The "Mixer," a Colorado pikeminnow spawning area in the San Juan River.

Flow Recommendations for the San Juan River

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Prepared by:
The San Juan River Basin
Recovery Implementation Program
BIOLOGY COMMITTEE

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PREFACE

This report was prepared by the Biology Committee of the San Juan River Basin Recovery Implementation Program (SJRIP) and is based on all data available at the time it was prepared. Some field collections from 1997 and early 1998 had not been fully analyzed and, therefore, were not included in the report. Information collected on the San Juan River during the 7-year research period that is not pertinent to flow recommendations is also not included. Final research reports and a Synthesis Report that will compile and synthesize information on other aspects of recovery of the endangered fish in the San Juan River are scheduled to be completed in 1999.

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EXECUTIVE SUMMARY

INTRODUCTION

This report presents the results of a process to develop flow recommendations for the native fish community, including the endangered Colorado pikeminnow (*Ptychocheilus lucius*) and razorback sucker (*Xyrauchen texanus*), in the San Juan River of New Mexico, Colorado, and Utah. Flow recommendations are a major milestone of the San Juan River Basin Recovery Implementation Program (SJRIP), which was initiated in 1992 with the following two goals:

1. To conserve populations of Colorado squawfish and razorback sucker in the basin, consistent with the recovery goals established under the Endangered Species Act, 16 U.S.C. 1531 et seq.

2. To proceed with water development in the basin in compliance with federal and state laws, interstate compacts, Supreme Court decrees, and federal trust responsibilities to the Southern Utes, Ute Mountain Utes, Jicarillas, and the Navajos.

Mimicry of the natural hydrograph is the foundation of the flow recommendation process for the San Juan River. Scientists have recently recognized that temporal (intra- and interannual) flow variability is necessary to create and maintain habitat and to maintain a healthy biological community in the long term. Restoring a more-natural hydrograph by mimicking the variability in flow that existed before human intervention provides the best conditions to protect natural biological variability and health. The linkages between hydrology, geomorphology, habitat, and biology were used to define mimicry in terms of flow magnitude, duration, and frequency for the runoff and base-flow periods. The flow characteristics of these linkages were compared with the statistics of the pre-Navajo Dam hydrology to assist in fine-tuning the flow recommendations. The flow recommendations require mimicry of statistical parameters of flow, based on the linkages developed and the statistical variability of the pre-dam hydrology rather than mimicry of each annual hydrograph. A 65-year-long period of record (1929 to 1993) was used to assess the relationship between water development scenarios and the ability to meet the flow recommendations.

Data were gathered and analyzed during a 7-year research period (1991 to 1997) to determine fish population and habitat responses to reregulation of Navajo Dam to mimic a natural hydrograph. The research involved quantification of several relationships, including flow/geomorphology, geomorphology/fish habitat, and flow/habitat availability relationships.

The SJRIP will use an adaptive management process, along with monitoring and continued research, to adjust the flow recommendations in the future. The ability to adaptively manage the system is important because flow recommendations can be refined in response to the emerging understanding of the mechanisms involved in recovery of the endangered species in the San Juan River.

This report is one of two reports that address the results of the 7-year research program. This report focuses on the analysis and integration of biological, hydrologic, and geomorphological data to determine flow needs of the endangered fish species. A companion report, to be produced in 1999, will compile and synthesize information on other aspects of recovery of the endangered fishes in the San Juan River. The companion report will specifically address issues such as contaminants, propagation, nonnative species control, and fish-passage needs.

RESULTS OF THE 7-YEAR RESEARCH PERIOD

The San Juan River is similar to other Upper Colorado River Basin (Upper Basin) streams, primarily the Green and Colorado rivers, in that they are all large rivers with high spring flows and low base flows, they are all fairly turbid most of the time, they typically have sand and cobble substrate, and they are all subject to late summer and fall thunderstorm activity. The San Juan River is also similar to other portions of the Upper Basin in that it once supported populations of Colorado pikeminnow and razorback sucker that have declined after the completion of major dams. However, the San Juan River is different than the Green and Colorado rivers primarily because it has a steeper overall slope, a higher overall sediment concentration, and more late summer and fall flood events. No wild razorback sucker were found in the San Juan River during the research period, and the Colorado pikeminnow population appears to be smaller than 100 individuals. Navajo Dam began affecting flows in the San Juan River in 1962, and post-dam flows had lower spring flows and higher late summer, fall, and winter flows than occurred during pre-dam periods. The advent of research flows in 1992 to 1997 produced flows more typical of the pre-dam era.

Habitat needs of the two endangered fishes in the San Juan River involve a complex mix of low-velocity habitats such as eddies, pools, and backwaters adjacent to swifter run and riffle habitats. Habitat use changes with time of year and activity (e.g., spawning, feeding, nursery areas). A natural hydrograph, in terms of peak spring flows and late summer base flows, is important to not only provide the proper habitats at the correct time, but also to provide natural temperatures and productivity cycles for those habitats.

Two key habitats important to Colorado pikeminnow and other native species that were used extensively in the flow recommendation process were cobble bars and backwaters. Cobble bars are spawning areas for Colorado pikeminnow, and the fish appear to have fidelity for a certain area of the San Juan River called “the Mixer” for spawning. In the Green River, similar fidelity to spawning areas is seen for both Colorado pikeminnow and razorback sucker. An important feature of Colorado pikeminnow spawning bars is that the cobbles are very clean with relatively little fine sediments between individual cobbles. Clean cobble bars are more rare in the San Juan River, as well as in other Upper Basin rivers, than just a typical cobble bar.

Backwaters are an important habitat for young native fishes, including Colorado pikeminnow. During studies of young stocked Colorado pikeminnow in the San Juan River, the fish were found in backwaters 60% of the time, but they were found in other low-velocity habitats (e.g. pools, pocket water) nearly 40% of the time. In the Green River, young Colorado pikeminnow are found in backwaters more often than fish in the San Juan River, and studies have shown that the San Juan River has relatively small amounts of backwaters compared with the Green and Colorado rivers. But the success of the stocked Colorado pikeminnow in the San Juan River has shown that this system has the habitats necessary for the survival and growth of these young fish.

Studies assessing the flows needed to build and maintain cobble bars and backwaters similar to those used by Colorado pikeminnow were an important part of the 7-year research effort. These studies showed that relatively high flows were needed to build and clean these habitats, but that lower flows were needed to make them more abundant at the proper time of the year.

During the 7-year research period, a number of responses to the reregulation of Navajo Dam were identified in the native fish community. Colorado pikeminnow young were found in very low numbers, or not at all, during low spring runoff years, and in larger numbers during higher flow years. The young of bluehead sucker and speckled dace, two other native species, were found in greater numbers during high flow years compared with low flow years. Flannelmouth sucker, another native species, tended to decline during the research period, but still remained the most abundant native species in the river. The change to a more-natural hydrograph during the research period resulted in more cobble and less sand habitats in the river, apparently favoring bluehead sucker and speckled dace rather than flannelmouth sucker.

Nonnative fishes in the San Juan River are potential predators and competitors with the native species and have been implicated in the decline of the native fishes throughout the Colorado River Basin. Populations of some nonnative fishes changed during the research period, but no major reduction in nonnative fish numbers were documented. Some authors have suggested that nonnative fishes may be reduced by high natural flows, but this was not the case in the San Juan River during the 7-year research period. Contaminants were also studied as a potential limiting factor for native fishes, but no pattern of contaminant concentrations and flow was found. Table S.1 summarizes the biological and habitat responses that were found during the research period and the flows that were important in producing those responses.

FLOW RECOMMENDATION

RiverWare, a generic hydrologic model, was used as the primary modeling tool for developing the flow recommendations. The model simulates the flow in the river at various gages at different points in time, including the past, present, and future. It does this by incorporating all past, present, and potentially future water development projects into the model. The 1929 to 1993 period of record was used in the model to simulate flows under the various development scenarios. Existing gaging stations were used to calibrate the model to ensure it was working properly for historic conditions.

Table S.1. Flow requirements needed to produce important biological responses and habitats in the San Juan River.

BIOLOGICAL RESPONSE/ HABITAT REQUIREMENT	FLOW CHARACTERISTIC
Reproductive success of Colorado pikeminnow lower in years with low spring runoff peaks, and higher in years with high and broad runoff peaks.	Mimicry of a natural hydrograph, especially during relatively high runoff years.
Decline in flannelmouth sucker abundance, increase in bluehead sucker abundance, and increased condition factor in both species.	Mimicry of natural hydrograph with higher spring flows and lower base flows.
Bluehead sucker reproductive success.	Increased number of days of spring runoff >5,000 and 8,000 cfs correlated with increased success.
Speckled dace reproductive success.	Increased number of days of spring runoff >5,000 and 8,000 cfs correlated with increased success.
Success of stocking YOY Colorado pikeminnow and subadult razorback sucker.	Mimicry of natural hydrograph has provided suitable habitat for these size-classes.
Eddies, pools, edge pools, other low-velocity habitats year round for adult Colorado pikeminnow and razorback sucker.	Mimicry of natural hydrograph has lowered base flows to provide more low-velocity habitats. Flows >10,000 cfs provide more channel complexity which provides for more habitat complexity.
Flows to cue razorback sucker and Colorado pikeminnow for migration and/or spawning.	Mimicry of natural hydrograph with higher spring flows.
Adult Colorado pikeminnow and razorback sucker use complex river areas.	Flows >10,000 cfs provide more channel complexity which provides for more habitat complexity, lower base flows add to amount of low-velocity habitats.
Clean cobble bars for spawning of all native species, especially Colorado pikeminnow.	Flows >8,000 cfs for 8 days to construct cobble bars, and >2,500 cfs for 10 days to clean cobble bars, during spring runoff.
Backwaters and other low-velocity habitats are important nursery habitats for Colorado pikeminnow and other native fishes.	High spring flows create conditions for backwater formation, low base flows allow them to appear in late summer and fall, flows >5,000 cfs for 3 weeks create and clean backwaters.
Flooded bottomlands appear to be important nursery areas for razorback sucker, but other habitats may be used in the San Juan River.	Overbank flows (> 8,000 cfs) increase flooded vegetation, and backwaters formed in association with edge features maximize on receding flows of 8,000 to 4,000 cfs.
Temperatures of 10 to 14 EC at peak runoff for razorback sucker spawning and near 18 to 20 EC at bottom of descending limb for Colorado pikeminnow spawning.	Proposed releases from Navajo Dam are too cool to replicate pre-dam temperature timing, but temperatures are above spawning threshold for Colorado pikeminnow during the correct period.
Reduction of nonnative fish abundance.	Most nonnative fishes did not decrease during research period, summer flow spikes reduce numbers of red shiner in secondary channels in the short term.

Note: cfs = cubic feet per second, YOY = young-of-the-year.

The model was completed with input from the Bureau of Reclamation, Bureau of Indian Affairs, and the states of New Mexico and Colorado.

Mimicry of the natural hydrograph is the foundation of the flow recommendation process for the San Juan River. The flow recommendations require mimicry of statistical parameters of flow based on flow/geomorphology/habitat linkages and the statistical variability of the pre-dam hydrology rather than mimicry of each annual hydrograph. Therefore, the resulting flows will not mimic a natural hydrograph in all years, but will mimic the variation and dynamic nature of the 65-year record of the San Juan River.

The hydrograph recommendations are designed to meet the conditions required to develop and maintain habitat for Colorado pikeminnow and razorback sucker and provide the necessary hydrologic conditions for the various life stages of the endangered and other native fishes. The conditions are listed in terms of flow magnitude, duration, and frequency during the spring runoff period. Duration is determined as the number of days that the specified flow magnitude is equaled or exceeded during the spring runoff period of March 1 to July 31. Frequency is the average recurrence of the conditions specified (magnitude and duration), expressed as a percent of the 65 years of record analyzed (1929 to 1993). The underlying assumption in the flow conditions is that, over a long period of time, history will repeat itself: if the conditions were met during the past 65 years, they will also be met in the future. To the extent that the water supply is different in the future, then the natural condition would also be altered and the conditions of mimicry would be maintained, although the exact flow recommendation statistics may not be met.

To allow for gage and modeling error and the difference between the flows at the historical gage at Bluff, Utah, and the Four Corners gage, maximum allowable durations are computed for 97% of the target flow rate. In most cases, the primary recommendation is for a specified flow rate (i.e., 10,000 cubic feet per second (cfs)) of a minimum duration (i.e., 5 days) for a specific frequency of occurrence (i.e., 20% of the years). In addition to the primary recommendation, variability in duration is desirable to mimic a natural hydrograph. Therefore, a frequency table for a range of durations for each flow rate is recommended. A maximum duration between occurrences is also specified to avoid long periods when conditions are not met, since such long periods could be detrimental to the recovery of the species. The maximum period without reaching a specified condition was determined as twice the average required interval (except for the 80% recurrence of the 2,500 cfs condition, where 2 years is used). For example, if the average interval is 1 year in 3, then the maximum period between meeting conditions would be 6 years. The maximum periods were based on the collective judgement of Biology Committee members after review of historical pre-dam statistics. Following are the conditions specified:

A. Category: Flows > 10,000 cfs during runoff period (March 1 to July 31).

Duration: **A minimum of 5 days between March 1 and July 31**.

Frequency: **Flows > 10,000 cfs for 5 days or more need to occur in 20% of the years on average for the period of record 1929-1993**. Maximum number of consecutive years without meeting at least a flow of 9,700 cfs (97% of 10,000 cfs) within the 65-year period of record is 10 years.

Purpose: Flows above 10,000 cfs provide significant out-of-bank flow, generate new cobble sources, change channel configuration providing for channel diversity, and provide nutrient loading to the system, thus improving habitat productivity. Such flows provide material to develop spawning habitat and maintain channel diversity and habitat complexity necessary for all life stages of the endangered fishes. The frequency and duration are based on mimicry of the natural hydrograph, which is important for Colorado pikeminnow reproductive success and maintenance of channel complexity, as evidenced by the increase in the number of islands following high flow conditions. Channel complexity is important to both Colorado pikeminnow and razorback sucker.

B. Category: Flow > 8,000 cfs during runoff period.

Duration: **A minimum of 10 days between March 1 and July 31**.

Frequency: **Flows > 8,000 cfs for 10 days or more need to occur in 33% of the years on average for the period of record 1929-1993**. Maximum number of consecutive years without meeting at least a flow of 7,760 cfs (97% of 8,000 cfs) within the 65-year period of record is 6 years.

Purpose: Bankfull discharge is generally between 7,000 and 10,500 cfs in the San Juan River below Farmington, New Mexico, with 8,000 cfs being representative of the bulk of the river. Bankfull discharge approximately 1 year in 3 on average is necessary to maintain channel cross-section. Flows at this level provide sufficient stream energy to move cobble and build cobble bars necessary for spawning Colorado pikeminnow. Duration of 8 days at this frequency is adequate for channel and spawning bar maintenance. However, research shows a positive response of bluehead sucker and speckled dace abundance with increasing duration of flows above 8,000 cfs from 0 to 19 days. Therefore, the minimum duration was increased from 8 to 10 days to account for this measured response. Flows above 8,000 cfs may be important for providing habitat for larval razorback sucker if flooded vegetation and other habitats formed during peak and receding flows are used by the species. This flow level also maintains mimicry of the natural hydrograph during higher flow years, an important feature for Colorado pikeminnow reproductive success.

Category: Flow > 5,000 cfs during runoff period.

Duration: **A minimum of 21 days between March 1 and July 31**.

Frequency: **Flows > 5,000 cfs for 21 days or more need to occur in 50% of the years on average for the period of record 1929-1993**. Maximum number of consecutive years without meeting at least a flow of 4,850 cfs (97% of 5,000 cfs) within the 65-year period of record is 4 years.

Purpose: Flows of 5,000 cfs or greater for 21 days are necessary to clean backwaters and maintain low-velocity habitat in secondary channels in Reach 3, thereby maximizing nursery habitat for the system. The required frequency of these flows is dependent upon perturbating storm events in the previous period, requiring flushing in about 50% of the years on average. Backwaters in the upper portion of the nursery habitat range clean with less flow but may be too close to spawning sites for full utilization. Maintenance of Reach 3 is deemed critical at this time because of its location relative to the Colorado pikeminnow spawning area (RM 132) and its backwater habitat abundance.

3. Category: Flow >2,500 cfs during runoff period.

Duration: **A minimum of 10 days between March 1 and July 31**.

