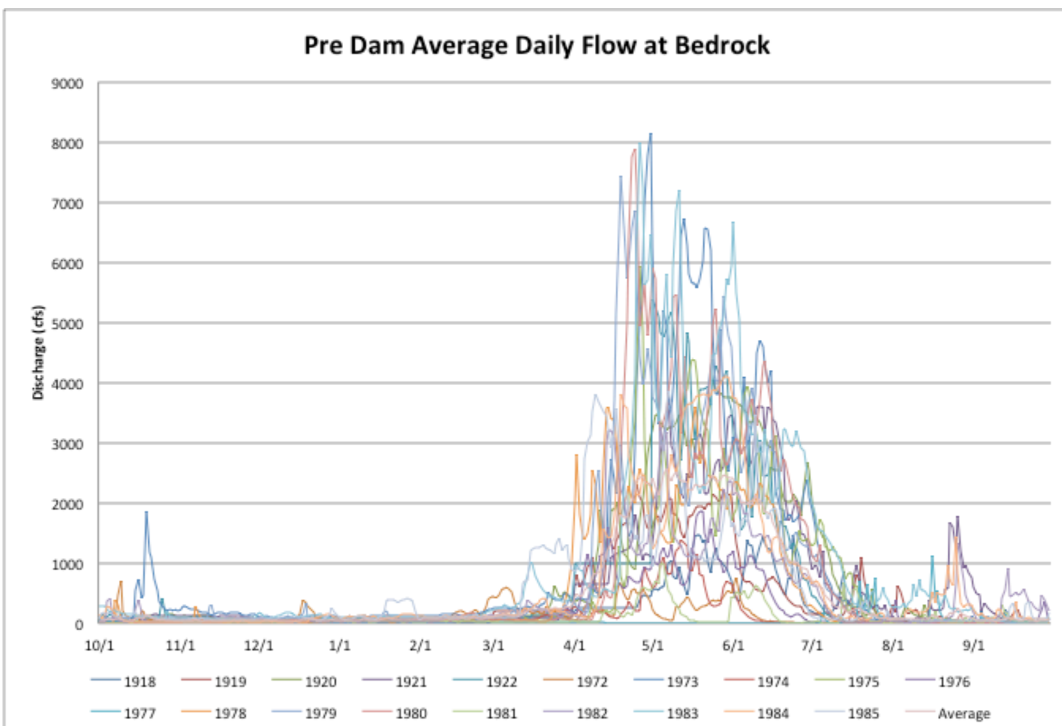

Figure 5. Dolores River at Bedrock annual pre dam hydrographs

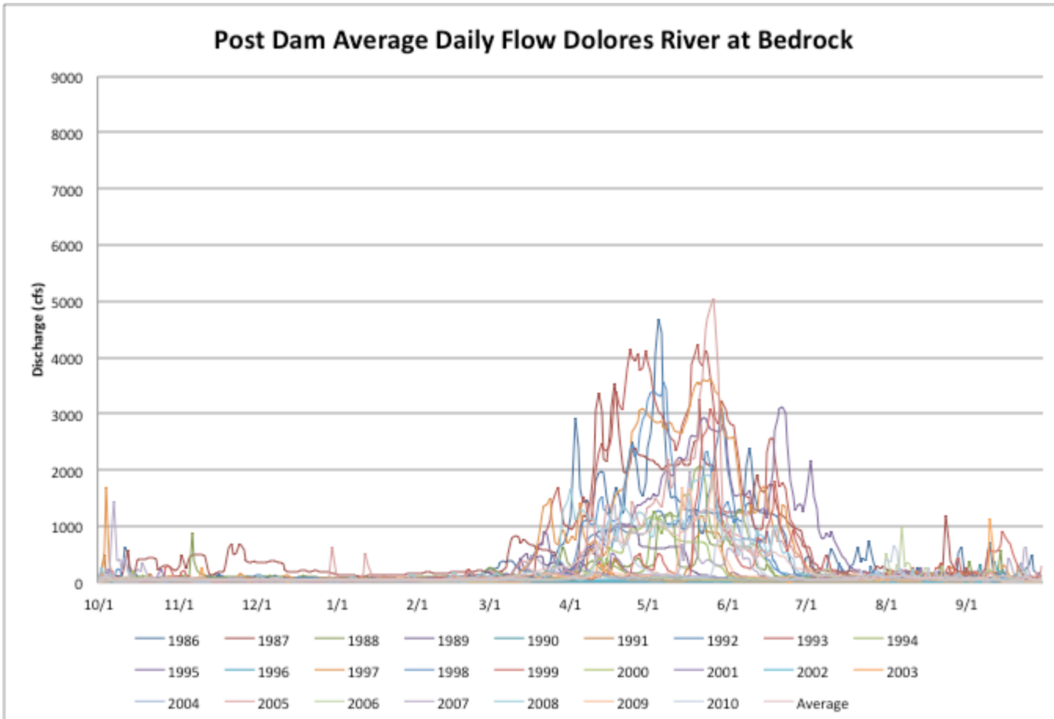

Figure 6. Dolores River at Bedrock annual post dam hydrographs