Frequency: **Flows > 2,500 cfs for 10 days or more need to occur in 80% of the years on average for the period of record 1929-1993**. Maximum number of consecutive years without meeting at least a flow of 2,425 cfs (97% of 2,500 cfs) within the 65-year period of record is 2 years.

Purpose: Flows above 2,500 cfs cause cobble movement in higher gradient areas on spawning bars. Flows above 2,500 cfs for 10 days provide sufficient movement to produce clean cobble for spawning. These conditions also provide sufficient peak flow to trigger spawning in Colorado pikeminnow. The frequency specified represents a need for frequent spawning conditions but recognizes that it is better to provide water for larger flow events than to force a release of this magnitude each year. The specified frequency represents these tradeoffs.

E. Category: Timing of the peak flows noted in A through D above must be similar to historical conditions, and the variability in timing of the peak flows that occurred historically must also be mimicked.

Timing: Mean date of peak flow in the habitat range (RM180 and below) for any future level of development when modeled for the period of 1929 to 1993 must be within 5 days ± of historical mean date of May 31 for the same period.

Variability: Standard deviation of date of peak to be 12 to 25 days from the mean date of May 31.

Purpose: Maintaining similar peak timing will provide ascending and descending hydrograph limbs timed similarly to the historical conditions that are suspected important for spawning of the endangered fishes.

F. Category: Target Base Flow (mean weekly nonspring runoff flow).

Level: 500 cfs from Farmington to Lake Powell, with 250 cfs minimum from Navajo Dam.

Purpose: Maintaining low, stable base flows enhances nursery habitat conditions. Flows between 500 and 1,000 cfs optimize backwater habitat. Selecting flows at the low end of the range increases the availability of water for development and spring releases. It also provides capacity for storm flows to increase flows and still maintain optimum backwater area. This level of flow balances provision of near-maximum low-velocity habitat and near-optimum flows in secondary channels, while allowing water availability to maintain the required frequency, magnitude, and duration of peak flows important for Colorado pikeminnow reproductive success.

G. Category: Flood Control Releases (incorporated in operating rule).

Control: Handle flood control releases as a spike (high magnitude, short duration) and release when flood control rules require, except that the release shall not occur earlier than September 1. If an earlier release is required, extend the duration of the peak of the release hydrograph. A ramp up and ramp down of 1,000 cfs per day should be used to a maximum release of 5,000 cfs. If the volume of water to release is less than that required to reach 5,000 cfs, adjust the magnitude of the peak accordingly, maintaining the ramp rates. Multiple releases may be made each year. These spike releases shall be used in place of adjustments to base flow.

Purpose: Historically, flood control releases were made by increasing fall and winter base flows. This elevates flows above the optimum range for nursery habitat. Periodic clean-water spike flows improve low-velocity habitat quality by flushing sediment and may suppress red shiner and fathead minnow abundance.

Operating rules for Navajo Dam were developed in cooperation with the Bureau of Reclamation to demonstrate how the dam may be operated to meet the flow recommendations. These suggested rules determine the timing and size of release flows to maximize the ability of the river to meet the flow recommendations. Releases to produce a peak spring flow are not made every year because saving water, (1) for human use, and (2) to make a larger peak in a future year, is incorporated into the rules. The flow recommendations, and use of the operating rules, will provide flows in the San Juan River that will promote the recovery of the two endangered fish species. As presently configured, the flow recommendations may also allow for a significant amount of future water development in the basin.

This report addresses the science of the development of flow recommendations for the San Juan River. It does not address the impact of the recommended flows on the holders of water rights in the San Juan River Basin. Legal and management factors to be considered by the U.S. Fish and Wildlife Service and affected parties will determine which holders of water rights will be affected by these flow recommendations. The SJRIP recognizes that the flow criteria and operating rules discussed herein are only recommendations that are subject to further refinement through the SJRIP adaptive management process and pursuant to the National Environmental Policy Act.

CHAPTER 1: INTRODUCTION

DOCUMENT PURPOSE

This document provides flow recommendations for the San Juan River of New Mexico, Colorado, and Utah designed to conserve and recover two endangered fishes, Colorado pikeminnow (*Ptychocheilus lucius*) and razorback sucker (*Xyrauchen texanus*). It is based on information gathered on the San Juan River during a 7-year research effort funded largely by the Bureau of Reclamation (Bureau) and the Bureau of Indian Affairs (BIA), although additional information related to the fish species of interest has been gathered from literature sources. The flow recommendations made in this report may be changed in the future, in response to new information, through an adaptive management process. A monitoring program is being developed that will evaluate the success of the flow recommendations and other actions that may be implemented to aid in recovery of the two endangered fish species.

The San Juan River Basin Recovery Implementation Program (SJRIP) was initiated in 1992 with the following two goals:

1. To conserve populations of Colorado pikeminnow and razorback sucker in the basin, consistent with the recovery goals established under the Endangered Species Act, 16 U.S.C. 1531 et seq.

2. To proceed with water development in the basin in compliance with federal and state laws, interstate compacts, Supreme Court decrees, and federal trust responsibilities to the Southern Utes, Ute Mountain Utes, Jicarillas, and the Navajos.

Emphasis within the SJRIP has been placed on identifying limiting factors and implementing actions to meet the environmental needs of the endangered fish species. Ongoing and proposed activities under the SJRIP include reregulation of flows from Navajo Dam to better meet species needs, control of nonnative fishes, propagation of target species, and identification and removal of fish-passage barriers.

The Colorado pikeminnow and razorback sucker were widespread and apparently abundant throughout much of the Upper Colorado River Basin (Upper Basin), including the San Juan River, during the settlement and initial development of the western United States (circa 1870s to 1950s) (Jordan 1891, Koster 1957, Quartarone 1993, Stanford 1994). Jordan (1891) noted that settlers reported both species upstream as far as Durango, Colorado, in the San Juan River system, and three juvenile Colorado pikeminnow were collected in 1936 in the portion of the river now inundated by Lake Powell (Platania 1990). Several other adult and juvenile Colorado pikeminnow were collected in the river during the mid-20th Century, but no thorough fish collecting studies were conducted on the San Juan River until 1978, well after Navajo Dam was completed. VTN Consolidated, Inc. and the Museum of Northern Arizona (1978) sampled the river from near Navajo Dam to Lake Powell in 1978 and collected one juvenile Colorado pikeminnow and reported (second hand) the occurrence of razorback sucker in that reach of river, suggesting that neither species was abundant in the system at that time. Current population size of these fish species is greatly reduced, and recruitment is limited throughout the Upper Basin, including the San Juan River. Decline of the endangered Colorado pikeminnow and razorback sucker in the Upper Basin and San Juan River has been attributed to habitat fragmentation and loss, alteration of historical flow regimes, and other environmental changes associated with the construction and operation of reservoirs. Contaminants, eradication of native fish and stocking of nonnatives as sportfish management activities, and predation and competition by introduced fishes have also been implicated in the decline of the Colorado pikeminnow and razorback sucker (Tyus 1991a, Minckley et al. 1991, USFWS 1997).

In 1987, a 3-year research effort concentrating on the two endangered species was initiated in the San Juan River by the U.S. Fish and Wildlife Service (USFWS), Bureau, New Mexico Department of Game and Fish (NMGF), and Utah Division of Wildlife Resources (UDWR). The study found a number of young and adult Colorado pikeminnow and an adult razorback sucker, confirming that both species still inhabited the San Juan River but apparently in relatively small numbers. These findings prompted reinitiation of Section 7 Consultation (Consultation) on major proposed water projects on the San Juan River. Consultation on the Animas-La Plata Project (ALP) in 1991 resulted in the Bureau agreeing to reoperate Navajo Dam and fund approximately 7 years of research on the San Juan River to study the effect of flow changes. Following Consultation on the Navajo Indian Irrigation Project (NIIP) in 1991, the BIA agreed to assist with funding and to participate in the 7-year research effort. This 7-year research effort was incorporated into the research requirements of the SJRIP when it was formed, and the research has been carried out by a multiagency group including the USFWS, NMGF, Bureau, BIA, UDWR, Bureau of Land Management (BLM), National Park Service, Southern Ute Tribe, Jicarilla-Apache Tribe, Navajo Nation, University of New Mexico, and other organizations.

A major milestone identified for the SJRIP was the development of flow recommendations for the endangered fish species. This milestone was formalized in the Long Range Plan (LRP) in 1995, a document detailing the proposed recovery effort including time lines, budgets, and milestones. Milestone 5.2.7 of the LRP states, "Identify, recommend and implement flows designed to maximize and maintain suitable habitats for all life stages of endangered and other native fish species." The LRP also includes milestones for other potential limiting factors, such as the effects of nonnative species and contaminants. Since flow recommendations were very important to all participants in the SJRIP and their development involved many detailed analyses, they were developed first. This report restricts itself to the issue of flow needs and does not discuss in detail other potential limiting factors. Discussions of other potential limiting factors will be presented in a companion document scheduled for completion in 1999.

Prior to Navajo Dam's regulation of the San Juan River in 1962, flows were highly variable and dominated by the spring snowmelt runoff. Pre-dam (1929 to 1961) mean monthly flows at Shiprock, New Mexico, ranged from a low of 44 cubic feet per second (cfs) in September 1956 to a high of 19,790 cfs in May 1941. Since the closure of Navajo Dam, flows in the San Juan River have been significantly altered by operations that typically store water during the spring runoff and release storage during the summer, fall, and winter months. Peak spring flows at Bluff, Utah, have been decreased by approximately 45%, while the average winter low flow has approximately doubled.

Additional depletions and redistribution of flows have occurred as a result of other large water development projects, including the NIIP and the San Juan-Chama Project. At the current level of development, the average annual flow volume at Bluff has been depleted by approximately 30% (USFWS 1996). Future proposed projects could significantly increase depletions in the basin.

In order to meet the objectives of the SJRIP, and especially Milestone 5.2.7. of the LRP, a number of studies were initiated by the SJRIP with the intent of providing a flow recommendation by 1998. The general plan for these studies was to alter Navajo Dam operations so that resulting flows below the mouth of the Animas River, a major tributary entering the San Juan River about 45 miles (mi) below the dam, would mimic a natural hydrograph. This mimicry primarily related to flow pattern and timing, including a spring runoff peak and low late summer and fall base flows, the primary components of the natural hydrograph altered by Navajo Dam. Consideration was also given to year-to-year variations in size of runoff that reflected the actual runoff conditions of that year in the San Juan Basin. Physical and biological studies were designed to evaluate the response of the aquatic system to these "research flows." Stanford (1994), in a review of studies from other portions of the Upper Basin, suggested that a healthy native fish community is needed for recovery of the endangered species. San Juan River studies emphasized the entire fish community, especially the native fish community, rather than concentrating on only the two endangered species. The physical studies concentrated on learning how the river functioned, especially in relation to formation and maintenance of habitats that were important to the native fish community. This involved intensive studies on the river's hydrology and geomorphology as well as development of a method to measure habitat at various flow levels.

This report is an integration of flow-related portions of various individual projects that were initiated as part of the SJRIP 7-year research plan. The purpose of this report is to provide initial flow recommendations for the San Juan River that promote the recovery of the endangered Colorado pikeminnow and razorback sucker, maintain important habitat for these two species as well as the other native species, and allow the evaluation of continued water development potential in the basin in light of the recommended flows. In addition, this report contains recommendations for Navajo Dam operations to meet the flow recommendations and fulfill commitments made as part of the ALP and NIIP Biological Opinions.

Specific objectives for this report include:

- Identify the range of flows (annual and seasonal) that will promote the recovery of endangered Colorado pikeminnow and razorback sucker in the San Juan River.

- Make recommendations for Navajo Dam operations to meet recommended flows that take into account the hydrology of the system, the physical capacities of Navajo Dam, and other institutional requirements.

The flow recommendations discussed in this report are considered an initiation of a process, rather than numbers that are "fixed in stone." These recommendations may be refined in the future as new information becomes available. The flows recommended in this report are based on the best knowledge of the San Juan River system at the time the report was being prepared. As new knowledge is gained and new management actions are taken, the evaluation of that information will be used to refine the recommendations. This refinement is part of an adaptive management process that will continually update the assumptions and models used to develop these flow recommendations.

Determination of flow requirements for aquatic ecosystem protection is an evolving science. During the 1960s and early 1970s, research concentrated on identifying minimum flows necessary to maintain the minimum habitat necessary to sustain a particular target species. In the 1970s the research progressed to examining flow/habitat relationships, thus quantifying habitat conditions over a range of flows with the ability to optimize habitat availability. Tools such as the Physical Habitat Simulation System (PHABSIM) and the Instream Flow Incremental Method (IFIM) were developed as a result of this work (Stalnaker et al. 1995).

Researchers now recognize the limitations of these habitat models and the need to more clearly define the processes that form important habitats, in addition to the potential range of flow conditions needed to maintain them (Osmundson et al. 1995). A goal stated by researchers working with IFIM is to identify new methods of determining flow requirements that include the link between flow events (floods or droughts) in preceding years upon habitat availability in the current year (Stalnaker et al. 1995).

More recently, studies are focusing on the importance of the natural flow regime, recognizing that temporal (intra- and interannual) flow variability is necessary to create and maintain habitat and to maintain a healthy biological community in the long term. The processes that link hydrology, geomorphology, habitat, and fish species are being recognized as important, yet these relationships are not always well understood. Recent literature suggests that restoring a more natural hydrograph by mimicking the variability in flow that existed before human intervention provides the best conditions to protect natural biological variability and health (McBain & Trush 1997, Williams et al. 1997, Poff et al. 1998, Richter et al. 1998).

Mimicry of the natural hydrograph is the foundation of the flow recommendation process for the San Juan River. The linkages between hydrology, geomorphology, habitat, and biology were used to define mimicry in terms of flow magnitude, duration, and frequency for the runoff and base-flow periods. The flow characteristics of these linkages were compared with the statistics of the pre-Navajo Dam hydrology to assist in fine-tuning the recommendations. The flow/geomorphology relationship, based on the examination of historical changes in flow regimes and 7 years of research emphasizing the channel's response to specific flow conditions, was a major component of this process. The geomorphology/habitat relationship was examined for the key habitat conditions appearing to be most at risk in the system or the most critical to the species. These relationships relate to the creation and maintenance of the particular habitats used by the rare fish. The flow/habitat availability relationship, once the habitats are created and maintained, was also identified and included in the flow recommendation process. A major step used to develop flow recommendations was identification of habitats important to the various life stages of each species studied and relating that information to the availability of those important habitats under differing flow scenarios. This step is critical to the identification of the most important or most limiting habitats, since those habitats become the primary focus of the flow recommendations. Finally, the direct response of the species studied to research flows was included to identify biological responses that may not be directly addressed in the relationships linking physical and biological processes.

While the San Juan River studies completed over the last 7 years do not answer all of the key questions on biological responses to flows and the linkages described, the studies do demonstrate the importance of maintaining a naturally shaped hydrograph and providing flow variability from year-to-year. In addition, certain durations and frequencies of specific flow magnitudes in the range of 500 to 10,000 cfs are identified as having particular importance in the creation and maintenance of geomorphological features and habitat that are both important to the species and provide a positive response in at least some of the native fish community. A reservoir operation process is recommended that will maintain the specified conditions and preserve the natural flow variability.

Section 5.7 of the LRP states "Implement and maintain an adaptive management program to ensure conduct of appropriate research and management activities to attain and maintain recovery of endangered fish species." "Adaptive management" is a process where lessons learned are used to adjust and refine an ongoing process. The SJRIP uses this process in its research and management activities. For example, the stocking of endangered fish was not envisioned in the LRP until 1997 or later, but actual stocking was initiated in 1994 when it became clear that existing population levels in the San Juan River system were too low to measure responses. It is anticipated that continued annual monitoring and assessment of the fish community's response to the flow recommendations will be used to adjust the flow recommendations in the future, according to this adaptive management program. It is important to recognize that continued monitoring is necessary, and future adjustment to the flow recommendations is likely, as more is understood about the processes and the response of the fishes to the restored hydrologic regime. The ability to adaptively manage the system is important because flow recommendations can be refined in response to the emerging understanding of the mechanisms involved in recovery of the endangered species in the San Juan River.

This report is one of two reports that address the results of the 7-year research program. This report focuses on the analysis and integration of biological, hydrologic, and geomorphic data to determine flow needs of the endangered fishes. A companion report, to be produced in 1999, will compile and synthesize all results from the 7-year research program not covered in this document. The companion report will also specifically address issues such as contaminants, propagation, nonnative species control, and fish-passage needs.