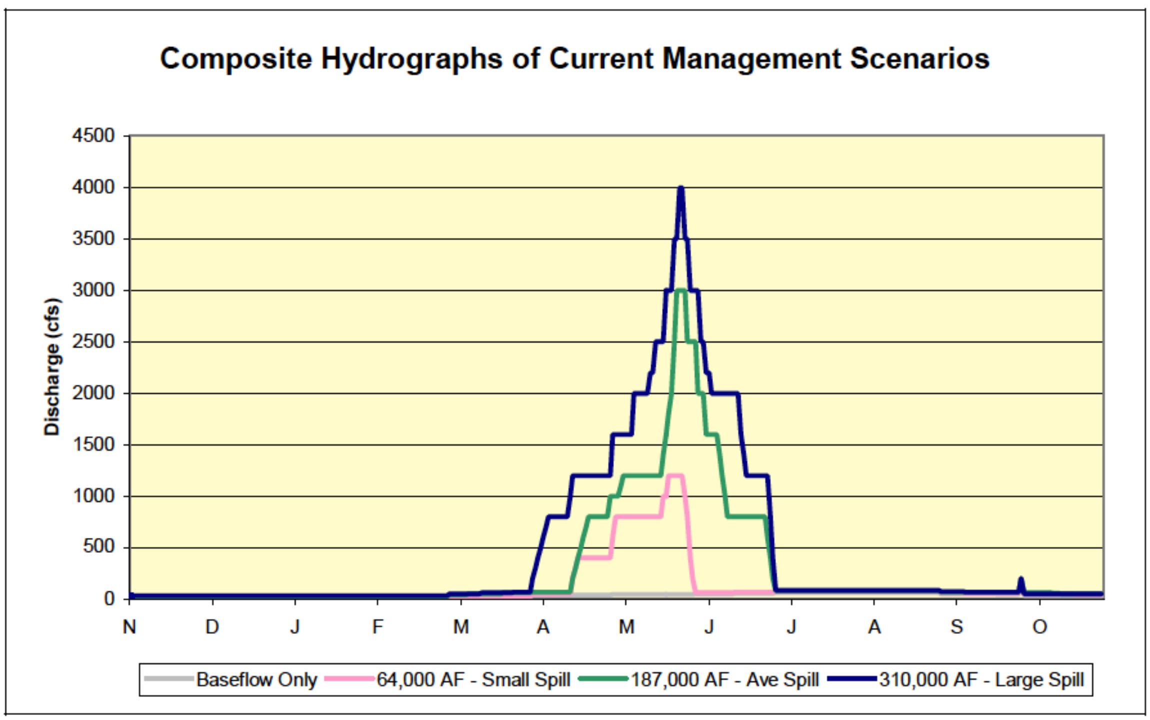

Figure 7. Composite hydrograph for management scenarios discussed in DRD Correlation report. (Source: DRD, 2006).