DOCUMENT ORGANIZATION

Chapters 2 and 3 of this document summarize background information concerning the physical and biological aspects of the SJRIP study area (study area). This summary primarily includes a review of river conditions pre- and post-Navajo Dam, and important life history aspects of the San Juan River fish community. Chapter 4, the major chapter of the document, describes the results of various studies conducted during the 7-year research period as they relate to flow recommendations. This chapter includes information on the research flows that were produced by reoperation of Navajo Dam, how those flows affected river geomorphology and fish habitat, and how the fish community responded to the flows. The biological basis for the flow recommendations is also discussed in Chapter 4.

Chapter 5 is a brief review of contaminants and water quality in the San Juan River. Chapter 6 summarizes the pertinent information found in Chapters 2, 3, 4, and 5 that formed the basis for the flow recommendations. Chapter 7 describes the modeling process that was used to turn the biological and physical information utilized in developing flow recommendations into a process that can be used to determine when flow recommendations are met and what level of water development may still be available in the basin. Chapter 8 presents the flow recommendations, summarizes modeling results, and provides a set of Navajo Dam operating rules for meeting the flow recommendations. Appendix A is a response to comments from the Peer Review Panel and SJRIP Coordination Committee on the December 4, 1998, draft of this report. Some of the responses resulted in changes that are reflected in this final version of the report, and others were most appropriately answered separately.

Throughout the document, English equivalents are used for most measures, although some common metric equivalents are also used. For example, fish measurements are typically made in millimeters (mm) and this report follows that fashion. However, the river was divided into River Miles (RM), and flows are typically described in terms of cfs, or acre-feet (af), so these English conventions were followed to make the document more understandable to the majority of the target audience.

CHAPTER 2: GEOMORPHOLOGY, HYDROLOGY, AND HABITAT

Formation and maintenance of aquatic habitat necessary for the native fish community are controlled by the physical (geomorphological and hydrological) characteristics of the river. This habitat response occurs in two ways: as a direct response to the flow in the river and as a secondary response to changes in channel morphology induced by hydrologic events. For example, cobble transport necessary for the formation of Colorado pikeminnow spawning bars is related to the stream gradient, cobble size, channel cross-section, and river flow. Definition of the flow conditions necessary to develop and maintain Colorado pikeminnow spawning habitat requires an understanding of these physical relationships in the San Juan River. Similar relationships exist for other habitat types, so an understanding of the history of physical processes that have acted upon the San Juan River and a characterization of the physical description of the river as it exists today are essential to the development of flow recommendations. This chapter discusses the physical characteristics of the San Juan River, how they are related to and affected by flow regime, how this physical environment has changed as a result of human influence in the basin, and what this means for fish habitat in the river today.

GEOMORPHOLOGY

General Description

The San Juan River Basin, from headwaters to the confluence with the Colorado River, covers an area of 24,945 square miles (mi^2), and the San Juan River runs a distance of 355 mi in Colorado, New Mexico, and Utah. The basin's climatic zones range from high elevation alpine forests (up to 14,000 feet (ft)), to low elevation arid plateaus at 3,700 ft. Approximately 224 mi of river (from Piute Farms Marina, located at the interface between Lake Powell and the San Juan River, to Navajo Dam) are included in the study area (Figure 2.1). Of the remaining river, 54 mi are within the inundated area of Lake Powell, and 77 mi are upstream of Navajo Dam. These areas are not included in the SJRIP because they either are not affected by river operations (Lake Powell) or are above the present range of the two endangered fishes. The following general discussion of the San Juan River's geomorphology will be limited in scope to the study area (the portion between Piute Farms at RM 0 and Navajo Dam at RM 224).

The contact geology of the San Juan River Basin ranges in age from Precambrian to Holocene. The lithology at the headwaters of the San Juan Mountains is primarily crystalline, igneous, and metamorphic. Sedimentary sandstone, siltstone, and shale of both marine and continental origin underlie the lower river reaches found in the study area (Thompson 1982). Much of the floodplain and adjacent terraces within the study area are overlain by Quaternary sand, gravel, and cobble deposits. These alluvial deposits were derived from the resistant igneous and metamorphic rock of the river headwaters, thereby providing a rich source of durable cobble throughout the study area (Miser 1924, USGS 1957). The active sediment load (bedload and suspended sediment) in the system mainly originates from the highly erodible sedimentary rock and aolian sand deposits.

The river is canyon bound through approximately one-third of the study length (lower 67 mi and upper 9 mi). The remainder flows through less-confined valleys of varying widths, thus allowing some lateral channel movement.

The first major sediment source in the study area, Canyon Largo, occurs 19 mi downstream of Navajo Dam. The frequency of similar ephemeral tributaries with high sediment loads increases downstream, thereby disproportionately increasing total sediment load relative to flow in the main river. The result is an extremely high sediment load in the lower reaches of the river. This large, active sediment load in the lower river plays an important role in the formation and maintenance of instream habitat.

The total sediment transport regime has changed in the San Juan River as climatic cycles and land management have changed. Daily suspended sediment concentration data were collected for the San Juan River near Bluff, Utah, from 1930 through 1980. During the period 1930 to 1942, the system yielded approximately 47,200,000 tons of suspended sediment per year. After very high flood flows occurred in 1941 and 1942 (4.2 and 3.1 million acre-feet (maf) with peak flows at 33,800 and 42,500 cfs respectively), suspended sediment load dropped to an average of 20,100,000 tons between 1943 and 1973. Suspended sediment load dropped again after 1973, to an average of 10,100,000 tons between 1974 and 1980, although flow was slightly higher than during the 1943 to 1973 period. This latter drop in sediment load could be partially because of improved sampling techniques in recent decades; however, analyses have shown that sampling bias does not account for the entire shift and that some degree of true sediment reduction has occurred in the system (Thompson 1982).

Analysis of aerial photographs from 1934 to 1937, 1950 to 1954, 1960 to 1963, and 1988 indicates changes in the channel corresponding with reduced sediment load over time. The 1930s photography shows a sand-loaded system, particularly below Four Corners. Where the channel was not confined by canyon walls, the river was broad at high flow and heavily braided at low flow. Aerial and oblique photographs from the period show that even the canyon reach between Bluff and Piute Farms was saturated with sand.

Between the mid-1930s and the early 1950s, the channel had narrowed by an average of 29% between the confluence with Chinle Wash (RM 67) and the location of Navajo Dam (RM 224), and riparian vegetation had begun to immobilize the floodplain. Between the early 1950s and the early 1960s, the channel continued to narrow by another 3% in this reach, and vegetation became more dense. Between the early 1960s and 1988, the channel narrowed to 35% of the width measured in the 1930s. Narrowing in the later period corresponds to two major changes: the modification of flows by Navajo Dam beginning in 1962 and the encroachment of Russian olive that invaded and became established in the basin between the early 1960s and 1988. These changes resulted in

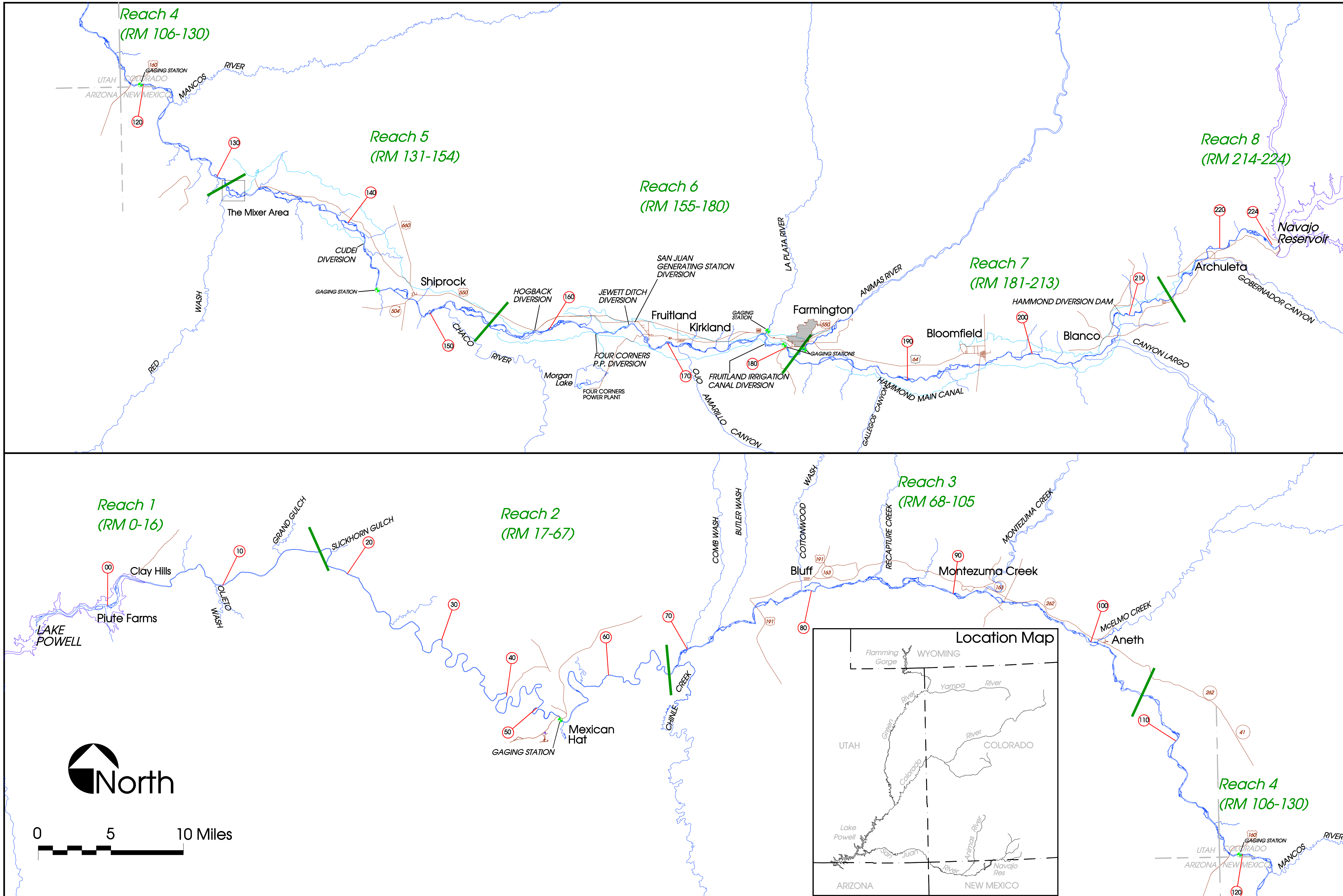


Figure 2.1. San Juan River Basin Recovery Implementation Program (SJRIP) research study area.

stabilized channel banks, a somewhat deeper, narrower main channel, and fewer active secondary channels, especially in the upper reaches. In addition, the comparison of photos taken between the 1930s and 1988 indicates a substantial loss of sand from the system since the 1930s.

There is some evidence that the sediment-laden condition of the river in the 1930s was not typical of the longer term historical condition. Heavy overgrazing of the basin in the last half of the 19th century, in conjunction with appreciable El Nino effects around the turn of the century (Bryan 1925, Graf 1987, Philander 1989, Gellis et al. 1991), caused heavy erosion in the basin and system sediment loading that, over time, has been gradually moving out of the system. Although no specific evidence of San Juan River conditions prior to European settlers exists, writings from explorers in the area during the early part of the 19th century describe tributaries that are now deep, heavily eroded arroyos with broad channels as narrow, shallow streams (Bryan 1925). The difference between these pre-settlement anecdotal accounts and later photographs suggests that by the 1930s, the San Juan River had already been extensively modified by human activity.

Comparison with Green and Upper Colorado Rivers

The largest Upper Basin populations of Colorado pikeminnow and razorback sucker are found in the middle and lower Green River below Flaming Gorge Dam and in the Colorado River from the Grand Valley Diversion to Lake Powell. Because much of the available life history information on the endangered fishes was gathered from these areas, a comparison of physical features was appropriate. Although the San Juan River carries less water than either system (33% of flow of Colorado River at Cisco, Utah, and 41% of flow of Green River at Green River, Utah, 1931 to 1993), it is most comparable, geomorphologically, to the Colorado River from the Grand Valley Diversion to Cisco. The cobble bar complexes in the vicinity of Grand Junction, Colorado, are similar to those between RM 130 and RM 180 in the San Juan River, although the Colorado River complexes are larger in scale and mean cobble diameter (Bliesner and Lamarra 1995). The gradient of the San Juan River in the study reach is most similar to the Green River from Green River, Utah, upstream to Desolation Canyon and the Colorado River from Westwater Canyon upstream to the Grand Valley Diversion near Grand Junction (Figure 2.2). Compared with the Green and Colorado rivers, the San Juan River has a more uniform gradient. The Green River is characterized by low-gradient reaches (confluence with Colorado River to Green River, Utah, and from Desolation Canyon to Jensen, Utah) between high-gradient canyon reaches. The Colorado River is much flatter below Cisco than the San Juan River, having about the same gradient as the Green River below Green River, Utah.

While the San Juan, Colorado, and Green rivers have similar sediment loads (10,100,000; 9,300,000; and 9,500,000 tons/year, respectively, for the period 1974 to 1980), the San Juan River has by far the highest sediment concentration relative to the other two rivers because of its lower discharge. Sediment concentrations averaged nearly 4,800 parts per million (ppm) for the San Juan River during this period, and only 1,250 ppm and 1,500 ppm, respectively, for the Colorado and Green rivers (Hydrosphere 1998). Further, the Colorado River did not have the large shift in sediment concentration between the 1943 to 1973 and 1974 to 1980 periods exhibited in the San Juan River, and to a lesser degree, in the Green River. The sediment load in the earlier period is twice the later

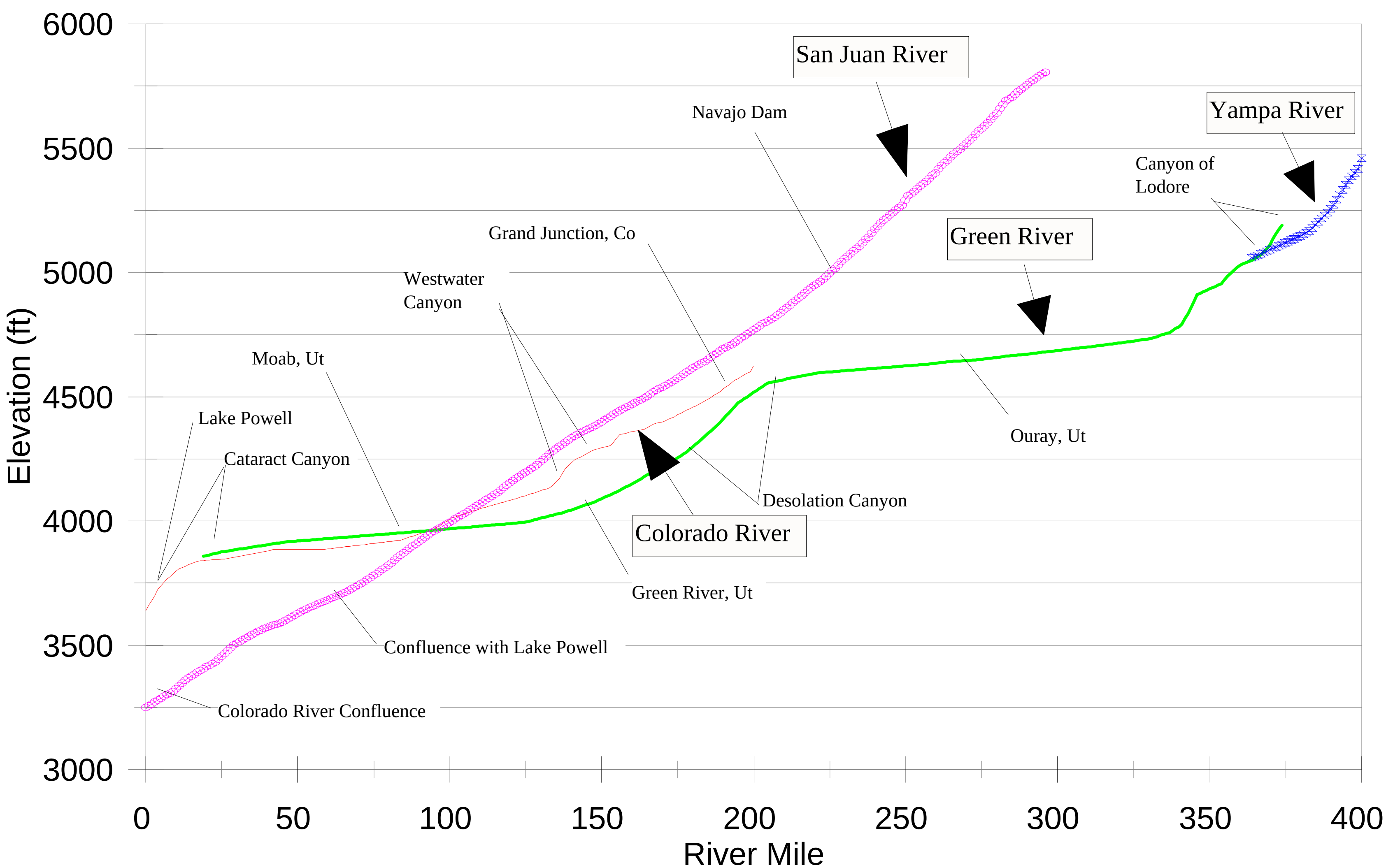


Figure 2.2. Generalized bed profiles for San Juan, Green, Yampa, and Colorado rivers.

period for the San Juan River and 1.6 times for the Green River, while the Colorado River was no different.

SJRIP Study Area

The study area defined by the SJRIP covers the San Juan River between the Lake Powell confluence and Navajo Dam. To more accurately assess river system response to research flows, this study area was analyzed for gross fluvial geomorphological characteristics, geology, and habitat availability. Habitat was determined by on-the-ground mapping of the river using aerial photographs developed from recent (within a few days or weeks) videography of the entire study area. Habitat types used in the mapping were similar to habitats used for other endangered fish studies in the Upper Basin and are shown in Table 2.1. The field mapping of habitat types was then digitized into a Geographic Information System (GIS).

The geomorphology varies considerably in the study area. While the gradient does not vary greatly, it is generally steeper in the upper portion of the river and flatter in the downstream portion, gradually changing over the full reach (Figure 2.2). Some cobble exists in the substrate throughout the study reach, with the exception of the lower 16 mi, but the percent composition relative to sand decreases with distance downstream. Through the valley reach (middle 150 mi), the river is primarily characterized as multithreaded (multiple channels separated by vegetated islands), with dense to moderately-dense riparian vegetation, moderate slope, and low channel sinuousity. Human-induced impacts include enhancement of riparian vegetation because of irrigation return flow, elevated groundwater adjacent to irrigated lands, and the presence of five diversions between RM 140 and RM 180 that affect bed elevation.

To better characterize the river and to allow for comparison among various reaches, eight distinct geomorphic reaches were defined based on an array of geomorphic features (Bliesner and Lamarra 1995), as described in Table 2.2 and shown in Figure 2.1. The reaches are numbered from the lower to the upper end, according to river mile. The following sections briefly describe the general characteristics distinguishing each of the reaches.

Reach 1 (RM 0 to 16, Lake Powell confluence to near Slickhorn Canyon) has been heavily influenced by the fluctuating reservoir levels of Lake Powell and its backwater effect. Fine sediment (sand and silt) has been deposited to a depth of about 40 ft in the lowest end of the reach since the reservoir first filled in 1980. This deposition of suspended sediment into the delta-like environment of the river/reservoir transition has created the lowest-gradient reach in the river. This reach is canyon bound with an active sand bottom. The thalweg meanders in the sand bottom, alternately scouring runs and sand shoals and depositing sandbars along the thalweg at all discharges. At low flow (below 1,000 cfs), backwaters form in main channel sandbars. At flows above 1,000 cfs, backwaters form in tributary mouths and invaginations in the canyon walls, and main channel backwaters are lost as the low sandbars are inundated. While this reach has the highest abundance (surface area per river mile) of backwaters among the reaches studied, the locations of backwaters are highly unpredictable and ephemeral because of the shifting thalweg, changing river flow, and varying seasonal and annual reservoir elevations.

Table 2.1. The major habitat types mapped in the San Juan River from color plates taken from airborne videography.

HABITAT	DEFINITION
Abandoned Channel (dry)	Non-flowing secondary channel.
Backwater	Typically an indentation of channel below an obstruction, water depth from < 10 cm to > 1.5 m, no perceptible flow, substrate typically silt or sand and silt. Occurs at mouths of dry secondary channels and tributaries, lower ends of eddy return channels, mouths of dry scour channels, and behind debris.
Backwater Pool	Same as backwater except maximum depth > 2 m.
Boulders	Large (> 30 cm diameter) rocks in channel.
Chute	Rapid velocity (**$**30 cm/sec) portion of channel (often near center) where gradient **$**10 cm/m. Channel profile often U- or V- shaped. Depth typically **$**30 cm. Substrate cobble or rubble and often embedded.
Cobble Bar	Bar of exposed substrate consisting primarily of cobble, usually found within the river channel but may be located along river bank.
Debris Pool	Same as pool, except organic debris such as tree limbs or tumbleweeds in pool.
Eddy	Same as pool, except water flow usually evident (but slow) and direction typically opposite that of channel or circular.
Edge Pool	Same as pool, except along shore and typically present downstream of shoreline or instream obstructions.
Embayment	Similar to backwater but formed when water pools up at upstream end of secondary channel with little or no outflow into the secondary channel.
Inundated Vegetation	Riparian vegetation inundated by flowing or non-flowing water; formed when river water overflows bank.
Irrigation Return	Channel where water is returning to river after application to agricultural fields.
Island	Dry, typically vegetated area of land surrounded by water and located within the river channel.
Isolated Pool	Small body of water in a depression, old backwater, or side channel that is isolated from the main channel as a result of receding flows.
Overhanging Vegetation	Vegetation hanging over river bank, often touching the water surface.
Pocket Water	Slackwater areas with little or no flow occurring amongst boulder clusters; usually located in canyon areas.
Pool	Area within channel where flow is not perceptible or barely so; water depth usually **$**30 cm; substrate is silt, sand, or silt over gravel, cobble, or rubble.
Rapid	Rapidly flowing (> 150 cm/sec) water over boulder substrate; typically found in steep canyon areas.
Riffle	Area within channel where gradient relatively steep, water velocity moderate to rapid (60 to 120 cm/sec), and water surface disturbed. Substrate usually cobble and portions of rocks may be exposed. Depths vary from <5 to 50 cm, rarely greater.
Riffle/Chute	Same as riffle except tail of riffle terminates in a chute (**>**120 cm/sec), gradient steeper (> 5 cm/m), and cobble substrate often embedded.
Riffle Eddy	Area adjacent to riffle where water velocity slow to moderate (5-10 cm/sec) and flow often circular. Substrate sand, gravel, or cobble. Depths usually about same as adjacent riffle or slightly deeper.
Rootwad Pile	Woody debris located within river channel.
Rootwad Pool	Pool formed by areas of rootwad piles; typically found along river margin.
Run	Typically, moderate to rapid velocity (30-90 cm/sec), and little or no surface disturbance. Depths usually 30-120 cm but may exceed 120 cm. Substrate usually sand but may be silt in slow velocity runs and gravel or cobble in high velocity runs.
Run/Riffle	Similar to run but some surface disturbance evident, typically shallower and swifter, and substrate usually cobble or rubble.
Sand Bar	Same as cobble bar but composed primarily of sand or silt substrate.
Scour Run	Same as run and where direction of flow cuts along or into bank.
Sand Shoal, Cobble Shoal	Generally shallow (< 15 cm) areas with laminar flow (< 30 cm/sec). Such areas found most often on inside bends of river meanders or at downstream ends of islands or bars.
Shoal/Riffle	Intermediate between shoal and riffle, consists of steep, lateral cobble bar with shallow (< 15 cm) and fairly rapid (> 30 cm/sec) flowing water.
Sand Shoal/Run, Cobble Shoal/Run	Same as shoal, except deeper (> 15 cm) and faster flowing (> 30 cm/sec), with either a sand or cobble substrate.
Shore Riffle	Same as riffle but along shore of channel, such areas do not extend across entire channel.
Shore Run	Same as run and where direction of flow parallel to bank with no obvious cutting.
Slackwater	Low -velocity (0 to 20 cm/sec) habitat usually along inside margin of river bends, shoreline invaginations, or immediately downstream of debris piles, bars, or other in-stream features.
Tributary	Tributary channel with flowing water entering main river channel.
Undercut Run	Same as run but with overhanging bank, often bound by rootmasses of riparian vegetation.

Table 2.2. Reach definitions, variables considered, and their mean values within each reach used in defining geomorphically different reaches.

CATEGORY	REACH	1		2		3		4		5		6		7		8
	RIVER MILE	**0-16**		**17-67**		**68-105**		**106-130**		**131-154**		**155-180**		**181-213**		**214-224**
HABITAT - m^2/mi																
High Flow	Total Water Surface	152,314	...[a]	97,161	...	199,049	...	171,983	...	206,925	...	133,983	...	102,519		150,883
	Low Velocity Types	1,920		2,015		1,481		1,893		1,861	...	946		1,241		13,642
	Riffles/Chutes	42	...	27,697		30,139		31,237		43,041	...	10,816	...	3,713	...	13,050
	Sand Type	5,704	...	363	...	15,132	...	279		3,224	...	760		1,615		337
	Cobble Type	0		43	...	3,726	...	120		147	...	632		364	...	1,692
	Islands 3 mi average	0		109	...	84,708	...	117	...	266	...	584		529		534
Intermed. Flow	Total Water	136	...	74,415	...	123,940		119,980		122,787						
	Low Velocity Types	4,646		1,192	...	2,136		2,256		2,546						
	Riffles/Chutes	3,827	...	19,013		14,373	...	252	...	38,382						
	Sand Type	43,108	...	1,962	...	8,932		6,923		3,392						
	Cobble Type	1,011		2,342	...	7,139		7,785	...	3,655						
	Islands 3 mi average	200		320	...	51,940	...	82,210	...	188,055						
Low Flow	Total Water Surface	114,291	...	72,142	...	113,314	...	104,522		107,422	...	92,933	...	77,043		94,636
	Low Velocity Types	2,239	...	890	...	1,897		2,026	...	4,328	...	8,929	...	732	...	17,921
	Riffles/Chutes	9	...	16,865		14,683		16,113	...	26,164		26,641	...	6,746	...	30,260
	Sand Type	26,112	...	1,125	...	7,195		5,526	...	2,918	...	586		1,337		0
	Cobble Type	309	...	1,522	...	2,572	...	403		3,197		2,584		3,185		2,988
	Islands 3 mi average	0		173	...	44,473	...	71,249	...	196,178	...	21,675	...	46,921		60,728
RIPARIAN VEGETATION - m^2/mi																
	Cottonwood					6,094	...	2,847		4,909	...	10,043				
	Russian Olive					26,643		28,701	...	46,053	...	35,119				
	Tamarisk					25,167	...	31,224		32,536	...	19,124				
	Willow					6,592		7,393	...	3,007		4,499				
	Upland Herbaceous					1,811		7,182	...	15,801	...	9,569				
	Upland Shrub					7,897	...	7,056	...	2,349		2,647				
	Wetland Herbaceous					524		718	...	8,737		11,509				

Table 2.2. Reach definitions, variables considered, and their mean values within each reach used in defining geomorphically different reaches (continued).

CATEGORY	REACH	1		2		3		4		5		6		7		8
	RIVER MILE	**0-16**		**17-67**		**68-105**		**106-130**		**131-154**		**155-180**		**181-213**		**214-224**
CHANNEL - 3 mile average																
	Valley Width - m	102	...	66	...	1122	...	986	...	2299		2028		1957	...	574
	Channel Slope - ft/ft	0.00105	...	0.00178	...	0.00143	...	0.00164	...	0.00193	...	0.00209		0.00213	...	0.00160
	Sinuosity	1.00000		1.00001	...	1.09096	...	1.12311	...	1.16862		1.18715		1.15081	...	1.19527
STREAM CHANNEL CONTACT																
	Bedrock - m/mi					206		182		243		140				
	Eroding Bank - m/mi (Sand/Gravel/Cobble)					713	...	324		323		316				
	Contains Sand					93.6%	...	96.4%		86.2%		84.6%				
	Contains Gravel					29.7%	...	31.1%	...	7.8%	...	26.5%				
	Contains Cobble					34.6%		64.0%		62.2%		58.1%				
	Sand Only					86.1%	...	66.4%		68.7%		41.0%				
	Gravel Only					21.3%	...	9.3%		6.2%		10.8%				
	Cobble only					15.2%		21.7%		23.2%		25.3%				
CATEGORICAL VARIABLES																
	Adjacent Irrigated Area - %	0.0%		0.0%		23.7%		0.0%		83.3%		100.0%		100.0%		30.0%
	Major Tributary - Ephemeral	0		0		6		3		2		0		2		2
	Major Tributary - Perennial	0		0		2		1		1		3		1		0
	Bridge	0		1		4		1		1		2		2		1
	Diversion	0		0		0		0		1		4		1		1
	Oil Well	0		2		4		0		0		0		0		0
	Pipe Crossing	0		0		1		0		2		1		0		0
	Borrow Pit	0		1		1		0		0		0		0		5
	Pond	0		1		6		2		2		0		0		0
	Road	2		1		6		0		0		0		0		0
	Sewage Treatment	0		0		3		0		3		3		0		0

[a] ... = not equal to.
Note: Shaded rows show significant variables.
Source: Bliesner and Lamarra 1995.

Reach 2 (RM 17 to 67, near Slickhorn Canyon to confluence with Chinle Creek) is also canyon bound but is located above the influence of Lake Powell. The gradient in this reach is higher than in either adjacent reach and the fourth highest in the system. The channel is primarily bedrock confined and is influenced by debris fans at ephemeral tributary mouths. Riffle-type habitat dominates, and the major rapids in the San Juan River occur in this reach. Because of the steeper gradient, narrow canyon bottom, and low sinuosity, backwater habitats are small and scarce in this reach. Low-velocity habitats are primarily created as sand deposits in eddies below debris fans. While sandbar-associated backwaters are present, they are often associated with either debris fan/eddy complexes or eddy deposits below shoreline colluvium. Some oil development exists within an isolated area of floodplain in this reach, near the town of Mexican Hat, Utah.

Reach 3 (RM 68 to 105, Chinle Creek to Aneth, Utah) is characterized by higher sinuosity and lower gradient (second lowest) than the other reaches, and a broad floodplain, multithreaded channel, high island count, and high percentage of sand substrate. This reach has the second highest density of backwater habitats after spring peak flows, but is extremely vulnerable to change during summer and fall storm events, after which this reach may have the second lowest density of backwaters. As a result, this reach is the most highly responsive reach to extreme discharge events, primarily summer and fall storm events. While cobble is present in this reach, it is frequently mixed with sand. Areas of clean cobble are usually small and ephemeral. The active channel results in a large number of organic debris piles (dislodged Russian olive trees) at lower flow.

Reach 4 (RM 107 to 130, Aneth, Utah, to below "the Mixer") is a transitional reach between the upper cobble-dominated reaches and the lower sand-dominated reaches. It has the most bedrock contact of any reach. Sinuosity is moderate compared with other reaches, as is gradient. Island area is higher than in Reach 3 but lower than in Reach 5, and the valley is narrower than in either adjacent reach. Total water surface area is somewhat less at all flows than in the adjacent reaches. River banks are more stable in this reach than in Reach 3, and about the same as in Reaches 5 and 6. Backwaters in this reach are subject to perturbation from summer and fall storm events, but Reach 4 is not as responsive as Reach 3. Backwater habitat abundance is low overall in this reach (third lowest among reaches) and there is little clean cobble. Perturbation of secondary channels because of summer and fall storm discharges occurs frequently in this reach. One perennial tributary, the Mancos River, enters the San Juan River in this reach.

Reach 5 (RM 131 to 154, the Mixer to just below Hogback Diversion) is predominantly multithreaded with the largest total wetted area (TWA) and largest secondary channel area of any of the reaches. Secondary channels tend to be longer and more stable than in Reach 3 but fewer in number overall. Riparian vegetation is more dense in this reach than in lower reaches but less dense than in upper reaches. Cobble and gravel are more common in channel banks than sand, and clean cobble areas are more abundant than in lower reaches. Channel gradient in Reach 5 is steeper than in all lower reaches but flatter than in Reaches 6 and 7. This is the lowermost reach where adjacent irrigated lands and irrigation return flow influence riparian vegetation and bank stability, and contribute to groundwater accretion. The river valley is broadest in this reach. One perennial tributary, Chaco Wash, enters the San Juan River in this reach. This is the lowermost reach containing a diversion (Cudei). Backwaters and spawning bars in this reach are much less subject to perturbation during summer and fall storm events than the lower reaches.