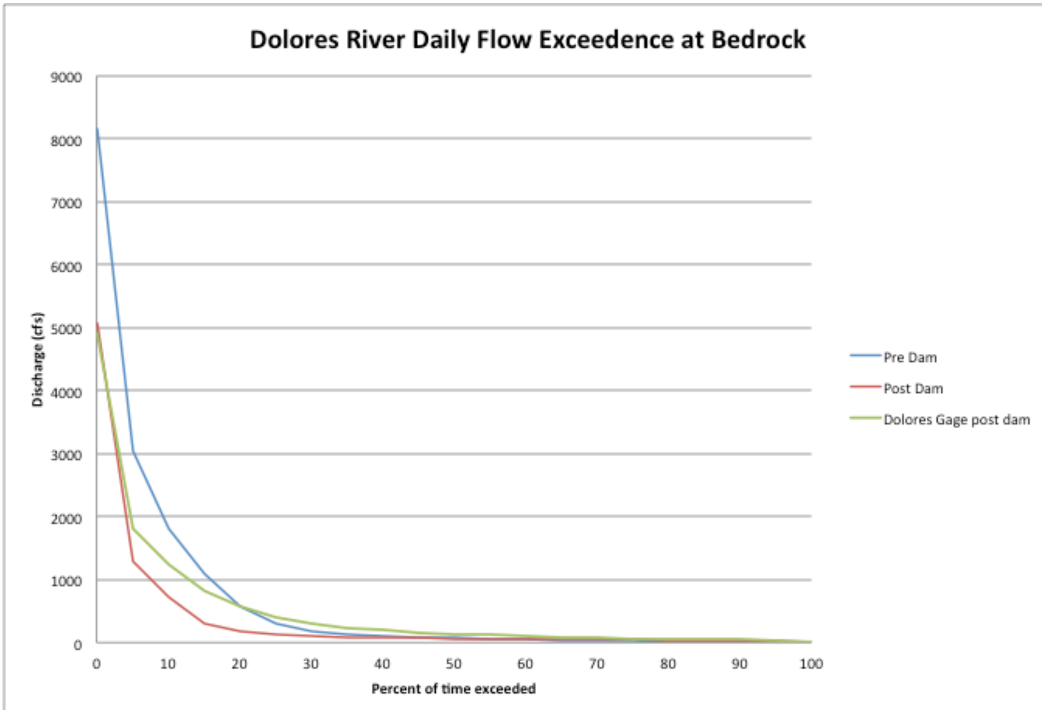

Figure 8. Comparison of pre dam and post dam daily flow exceedance for the Dolores River at Bedrock.

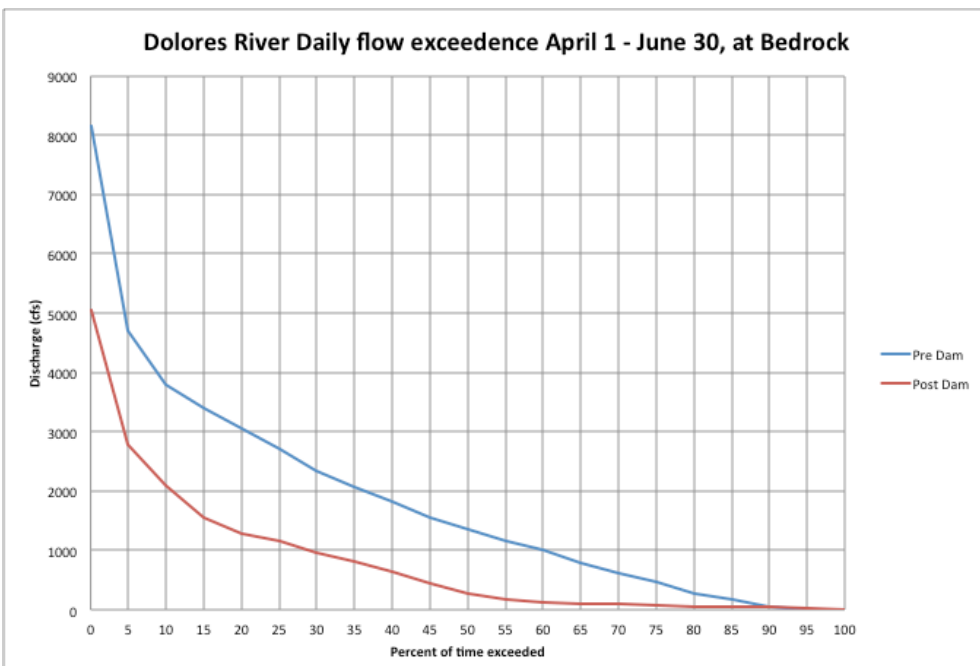

Figure 9. Comparison of pre dam and post dam daily for exceedance from April 1 through June 30 for the Dolores River at Bedrock.