Reach 6 (RM 155 to 180, below Hogback Diversion to confluence with the Animas River) is predominately a single channel, with 50% fewer secondary channels than Reaches 3, 4, or 5. Cobble and gravel substrates dominate, and cobble bars with clean interstitial space are more abundant in this reach than in any other. Irrigated land adjoins the river for the full length of this reach, often on both sides of the river. There are four diversions that may impede fish passage in this reach (Figure 2.1). Backwater habitat abundance is low in this reach, with only Reach 2 having less. Gradient is the second steepest of all reaches, although about 10% of the elevation change occurs at the diversions, making the effective slope about the same as that in Reach 5. Two perennial tributaries enter in this reach: the LaPlata River, which carries little water to the San Juan River except during runoff, and the Animas River, which is the largest tributary to the San Juan River in the study area. A third tributary, the Ojo Amarillo, is naturally ephemeral but is effectively perennial at present because of irrigation return flow. Irrigation return flow influences riparian vegetation and groundwater accretion in this reach. The channel has been altered by dike construction in several areas to control lateral channel movement and overbank flow.

Reach 7 (RM 181 to 213, Animas River confluence to between Blanco and Archuleta, New Mexico) is similar to Reach 6 in terms of channel morphology, with about the same secondary channel count, TWA, and valley width. Irrigated land adjoins most of this reach on both sides of the river, and groundwater accretion contributes to an increase in grass understory. The river channel is very stable. The reduction in magnitude of peak flows with the construction of Navajo Dam caused a reduction in overall shear stress and a reduced ability to move large-grained embedded cobble. In addition, much of the river bank has been stabilized and/or diked to control lateral movement of the channel and overbank flow. While the dominant substrate type is cobble, armoring has occurred that, coupled with the bank armoring and grass understory, limits availability of new cobble sources within this reach. Water temperature is influenced by the hypolimnetic release from Navajo Dam and is colder during the summer and warmer in the winter than the river below the Animas confluence. Sediment load is also reduced because of the sediment-trapping influence of the dam and limited tributary influence resulting in relatively clear water compared with downstream reaches.

Reach 8 (RM 213 to 224, between Blanco and Archuleta and Navajo Dam) is the most directly influenced by Navajo Dam, which is situated at its uppermost end (RM 224). This reach is predominantly a single channel, with only four to eight secondary channels, depending on the flow. This reach has the lowest number and TWA of secondary channels of any reach above the lower canyon (Reaches 1 and 2). The valley narrows in this reach, with less irrigation influence and less artificial stabilization of the channel. Cobble is the dominant substrate type, and because lateral channel movement is less confined in this reach, some loose, clean cobble sources are available from channel banks. In the upper end of the reach, just below Navajo Dam, the channel has been heavily modified by excavation of material used in dam construction. In addition, the upper 6.2 mi of this reach above Gubernador Canyon are essentially sediment free, resulting in the clearest water of any reach. Because of Navajo Dam, this area experiences much colder summer and warmer winter temperatures. These cool, clear water conditions have allowed development of an intensively managed blue-ribbon trout fishery to the exclusion of the native species in the uppermost portion of the reach.

HYDROLOGY

No hydrology data exist for the San Juan River that pre-date the early water development in the basin. While the pre-Navajo Dam hydrograph was natural in shape, it was depleted in volume by about 16% from natural conditions, with most of the depletion coming during the summer months. Since the depletion prior to Navajo Dam was relatively small and the flow was not regulated by major storage reservoirs, the conditions during the pre-dam period are used to judge effects of later development and the value of future modification of the hydrology for the benefit of the endangered fishes.

Daily flow data recorded by the U.S. Geological Survey (USGS) (Hydrosphere 1998) from 1929 through the present are available for the San Juan River. These data have been used to analyze the changes in hydrology with time. The San Juan River's hydrology was very different before regulation by Navajo Dam began in 1962. Hydrology is discussed separately for the two periods (pre- and post-dam eras) to contrast the change. In addition, research flow period hydrology is discussed separately, indicating the restorability of more natural hydrologic conditions.

Pre-Navajo Dam (1929 to 1961)

The San Juan River is typical of dynamic rivers in the southwestern United States that are characterized by large spring snowmelt peak flows, low summer and winter base flows, and high-magnitude, short-duration summer and fall storm events. For the period 1929 to 1961 at the USGS gage station near Bluff, approximately 72% of the total annual discharge occurred during spring runoff between March 1 and July 31. The median daily peak discharge (peak daily mean discharge as recorded by USGS does not represent instantaneous peak flow) during spring runoff was 10,500 cfs, with a range of 3,810 to 33,800 cfs. The average pre-dam hydrograph (average of all daily flows from 1929 to 1961) for the San Juan River near Bluff is shown in Figure 2.3.

While the spring runoff produces the largest total volume of water, about 30% of the time the yearly peak flow does not occur during spring. Furthermore, the maximum daily average discharge for the period during spring is 33,800 cfs, while the maximum daily average discharge annually is 42,500 cfs. This difference is because of summer and fall storm events. These summer and fall storm events have a small impact on the total water supply, but because of the heavy sediment load, these events substantially influence habitat formation and maintenance.

The magnitude of summer and fall storm events in the San Juan River Basin is higher in relation to the median flow than those noted in the Colorado and Green river basins. In the San Juan River, 97% of the years between 1929 and 1961 had at least one storm event during the period of August

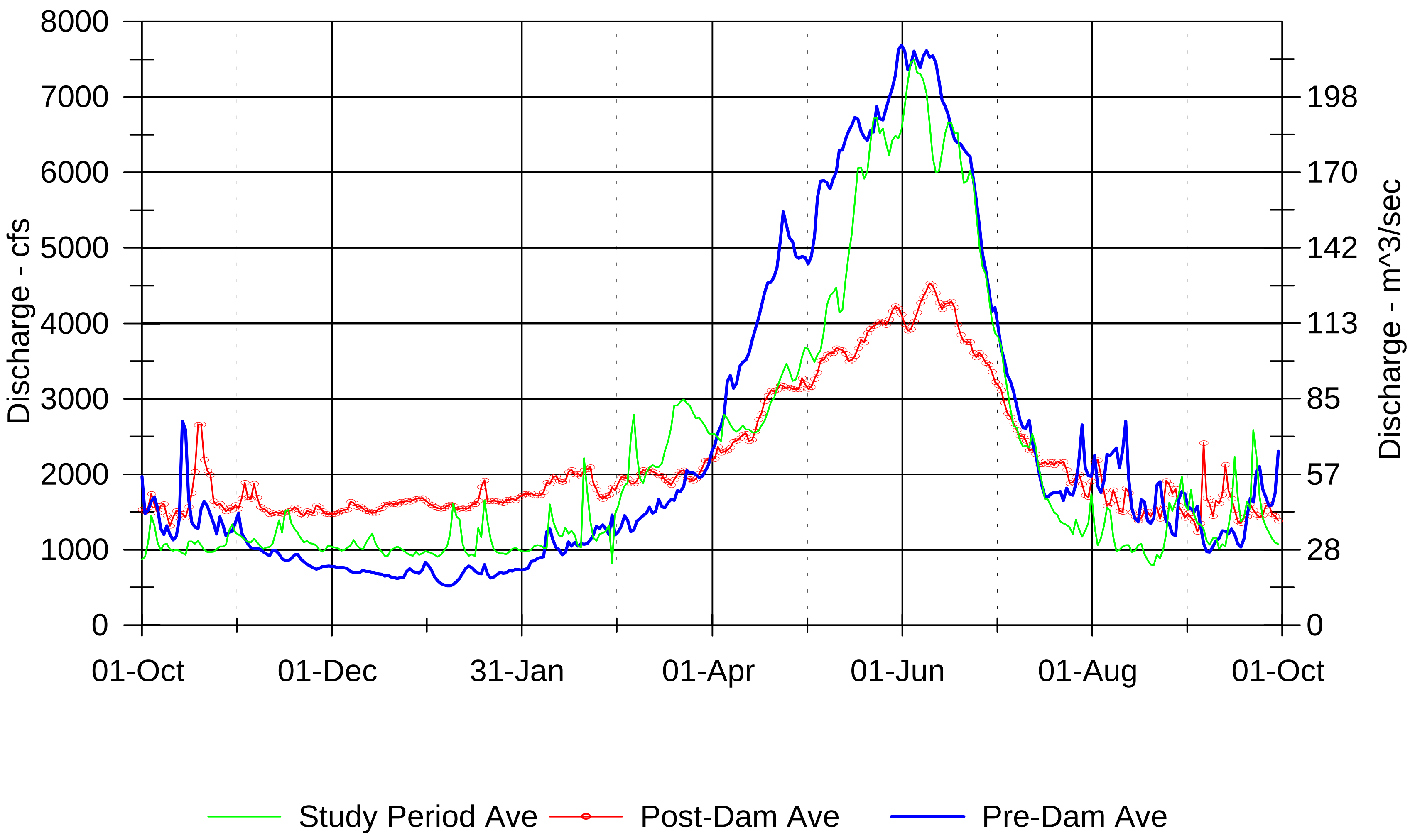


Figure 2.3. San Juan River near Bluff, Utah, average hydrographs for pre-dam, post-dam, and 7-year research period.

through November that resulted in flows three or more times the average base flow (mean daily flow of the river during nonsnowmelt, nonstorm runoff periods). Fifty-five percent of the time, the resultant discharge was eight or more times the base flow, with a maximum daily mean peak to average base-flow ratio of nearly 13. In comparison, neither the Green River gage nor the Colorado River gage has ever recorded a storm event with a daily mean peak greater than five times the base flow.

The frequency of summer and fall storm events is also higher in the San Juan River Basin compared with the Green or Colorado rivers. For the period 1929 to 1961, the San Juan River Basin had nearly five times as many days per month with storm events above two times the average base flow. The comparison of average monthly ratios of maximum mean daily flow to daily average flow for the month for the three rivers, along with the average duration of flows above two times the base flow for the three rivers, appears in Table 2.3.

Table 2.3. Comparison of storm magnitude and frequency for the Colorado River at Cisco gage, Green River at Green River gage, and San Juan River near Bluff gage.

	RATIO AVE MAX DAILY /AVG MONTHLY DISCHARGE			AVG NO. OF DAYS FLOW EXCEEDED 2 TIMES AVE MONTHLY FLOW		
Month	**Colorado R. at Cisco**	**Green R. at Green R.**	**San Juan R. near Bluff**	**Colorado R. at Cisco**	**Green R. at Green R.**	**San Juan R. near Bluff**
Oct	1.59	1.46	3.08	0.36	0.12	3.31
Nov	1.24	1.24	1.87	0.00	0.12	0.90
Dec	1.26	1.39	1.75	0.06	0.00	0.66
Jan	1.22	1.25	1.83	0.00	0.00	0.84
Feb	1.24	1.34	1.96	0.00	0.06	1.98
Mar	1.41	1.80	1.91	0.06	2.16	1.38
Apr	1.89	1.74	1.81	1.98	0.96	1.14
May	1.72	1.60	1.78	0.96	0.30	1.02
June	1.54	1.42	1.75	0.18	0.00	0.84
July	1.87	1.90	2.70	1.08	1.56	4.15
Aug	1.75	1.62	3.52	0.84	0.24	5.53
Sep	1.84	1.66	3.78	0.78	0.36	4.99
Ave	1.55	1.54	2.31	0.53	0.49	2.23

High annual discharge variability is also a characteristic of the San Juan River. The annual discharge near Bluff for the pre-dam period ranged from 618,000 af to 4,242,000 af with a median of 1,620,000 af. Furthermore, the hydrology appears to follow cyclic patterns of multiple years of high flow followed by multiple years of low flow where up to 4 sequential years may have total annual discharge less than 1,000,000 af.

Although the pre-dam era is considered relatively natural, irrigation and other water development depletions have occurred annually since the settlement of the San Juan River Basin in the late 1800s. As a result, the pre-dam hydrology was not pristine. Summer and winter base flows during the pre-dam period were low but variable. Typically, summer flows were lowest because of irrigation depletions, and periods of near zero flow were not uncommon. Flows of less than 50 cfs have a recurrence frequency of 29%, with an average duration of 11 days. Monthly mean flows were as low as 65 cfs.

Post-Dam Period (1962 to 1991)

Completion of Navajo Dam and subsequent dam operation substantially altered the natural hydrograph of the San Juan River below the dam. Although the Animas River ameliorated some effects of the dam and maintained an elevated spring runoff, the system overall experienced an appreciable reduction in magnitude and change in timing of the annual spring peak. In years of high runoff, dam releases began earlier than under pre-dam conditions to allow space in the reservoir to store the runoff. In the wettest years, releases continued through the peak season (May and June), but during many years, dam releases in May and June were close to the average base release of about 600 cfs. The peak discharge during the post-dam period averaged 54% of the spring peak during the pre-dam period.

Base flows were substantially elevated in the post-dam compared with the pre-dam period. The median monthly flow for the base-flow months of August through February averaged 168% of the pre-dam period. Minimum flows were also elevated. The near-zero flow periods were eliminated, with a minimum monthly flow during base-flow periods of 250 cfs compared with 65 cfs for the pre-dam period. Summer storm runoff was not directly affected by the dam, especially in terms of high sediment input, because these events can be generated below the influence of the dam. Hydrologic statistics from the two periods are compared in Table 2.4. The average post-dam hydrograph (average of daily flows for 1962 to 1991) is shown in Figure 2.3, allowing comparison with the average pre-dam hydrograph.

Research Period (1992 to 1997)

Also shown in Table 2.4 are the statistics for the research flow period (1992 to 1997), compared with the pre- and post-dam periods. While some more-natural hydrologic conditions were restored during the 7-year research period, peak magnitude was not matched because of outlet work operating restrictions at Navajo Dam and uncertainty about channel capacity above 5,000 cfs. Because of the short period of record, the statistics are not directly comparable, but these numbers give an idea of how this period compares with the other two periods. On average, this period was about 8% wetter than the pre-dam and 19% wetter than the post-dam period, with a much smaller range of annual flows than during either period. Figure 2.3 shows the average hydrograph for the 7-year research period for comparison with pre- and post-dam hydrographs. Because 1991 was a control year without dam reoperation, it is included with the post-dam period rather than the 7-year research

Table 2.4. Comparison of hydrograph statistics for pre-dam (1929 to 1961), post-dam (1962 to 1991), and research periods (1992 to 1997) for the San Juan River near Bluff, Utah.

PARAMETER	1929-1961 PRE-DAM PERIOD			1962-1991 POST-DAM PERIOD			1992-1997 STUDY PERIOD		
	Average	**Minimum**	**Maximum**	**Average**	**Minimum**	**Maximum**	**Average**	**Minimum**	**Maximum**
Peak Runoff - cfs	12,409	3,810	33,800	6,749	2,660	15,200	8,772	3,280	11,600
Runoff (Mar-Jul) - af	1,263,890	352,551	3,361,882	891,712	177,190	2,458,190	1,132,899	421,001	1,681,192
Runoff (total annual) - af	1,750,643	618,101	4,241,998	1,587,242	611,196	3,266,017	1,628,165	797,821	2,271,912
Runoff (total annual) - af, adjusted to pre-dam depletions							1,898,000	1,068,000	2,542,000
	Years	**Total Yrs**	**Frequency**	**Years**	**Total Yrs**	**Frequency**	**Years**	**Total Yrs**	**Frequency**
Peak>10,000 cfs	18	33	55%	6	30	20%	2	6	33%
Peak>8,000 cfs	22	33	67%	11	30	37%	5	6	83%
Peak>5,000 cfs	30	33	91%	16	30	53%	5	6	83%
Peak>2,500 cfs	33	33	100%	27	30	90%	6	6	100%
AF>1,000,000	18	33	55%	12	30	40%	4	6	67%
AF>750,000	22	33	67%	14	30	47%	5	6	83%
AF>500,000	30	33	91%	20	30	67%	5	6	83%
	Ave Date	**Std Dev**		**Ave Date**	**Std Dev**		**Ave Date**	**Std Dev**	
Peak Date	31-May	23		Jun-04	35		07-Jun	8	
Flow duration	Avg all yrs	Avg flow yrs	Maximum	Avg all yrs	Avg flow yrs	Maximum	Avg all yrs	Avg flow yrs	Maximum
Days>10,000 cfs	14	27	76	3	15	48	2	7	8
Days>8,000 cfs	23	34	81	8	22	84	10	12	22
Days>5,000 cfs	46	51	108	28	52	124	51	62	109
Days>2,500 cfs	82	82	140	67	74	150	90	90	137
Base Flow	Median	High 10%	Low 10%	Median	High 10%	Low 10%	Median	High 10%	Low 10%
August	1,156	4,782	300	1,566	3,242	407	1,107	2,497	476
September	1,033	3,383	201	1,174	3,279	478	1,286	2,760	861
October	1,000	2,551	400	1,608	3,317	635	1,089	1,521	716
November	752	1,387	497	1,199	3,205	765	1,141	1,479	982
December	667	1,325	434	1,288	3,389	711	1,049	1,187	769
January	609	1,267	471	1,440	3,226	582	934	2,053	739
February	872	2,265	572	1,661	3,188	823	1,006	2,256	807

period. The 7-year research period was preceded by a significant drought from 1988 to 1992. Figure 2.4 shows the annual hydrographs at Four Corners for 1987 to 1990, and Figure 2.5 shows the annual hydrographs for the San Juan River at Four Corners for the 7-year research period (1991 to 1997).

WATER TEMPERATURE

Water temperature data for the San Juan River have been collected and reported by the USGS since 1948. Consistent data collection began in 1950 or 1951 at most stations. While there are missing data for all stations, sufficient data exist to examine the effect of Navajo Dam on water temperatures below the dam. Figure 2.6 presents the 5-day running average daily water temperature for the period of available record before and after construction of Navajo Reservoir at Archuleta and Shiprock, New Mexico. The cooling effect of the reservoir is obvious at both locations, although it is much more pronounced at Archuleta because of the dam's proximity. As a check on the comparison of these two periods, the temperature conditions for the Animas River at Farmington, New Mexico, were compared, indicating much less difference between the two periods than between either of the San Juan River sites. Based on the results shown in Figure 2.6 and assuming a 20E C threshold for Colorado pikeminnow spawning on the descending limb of the hydrograph (see Chapter 3), it appears that the pre-dam condition at Archuleta would have allowed spawning at that site by about the same date as the post-dam condition at Shiprock. The post-dam conditions at Archuleta were likely too cold for successful Colorado pikeminnow spawning, and the threshold temperature was reached about 2 weeks later on average at Shiprock.

Nine temperature recorders were installed in the San Juan River in the summer of 1992 (Bliesner and Lamarra 1995, 1996). Figure 2.6 shows the average daily temperature of the San Juan River for the period 1992 to 1997 projected for Shiprock (correlation to Farmington and Montezuma Creek). The plot shows a temperature depression during runoff (May and June) that was attributable in part to cooler temperatures in the Animas River during this period than during the 1964 to 1986 period. However, the cooler Animas River water accounts for only about one-half of the temperature difference between the 1964 to 1986 and the 1992 to 1997 San Juan River temperature at Shiprock. The increased release of the cool reservoir water into the San Juan River suppressed the water temperature about 1.5E C during runoff. Thus, the threshold spawning temperature at Shiprock was delayed about 1 to 2 weeks from the post-dam period (1963 to 1991).

HABITAT

Aquatic habitat is generally described by either its related bedform, such as cobble bar or shoal, or the effective hydraulic feature, such as riffle, run, or eddy. The approach used usually depends on the desired characteristic of the feature. For example, cobble bars are a bedform described as aquatic habitat because the interstitial spaces and substrate size are important for reproductive success. Alternatively, eddies are described as habitat for adults because the hydraulic circulation provides

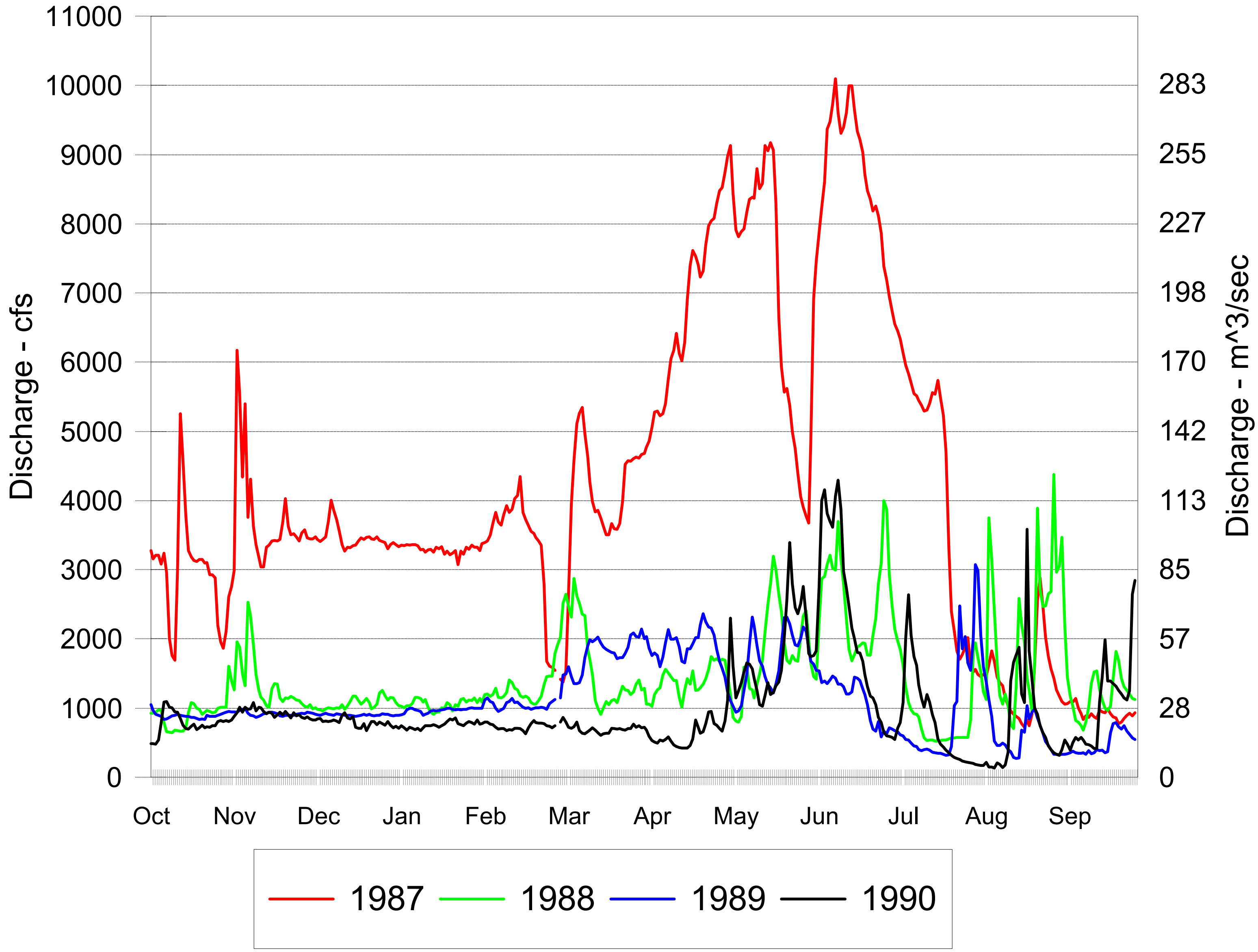


Figure 2.4. **Annual hydrographs for the San Juan River at Four Corners for 1987 to 1990.**

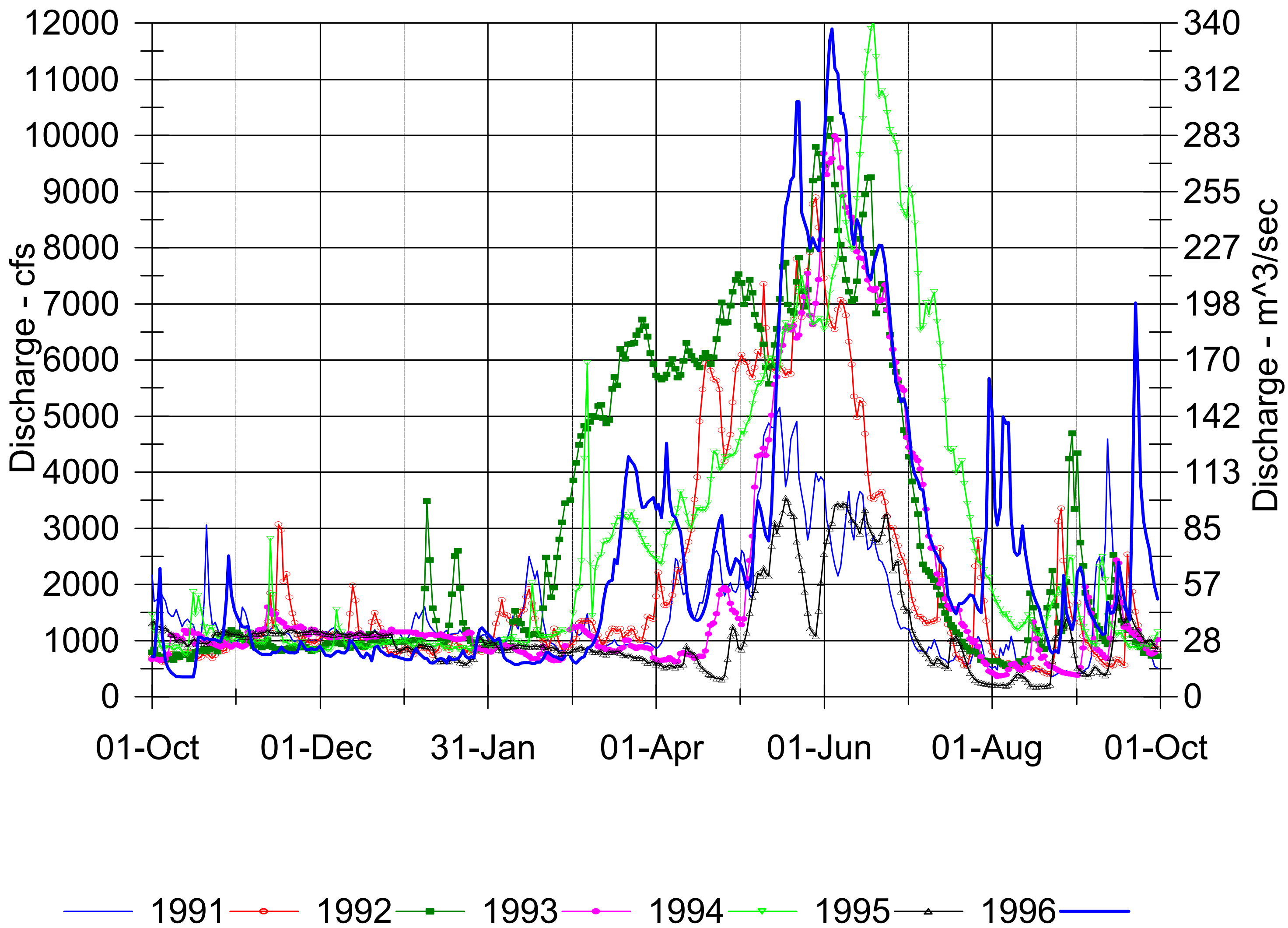


Figure 2.5. Annual hydrographs for the San Juan River at Four Corners for 1991 to 1997.

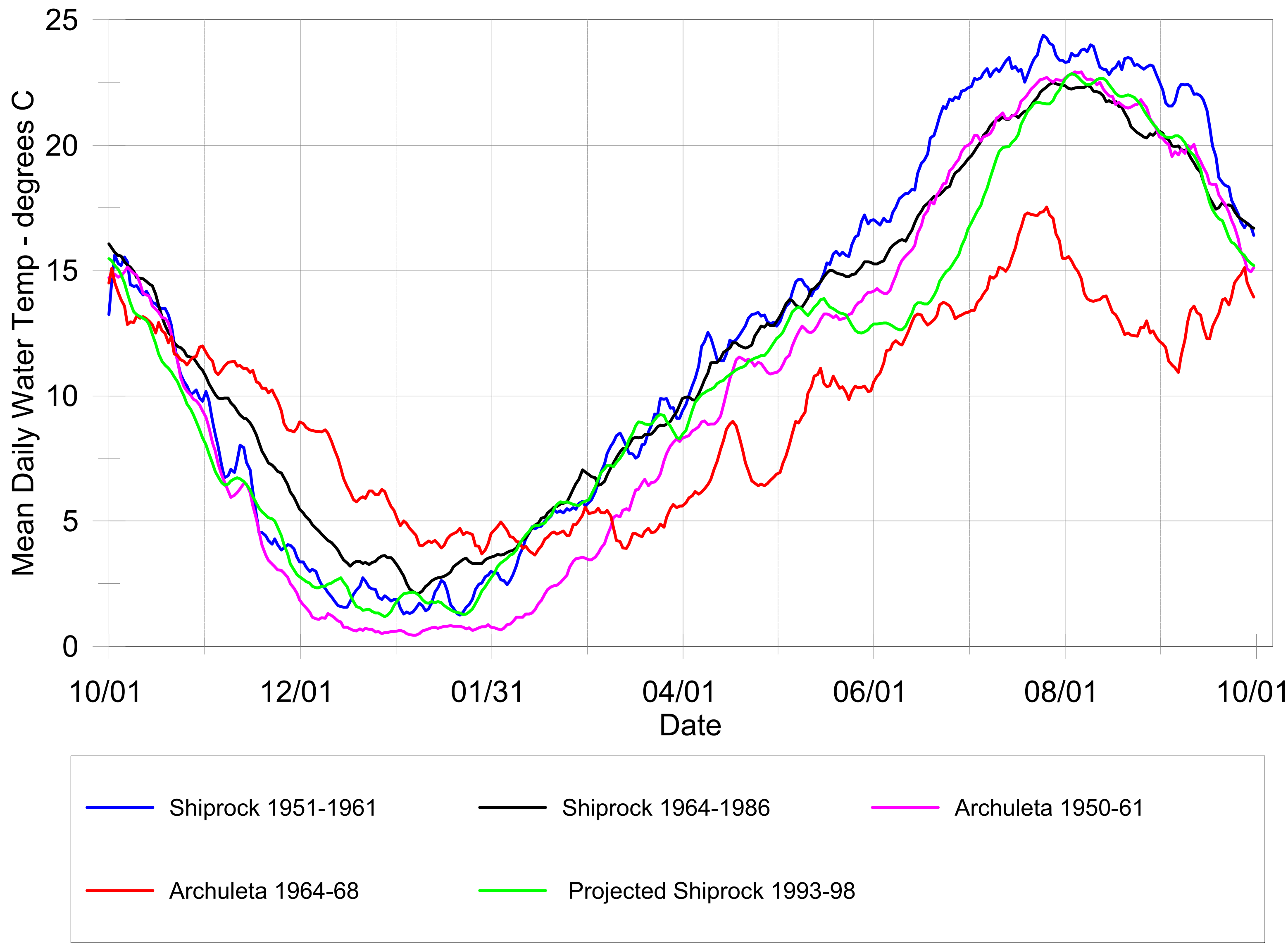


Figure 2.6. **Mean daily water temperature for the San Juan River at Archuleta, New Mexico, and at Shiprock, New Mexico, during pre-dam and post-dam conditions.**

a concentration and deposition of food items. Channel geomorphology and hydrology directly affect aquatic habitat conditions, both in quantity and quality. Several habitat types have been identified as important and perhaps limiting to the endangered Colorado pikeminnow and razorback sucker; these habitats have been the focus of habitat studies. In particular, spawning habitat may limit reproduction, and nursery habitat (backwaters and low-velocity habitat) is known to be crucial to the survival of young Colorado pikeminnow in their first year (Holden and Selby 1978, Valdez et al. 1982). In addition, certain hydraulic habitats are important for adult feeding and resting. The following discussion describes some specific relationships between flow regime and habitat quantity and quality, as well as the relationships between river reach and habitat quantity and quality that are known to be important to the endangered and other native species.