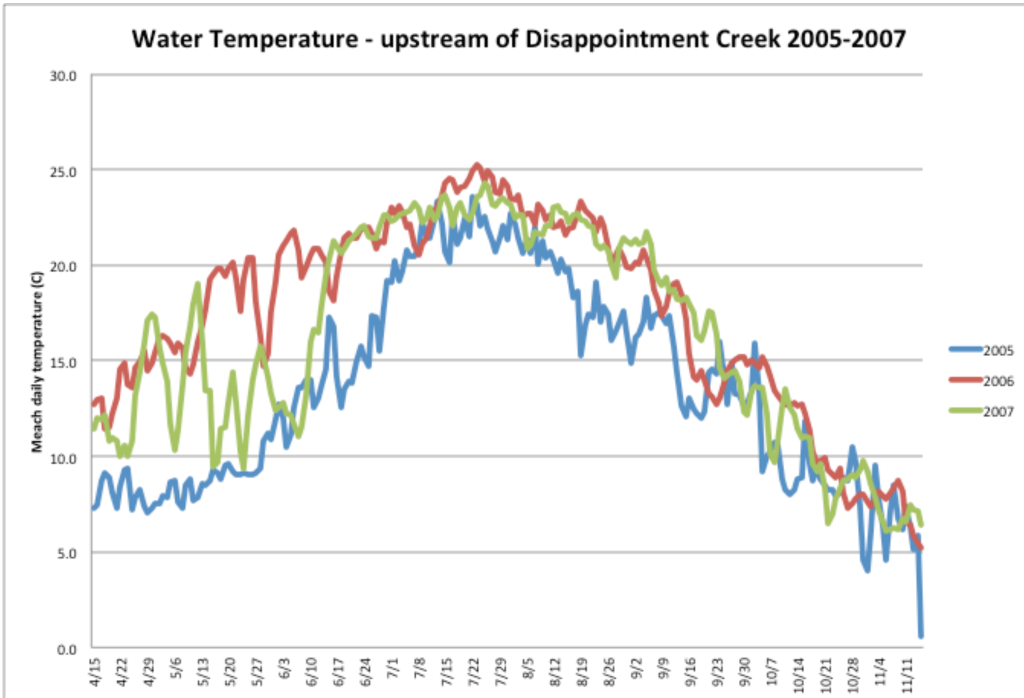

Figure 10. Dolores River water temperature upstream of Disappointment Creek, 2005 – 2007 (Source: CDOW).

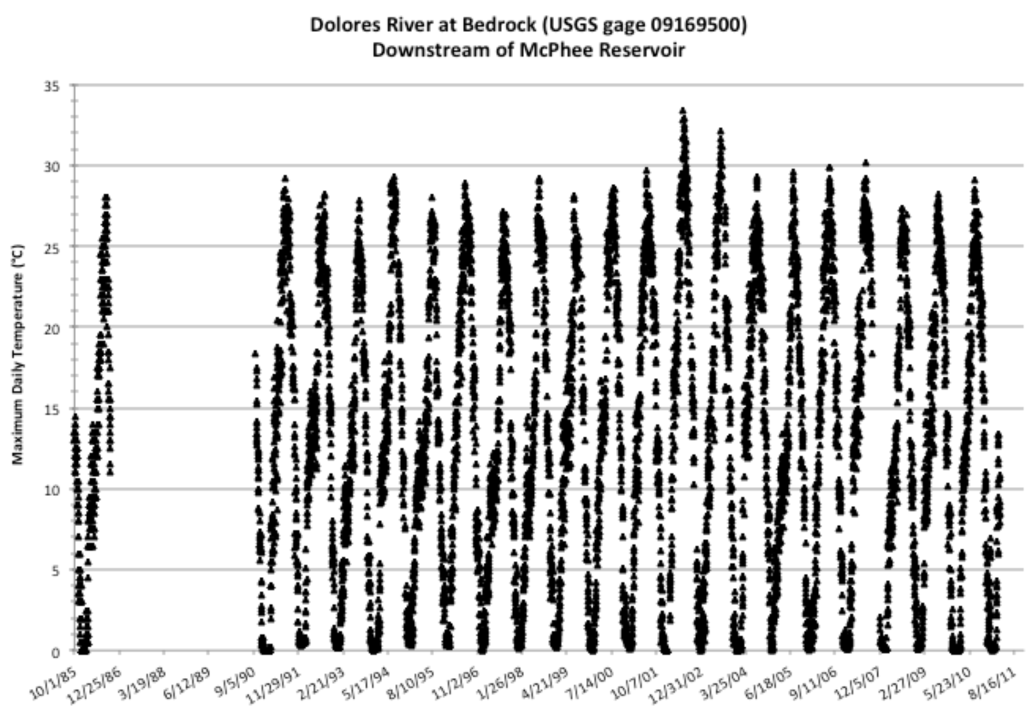

Figure 11. Maximum daily water temperature for the Dolores River at Bedrock (USGS gage 09169500) 1985 – 2011.