Habitat Quantity

Colorado pikeminnow and razorback sucker spawning habitat (clean cobble/gravel) maintenance depends upon flows producing sufficient shear stress to transport cobble and remove sand from the interstitial spaces. These conditions may occur during cobble bar formation at relatively high flows in the system or during cobble bar reshaping at somewhat reduced flows on the descending limb of the spring peak. Regular reworking and mobilization of the cobble are required to prevent the armoring or embedding of cobble substrates by the predominately sand bedload.

Certain flows are required on an annual basis to shape substrate and scour fine sediment to create and maintain backwaters and other low-velocity habitats. Both the magnitude and duration of the spring peak can affect the quality and quantity of backwater habitat. Large, deep, more-permanent backwaters have been noted as preferred by young-of-the-year (YOY) Colorado pikeminnow over shallow, ephemeral backwaters (Holden 1977). High sediment input during summer and fall storm events fills low-velocity habitats with sediment, reducing the availability and quality of these habitats during crucial post-larval Colorado pikeminnow growth periods. The extent to which these habitats become filled, and subsequently unavailable to fish during late summer base flows and storm events, depends on the duration and magnitude of the spring peak flows that form and maintain them relative to the summer flows that may fill or destroy them.

The distribution and abundance of all habitat types (bedforms and hydraulic) are affected by both snowmelt runoff flows and base flows. To characterize the distribution and abundance of habitat in the San Juan River and to measure the response of habitat to flows over a 7-year period, aquatic habitat was mapped on 11 separate occasions during different seasons, years, and flow levels. Mapping has been completed for the entire 224 mi of the San Juan River from Lake Powell to Navajo Dam, but the most intensively mapped reach was between RM 154 and RM 2, constituting Reaches 1 to 5.

As defined in Table 2.1, 37 habitat types were identified to map the river, and these types were divided into the eight general categories shown in Table 2.5. Mapping occurred in the field using recent aerial videography from 1991 to 1997 as the base map. Maps were entered into a GIS for analysis. Processing the data in the GIS produced coded polygons (habitats) for which surface areas

Table 2.5. Eight general categories of habitat types on the San Juan River.

LOW VELOCITY TYPES	RUN TYPES	RIFFLE TYPES	BACK-WATER TYPES	SHOAL TYPES	SLACK-WATER TYPES	VEGETATION ASSOCIATED HABITAT TYPES	OTHER TYPES
pool	shoal/run	riffle	backwater	sand shoal	slack-water	overhanging vegetation	isolated pool
debris pool	run	shore riffle	backwater pool	cobble shoal	pocket water	inundated vegetation	cobble bar
rootwad pool	scour run	riffle chute	embayment				rootwad pile
eddy	shore run	shoal/ riffle					abandoned channel (dry)
edge pool	undercut run	chute					sand bar
riffle eddy	run/riffle	rapid					tributary
							island
							irrigation return
							boulders

were computed and sorted individually. The data were then retrieved and analyzed by cross-tabulation of the factors being correlated (e.g., habitat area by RM).

To compare habitat availability at various flow levels, the mapping data were summarized for three flow levels: <700 cfs; 3,000 cfs; and >7,000 cfs (Figure 2.5). Run-type habitats (Table 2.5) were the most common for all San Juan River flow levels (Figure 2.7). These habitat types were 81.5%, 84.3%, and 79.6% of the TWA for the high-, medium-, and low-flow mapping runs, respectively (Figure 2.7).

Riffle and shoal habitat types represented the second most abundant habitat types found in the San Juan River at medium and low flows. Riffle habitats were found to be 5.7% at medium flows and 6.0% at low flows, while shoals were 3.2% and 9.5% for medium and low flows. At high flows, riffles and shoals were only 0.5% and 2.3% of the TWA, respectively. However, inundated vegetation was 5.6% of the TWA at high flows, the only flows where this habitat type was greater than 1% of the TWA.

Slackwaters and low-velocity habitats (embayments, eddies, pools, etc.) together made up 3.4% of high-flow habitats, 3.6% of medium flows, and 3.5% of low flows. Backwater types had the lowest overall percent of TWAs with 0.5%, 0.3%, and 0.9% for high, medium, and low flows, respectively.

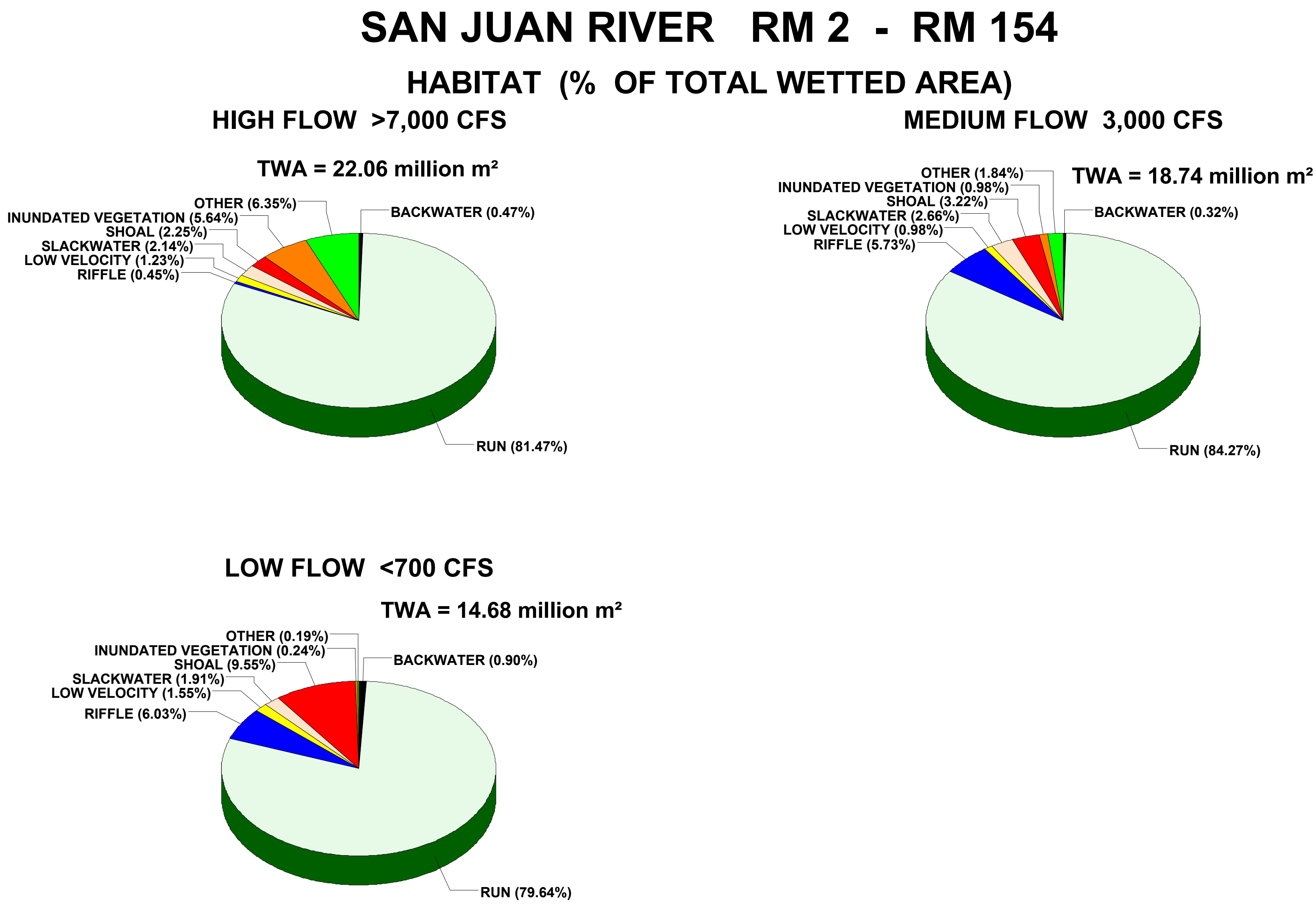


Figure 2.7. Habitat types as a percent of total wetted area (TWA) for the San Juan River at three flow levels.

Based upon the habitat-use information gathered for many of the native fishes and especially for the two endangered species in the Upper Basin, as well as on the San Juan River (see Chapters 3 and 4 for more detail), many of the habitats that are relatively rare in the San Juan River are typically heavily used. Even though relatively rare in the San Juan River, the quantity of many of these habitats varies with flow. Based on Figure 2.7, low-velocity habitat quantity makes up a larger amount of the available habitat at low flows (1.55% of habitat), and is lowest at intermediate flows (0.98% of habitat). Backwaters, as a percent of total habitat, nearly double (0.47% to 0.90% of habitat) from high flows (>7,000 cfs) to low flows(<700 cfs). The percent of shoal area also dramatically increases at low flows (2.25% to 9.55% of habitat) compared with high flows.

Pools and eddies are also important native fish habitats, and both are included in the low-velocity types (Table 2.5). An analysis similar to the one shown in Figure 2.7 reveals that pool habitat is also somewhat lower at high flows, but eddy habitat tends to increase with flow.

Run habitats are the most common habitat (as a percent of the TWA) at all flows. Although runs are used by the native fish community, the less numerous low-velocity backwater, shoal, and riffle habitats are used more than would be expected based on their availability, and they are generally considered more important than runs. These habitats, which tend to reach greatest densities at low flows, show distinct spatial patterns throughout the river. Figure 2.8 shows the longitudinal distribution of the eight major habitat types by geomorphic reach during September 1995 at a low flow of 1,000 cfs.

In Reach 1 (which is canyon bound but under the influence of Lake Powell), habitats other than runs were dominated by shoals comprising 20% of the total habitat. These shoals were midchannel features with a shifting sand substrate. Reach 2, which is also canyon bound, had riffles and riffle-associated slackwaters as the second most common habitat. Few shoals were present in this steeper gradient reach of the river. Reach 3 appeared to be a transitional reach between the canyon reaches (1 and 2) and the multichannel upper reaches (4 to 7), with intermediate levels of riffles, slackwaters, and shoals. Reaches 4 through 7 tended to be dominated more by run habitat than the reaches above (Reach 8) or below (Reaches 1 to 3). Reach 8, immediately below Navajo Reservoir, was mostly single channel with shallow gradient and numerous shoals. Reach 3 contained the highest amount of backwater habitat at base flow (1.54% of TWA). With the exclusion of runs and backwaters, the remaining minor habitat types appear to be equally distributed as a percent of the TWA in Reaches 4 to 7.

In summary, habitat quantity varies in the San Juan River with both flow level and location in the river. Run habitats dominate, and many of the other habitats important to the native fish community are relatively rare in the system, but specific flow levels can maximize the amount of these habitats.

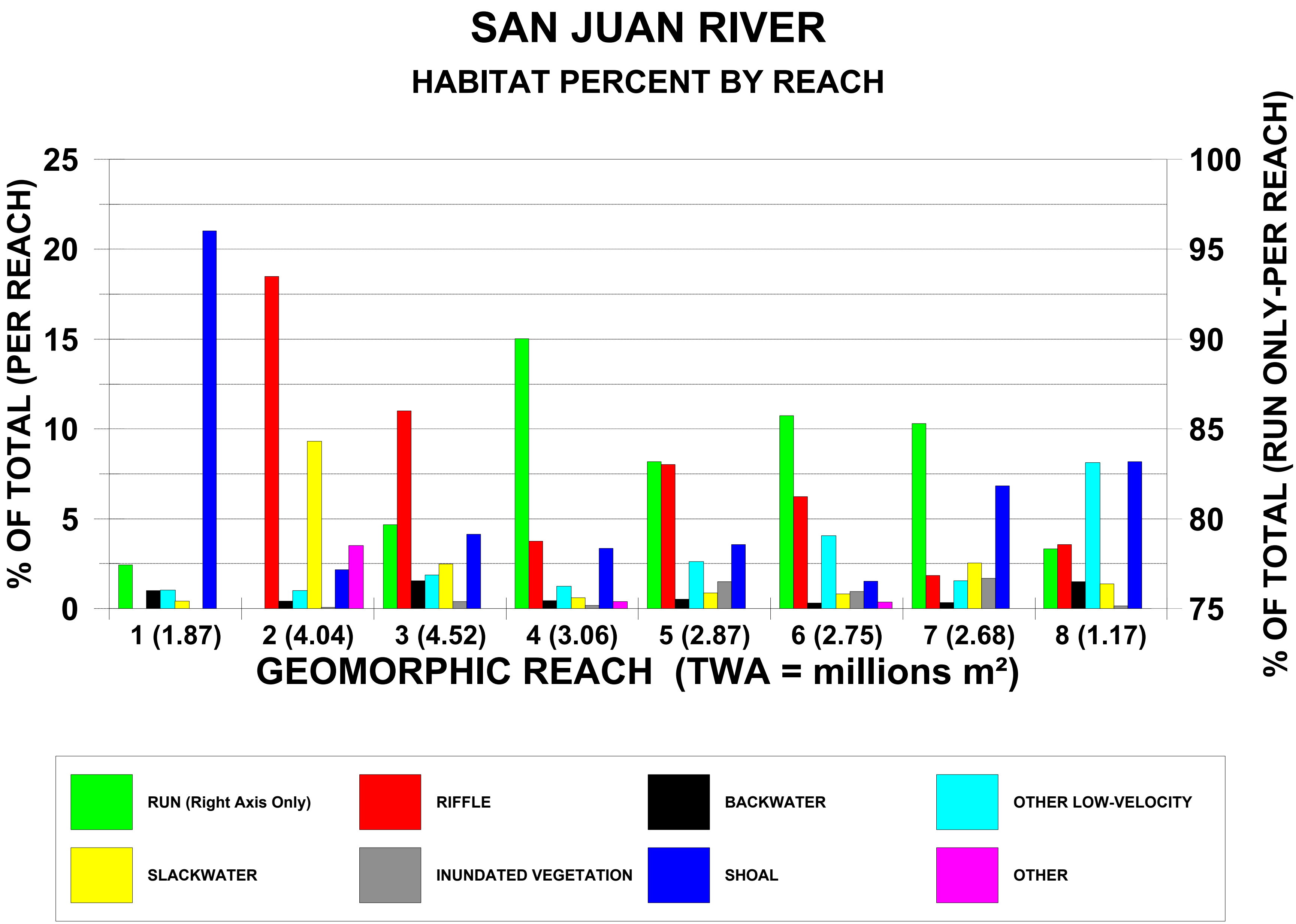


Figure 2.8. **The distributions of the major habitat types by geomorphic reach for a base-flow condition (September 1995).**

Habitat Quality

Habitat quality relates to the features (size, depth, productivity) of a particular habitat that define how well that habitat may support the native fishes. The primary factor that negatively affects habitat quality in the San Juan River, as well as most other rivers, is fine sediment (silt and sand).

Fine sediment generally enters the river during spring runoff and storm activity. During spring runoff, flows are typically high enough to move the fine sediments down the system or deposit them on islands and shorelines. During storm-event flooding, flows are typically insufficient to move the heavy sediment load brought in from tributaries downstream or to shoreline areas, resulting in deposition in various habitats. The filling of interstitial spaces in cobble/gravel substrates of higher-velocity habitats such as runs and riffles tends to reduce their quality by limiting the use of those spaces for primary and secondary production, as well as reducing their use as spawning habitat for native fishes.

Lower-velocity habitats such as backwaters and eddies tend to have finer substrate than runs and riffles (Table 2.1), but their quality can also be reduced by the addition of silt and fine sand that accumulate during storm flood events. These low-velocity habitats can fill with silt and fine sand, effectively reducing their depth and smothering primary and secondary production areas. The frequent late summer and fall storm events in the San Juan River cause dramatic reductions in habitat quality in low-velocity habitats because of filling by fine sediments. Bliesner and Lamarra (1995) reported on changes in habitat quality in the San Juan River between samples in November and December 1994 because of a storm event. Sedimentation of 8 to 15 cm of sand occurred in a run in RM 155 during a 3-week period that included a major storm event, and both backwater habitat number and depth were affected by fall storms that year. Perturbation of habitats in the San Juan River because of late summer and fall storm events is likely the most common form of habitat quality degradation in this system (Bliesner and Lamarra 1995, UDWR 1998). Reductions in habitat quality because of fine sediment can be reversed by high flows that scour the fine sediments from the habitats.