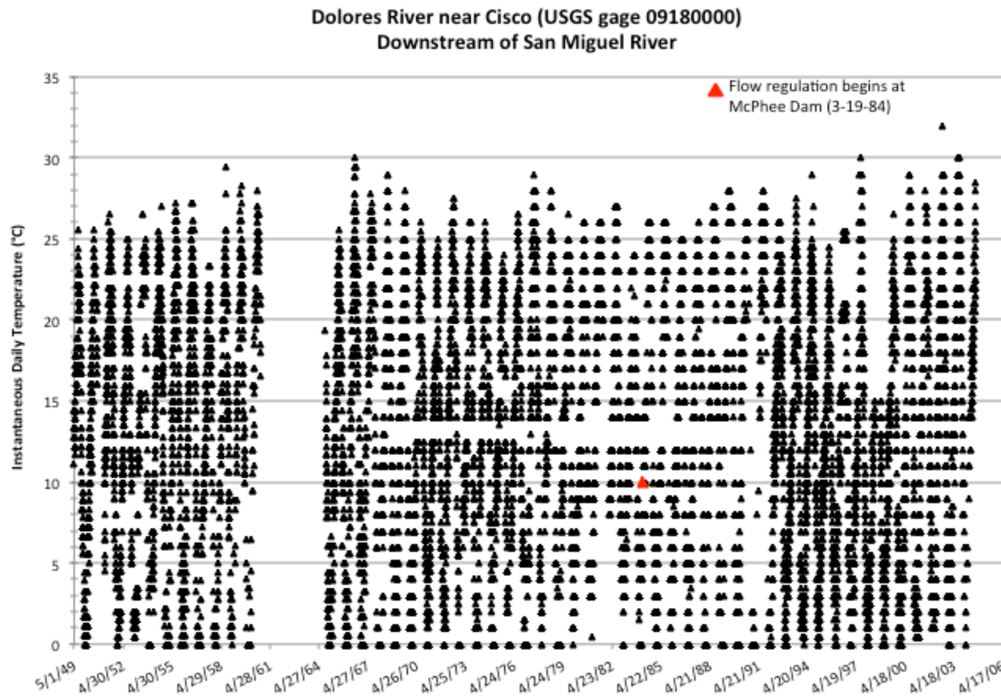

Figure 12. Water temperature for the Dolores River near Cisco, Utah (USGS gage 09180000) 1949 – 2005.

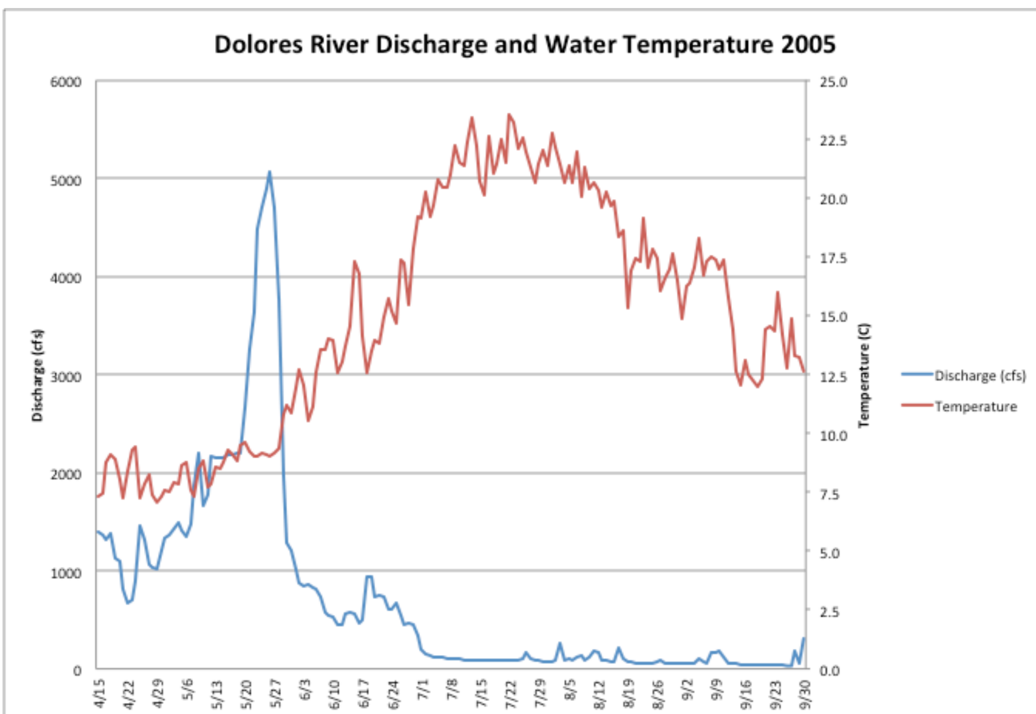

Figure 13. Dolores River discharge at Bedrock and water temperature upstream of Disappointment Creek, 2005.

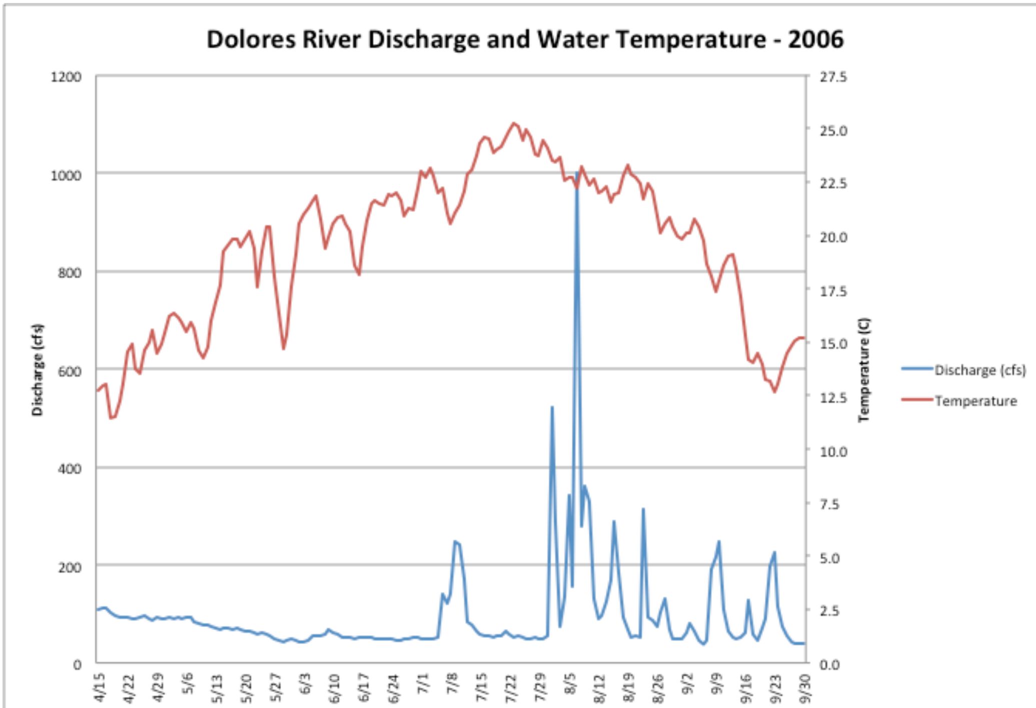

Figure 14. Dolores River discharge at Bedrock and water temperature upstream of Disappointment Creek, 2006.

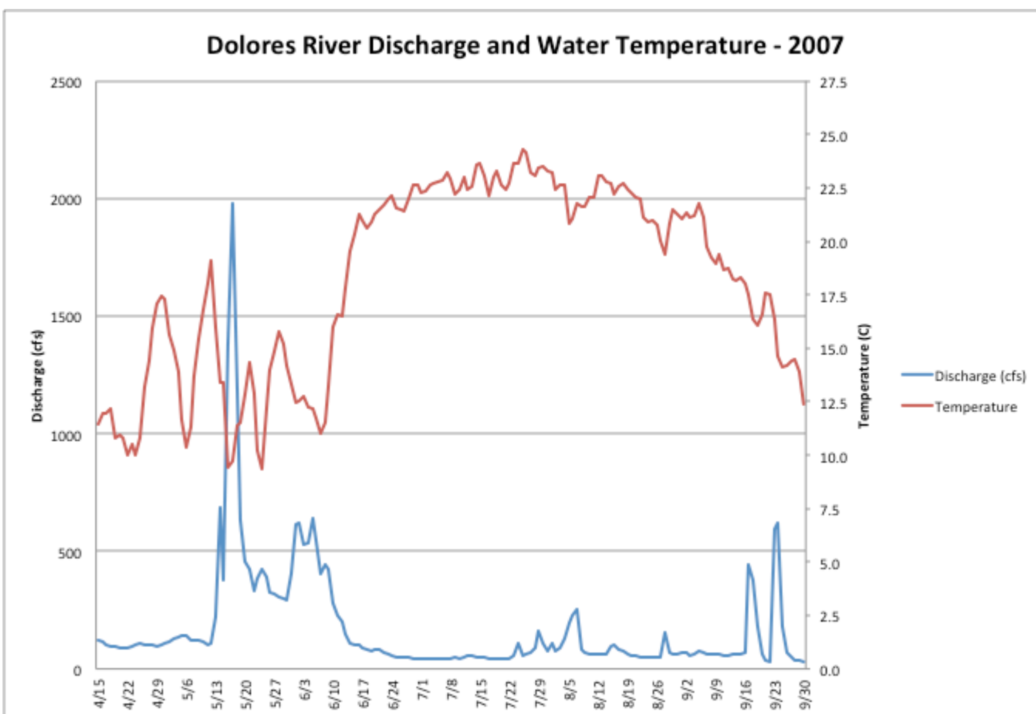

Figure 15. Dolores River discharge at Bedrock and water temperature upstream of Disappointment Creek, 2007.

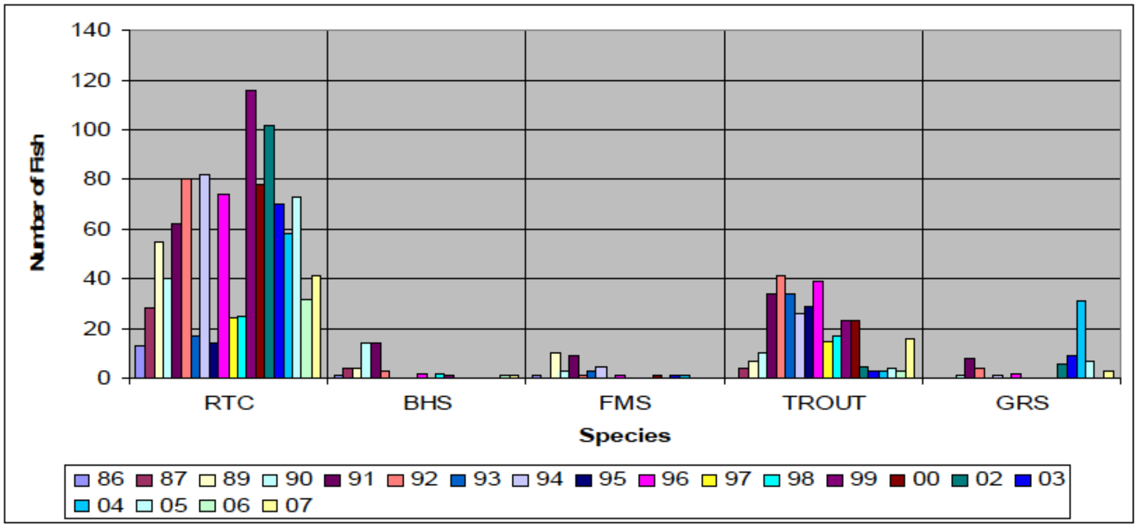

Figure 16. Fish capture data at the Dove Creek pump site, 1986 – 2007, Source: White et al. 2007, CDOW data.

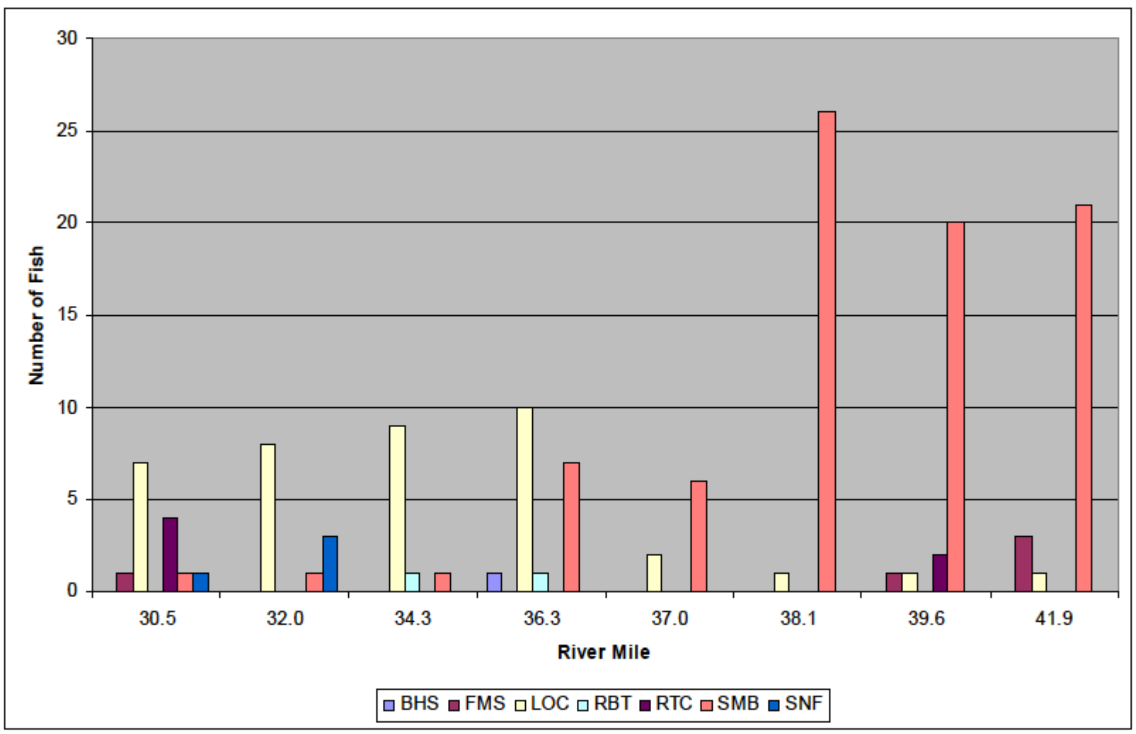

Figure 17. Abundance and distribution of large bodied fishes captured in the Pyramid to Disappoint Creek section of the Dolores River, May 2007, Source: White et al. 2007 CDOW data.

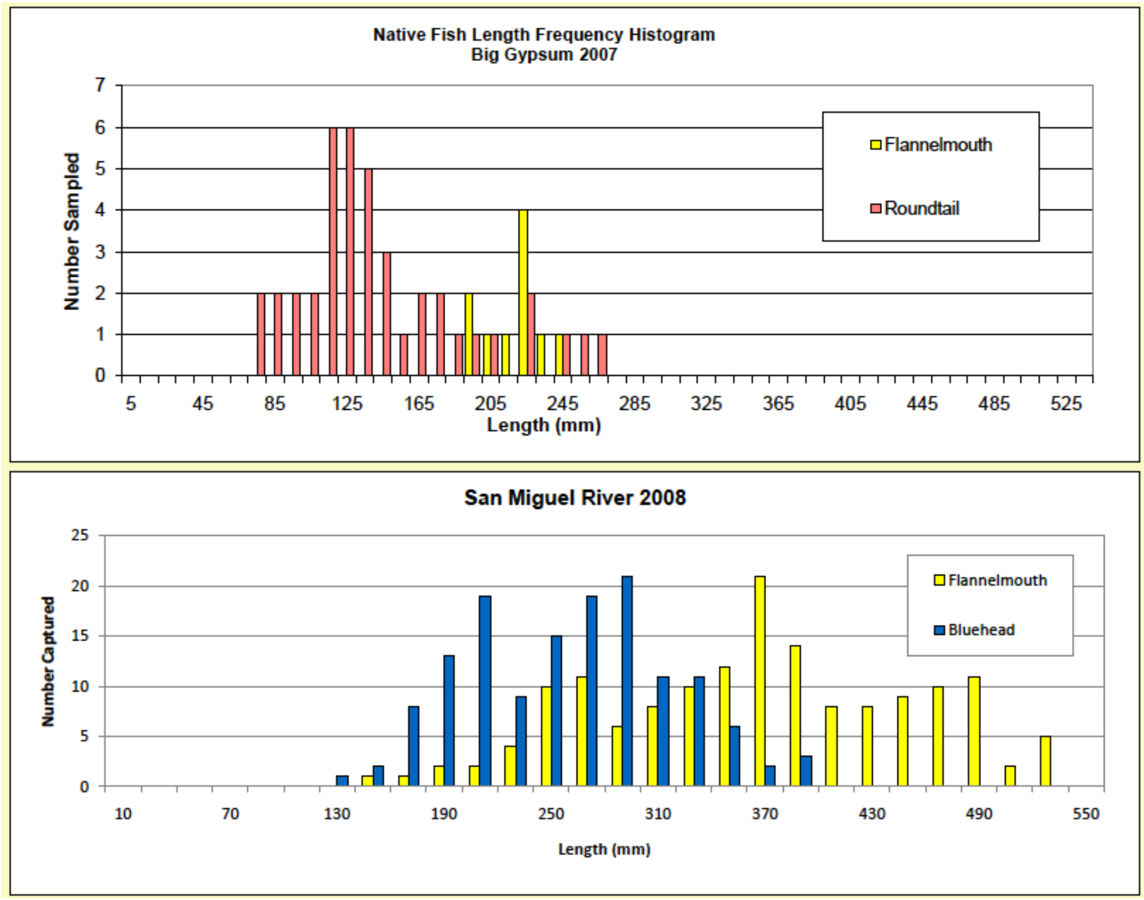

Figure 18. Comparison of fish length frequency distributions at the Big Gypsum site in the Dolores River and the lower San Miguel River. Source: Kowalski et al. 2010. CDOW data.

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