Riffle and run habitats are the two most dominant habitat types relative to the TWAs found in the San Juan River (Figure 2.7) and were selected for investigation of general habitat quality in the study area. During 1994, 1995, and 1996, primary and secondary biomass, as well as physical substrate characteristics, were quantitatively determined for replicate run and riffle sites within each geomorphic reach of the San Juan River to provide an estimate of habitat quality. Parameters measured to estimate production were invertebrate dry weight, detritus dry weight, periphyton dry weight, and the total dry weight of all three combined. Substrate parameters measured percent embeddedness and depth of embeddedness primarily related to embeddedness of the cobble substrates. Another measured parameter, D_{50}, estimated the size (diameter) of the median substrate in the study area based on measurement of 100 individual cobbles. Cobble substrates are typically more productive than sand substrates, and more embeddedness generally is related to poorer biological productivity (Hynes 1970, Farnworth et al. 1979).

In order to characterize longitudinal patterns in habitat quality in riffles and runs, the data were sorted by geomorphic reach and averaged over all sample periods. Tables 2.6 and 2.7 contain the mean and standard errors for each parameter when summed over sample period and geomorphic reach.

The mean depth to embeddedness values for each geomorphic reach did not demonstrate significant differences in riffles or runs by geomorphic reach, but did demonstrate significantly greater depth levels in riffles compared with runs for a given geomorphic reach. Although some spatial patterns were evident for mean substrate sizes in geomorphic reaches in riffles and runs, the most obvious differences were the uniformly larger substrates in riffles compared with runs in all geomorphic reaches (Table 2.6). The only exception was in Reach 6, where the riffle and run D_{50} values were similar. Percent embeddedness was lowest in Reach 8, immediately below Navajo Dam. For riffle habitats, Reaches 6 and 7 were the most embedded, although they were not statistically different from the other downstream reaches.

The spatial patterns observed in the biological components (periphyton, macroinvertebrates, and detritus) were very similar, with the upper reaches of the river (Reach 6, 7, and 8) being higher than the middle reaches (Reach 3, 4, and 5). Reach 2 had the lowest concentrations of organic materials, and Reach 1 had densities equal to or greater than the middle and upper reaches. These patterns are exemplified by the macroinvertebrates (Table 2.6).

The information used to compare river reaches was also used to compare runs and riffles over time. The mean and standard error for each parameter when summed over sample period and geomorphic reach is shown in Table 2.7. Substrate characteristics demonstrated significant differences between riffles and runs, as well as seasonal changes (Table 2.7). For example, depth to the embedded layer was significantly greater in riffles compared with runs, which is reasonable because of the higher velocities of riffles. In addition, both riffles and runs had significant increases in the depth to the embedded layer between April 1994 and November 1994, a period that spanned the spring runoff when cleansing of cobbles by removal of fine sediments would be expected (Table 2.7). Between November 1994 and September 1996, the depth values decreased in both habitat types. In contrast, the percent of surface area embedded showed an inverse pattern, with the November 1994 data having the lowest value and increasing from that date until September 1996. The final substrate characteristic, the D_{50} value, was significantly higher in the riffle habitats (mean values of 3.12 to 3.51 inches (in.)) compared with the runs (mean values 1.56 to 2.73 in.) for all sample periods. No significant differences between seasons were found for runs or riffles (Table 2.7).

Biological parameters were measured to define the primary and secondary biomass within riffles and runs. Periphyton biomass was quantitatively measured on substrates in riffles and runs for the five time periods. These data, expressed as riverwide mean values for each sample period (Table 2.7), indicate a similar pattern between the two habitat types with the riffles having the highest mean value. However, the differences between the two habitat types were not statistically different. Macroinvertebrates, which had about the same amount of organic biomass as periphyton, had similar temporal patterns in riffles and runs. April 1994 had the highest levels of biomass, and November

Table 2.6. A comparison of habitat quality features in runs and riffles by geomorphic reach for 1995, 1996, and 1997 combined in the San Juan River.

	% Embeddedness		D_{50} (mm)		Depth to Embedd. (cm)		Invertebrate Dry Weight (gm/m2)		Detritus (gm/m2)		Periphyton (gm/m2)		Total biomass (gm/m2)	
Date	Mean	Std. Err.	Mean	Std. Err.	Mean	Std. Err.	Mean	Std. Err.	Mean	Std. Err.	Mean	Std. Err.	Mean	Std. Err.
Riffles														
1	12.0%		62.60		8.00		6.00		34.40		5.00		45.40	
2	12.2%	3.4%	100.12	6.46	10.17	0.91	0.53	0.13	26.36	4.46	1.49	0.40	28.28	4.34
3	20.7%	6.5%	69.91	7.54	8.53	1.17	1.15	0.67	32.98	11.40	3.37	0.82	37.50	11.39
4	10.8%	3.2%	88.77	4.21	11.15	0.85	3.52	1.05	68.03	14.09	3.49	0.95	75.06	14.60
5	10.4%	2.4%	71.77	5.07	8.93	0.61	1.90	0.52	42.94	8.22	3.67	0.49	48.51	8.58
6	24.4%	4.3%	109.52	9.31	9.29	0.94	5.06	1.42	62.74	10.19	6.09	1.56	73.87	11.61
7	29.2%	5.5%	80.05	8.01	7.59	0.83	5.70	1.33	80.75	23.25	3.89	0.59	90.35	23.23
8	7.1%	1.9%	111.38	12.19	11.13	1.04	19.19	8.53	135.68	36.59	3.65	0.61	158.49	40.70
Runs														
1	70.0%		49.80		3.00		0.50				4.30		4.80	
2	45.2%	6.3%	59.58	8.92	7.31	0.88	0.27	0.16	14.09	3.61	1.28	0.34	15.64	3.69
3	53.0%	8.5%	43.25	8.82	3.86	0.65	0.49	0.20	14.16	3.91	2.71	0.40	17.37	4.23
4	55.2%	10.5%	46.58	10.41	4.54	1.21	0.60	0.25	14.85	3.66	3.37	0.68	18.79	3.76
5	36.2%	4.2%	69.31	6.55	5.40	0.61	0.72	0.25	13.89	3.39	3.01	0.47	15.72	3.22
6	50.9%	6.5%	78.54	11.46	4.86	0.69	1.34	0.40	35.13	8.59	4.09	0.62	40.55	8.98
7	52.9%	6.4%	56.65	13.22	7.59	2.44	2.10	0.64	24.13	6.42	3.40	0.75	29.63	6.96
8	28.1%	11.6%	49.81	12.33	5.38	2.00	5.64	1.72	55.17	26.47	3.49	0.56	57.38	23.93

Table 2.7. A riverwide comparison of habitat quality features for five sample periods in the San Juan River.

	% Embeddedness		D_{50} (mm)		Depth to Embedd. (cm)		Invertebrate Dry Weight (gm/m2)		Detritus (gm/m2)		Periphyton (gm/m2)		Total biomass (gm/m2)	
Date	Mean	Std. Err.	Mean	Std. Err.	Mean	Std. Err.	Mean	Std. Err.	Mean	Std. Err.	Mean	Std. Err.	Mean	Std. Err.
Riffles														
Apr 94	26.6%	6.0%	80.86	9.33	5.25	0.52	8.15	2.04	59.05	15.79	7.19	1.12	74.37	17.88
Nov 94	14.1%	4.2%	93.16	6.42	11.59	0.87	1.91	0.48	51.68	12.10	4.54	0.67	58.13	12.72
Apr 95	14.8%	3.2%	77.29	3.80	10.48	0.65	1.93	0.60	30.26	4.04	2.36	0.29	34.46	4.22
Feb 96	14.0%	2.1%	100.33	6.85	10.09	0.53	8.44	3.20	53.61	9.88	2.83	0.37	64.89	12.38
Sep 96	18.4%	4.7%	90.31	7.91	8.73	0.74	1.22	0.40	96.19	20.87	2.39	0.77	99.79	21.40
Runs														
Apr 94	40.3%	7.6%	74.08	12.21	4.31	0.43	2.84	0.63	36.07	8.33	5.62	0.88	33.19	7.97
Nov 94	32.5%	5.7%	57.63	8.43	7.53	0.94	1.55	0.49	28.36	8.22	3.59	0.40	33.48	8.70
Apr 95	44.0%	4.0%	44.03	7.12	6.04	1.87	0.63	0.22	13.13	2.87	2.52	0.31	16.27	2.88
Feb 96	56.3%	6.4%	71.90	7.31	5.91	0.68	2.10	0.78	14.69	3.29	2.97	0.30	19.77	3.69
Sep 96	56.9%	6.8%	49.62	9.43	4.32	0.79	0.26	0.14	29.05	9.04	1.55	0.43	30.87	9.37

1994 and April 1995 had the lowest levels. In April 1994 and April 1995, riffles had significantly higher invertebrate biomass when compared with run habitats.

Detritus, which represented the largest fraction of organic material sampled in riffle and run habitats, was significantly greater in riffle habitats in three out of five sample periods (April 1995, February 1996, and September 1996). The lowest detrital levels were found in April 1995.
In summary, an analysis of habitat quality in riffles and runs did show some differences between reaches, primarily in biological components in the upper three river reaches (6, 7, and 8). In addition, habitat quality also showed differences among seasons and years.

Comparison with Green and Colorado Rivers

While a full comparison of habitat composition with the Green and Colorado rivers is not possible because of study design differences in the different drainages, some comparisons can be made. Studies in 1990 and 1991 characterized habitat composition in relation to flow for the "15-mile reach" of the Colorado River near Grand Junction, Colorado (Osmundson et al. 1995). The results have been summarized in Table 2.8, showing the percent composition of selected habitat types. Compared with the San Juan River (see Figure 2.7), the 15-mile reach of the Colorado River has a greater abundance of backwater, low velocity, and riffle habitats at all flows. At low flow, backwater habitats constitute almost five times more and other low-velocity habitats three times more of the TWA than in the San Juan River. Even when compared with Reach 1, where backwaters are the most abundant in the San Juan River, backwaters are three times more abundant relative to TWA in the 15-mile reach of the Colorado River. Further, backwater habitat appears to increase with increased flow, counter to the trend in the San Juan River. The responses to flow for the other habitat types in the Grand Valley are similar to the San Juan River.

Table 2.8. Habitat types as a percent of total wetted area (TWA) for the 15-mile reach of the Colorado River at three flow levels.

Flow - cfs	> 7,000	2,000-7,000	<2,000
Backwaters	6.9%	6.6%	4.3%
Other Low-Velocity Types	3.8%	5.3%	6.5%
Runs	78.0%	69.4%	55.2%
Riffles	8.0%	17.7%	23.6%

Source: Osmundson et al. 1995.

Studies by Pucherelli and Clark (1990) and Pucherelli et al. (1990) measured backwaters per river mile in the San Juan and Green rivers. The Green River had three times more backwater habitat than the San Juan River for the areas analyzed. Other characteristics of the San Juan River also were different when compared with the Green and Colorado rivers. The San Juan River exhibited a relatively higher and more-consistent gradient throughout the study reach, resulting in more run and riffle habitats than found in the Green or Colorado rivers. Secondary channels and cobble and gravel substrates also appeared to be more prevalent in the San Juan River than in the lower Green and Colorado rivers.

CHAPTER 3: LIFE HISTORY OF THE FISHES

The native fish fauna of the Colorado River has one of the highest levels of endemism (fishes found only in that basin) of any basin in North America (Miller 1959). In addition, the native fish fauna includes several species highly adapted to swift-water habitats, as well as North America's largest member of the minnow family. The uniqueness of the Colorado River fish fauna includes life history strategies revolving around extensive variations in the annual hydrograph and the ability to live and prosper in a frequently flooded, highly turbid basin. Mainstem dam regulation of much of the Colorado River has changed many of the features necessary for the survival of native fishes and especially the four large mainstem endangered species (Holden 1979). Identification of the native fish community's life history needs, especially for the two endangered species, is essential for the development of flow recommendations.

Nonnative fishes, along with dams, have been implicated as a major factor in the decline of native Colorado River fishes. Minckley and Meffe (1987) suggested that many nonnative species are not as well adapted as the native species to the floods and turbidity found in the Colorado River system. This suggests that nonnative fish life history strategies may be used in the development of flow recommendations in an attempt to reduce their abundance.

This chapter describes the life history of the native and nonnative fish species that have been the focus of the SJRIP studies. The life history information presented here was developed from studies on the San Juan River, as well as through literature sources. The following section relates the biology of each species to physical processes of the river. These life history components, especially habitat needs of the native fish species, are the biological basis for much of the flow recommendations.

COLORADO PIKEMINNOW

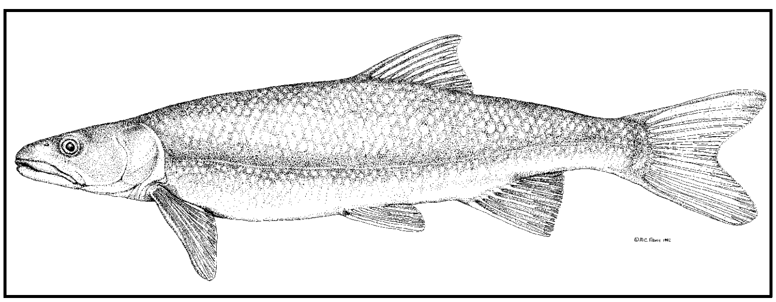


Plate 3.1. Colorado pikeminnow (*Ptychocheilus lucius*).

Colorado pikeminnow (*Ptychocheilus lucius*) is endemic to the Colorado River system and is thought to be the largest North American member of the minnow family, *Cyprinidae,* once attaining a size of nearly 6 ft in length (Minckley 1973). They were used by Native Americans for food, and early white settlers called them white salmon because of their migratory behavior. Before mainstem dams were constructed in the basin, Colorado pikeminnow were found throughout the basin, from near the brackish estuary in Mexico to tributaries in the mountains of Colorado. The advent of major dams, beginning with Hoover Dam in 1935, reduced the ability of this species to move about the basin. The reservoirs that developed behind the dams were apparently not suitable habitat for this species, and Colorado pikeminnow never has developed reservoir populations. However, they have been occasionally found in reservoirs, such as Lake Powell, that have access to upstream riverine habitat that contains populations of Colorado pikeminnow. At present, the species does not inhabit the Colorado River Basin below Lake Powell, the upper Green River above Flaming Gorge Dam, the upper portions of the Colorado River above irrigation dams near Grand Junction, or the San Juan River above Navajo Dam. Completion of a fish ladder on the Gunnison River has resulted in Colorado pikeminnow moving upstream into the Gunnison River in 1997 and 1998 (F. Pfeifer, USFWS, personal communication), an area where they were historically found. This is the first example of a fish-passage structure specifically constructed to allow native Colorado River fishes to move upstream over a dam. The largest existing Colorado pikeminnow population occurs in the Green and Yampa river systems of Colorado and Utah, with smaller populations in the Colorado River of Colorado and Utah and the San Juan River of New Mexico, Colorado, and Utah.

Since the early 1960s, the San Juan River population of Colorado pikeminnow has been effectively isolated from other populations by Lake Powell. Although historical information about population abundance in the San Juan River is lacking, anecdotal information (summarized by Platania 1990) suggests the species was common in the system, including the lower Animas River and San Juan River now under Navajo Reservoir, prior to the completion of Navajo Dam. Based on recent SJRIP collections, the adult population of Colorado pikeminnow in the San Juan River is likely fewer than 100 individuals, and may be fewer than 50 individuals.

This section describes the life history needs of Colorado pikeminnow as they relate to potential use in flow recommendations. Much of the available information comes from research in the Green, Yampa, and Colorado rivers, and information from recent research on the San Juan River is included where appropriate. The available information shows that this species has rather specific life history needs, especially related to spawning times, spawning areas, and habitat for young fish, which are related to important changes in the basin's natural hydrograph.

Spawning

Colorado pikeminnow appear to exhibit a spawning-associated homing behavior, with some members of spawning groups migrating upstream and others downstream to spawning areas. In the Green and Yampa rivers, Colorado pikeminnow may migrate more than 93 mi during spring to reach spawning areas; two major spawning areas, one in the Yampa River and one in the middle Green River, have been identified (Tyus 1985, Tyus 1990). Tyus (1985) suggested that the homing behavior of Green and Yampa river Colorado pikeminnow populations may be because of olfactory imprinting in early developmental stages (egg and early larval) before larvae become entrained and drift downstream. Tyus (1985) found that during spawning migrations, seemingly adequate habitats are passed over in favor of specific spawning sites. In contrast, radio-implanted Colorado pikeminnow in the upper Colorado River, from Palisade, Colorado, to Lake Powell, Utah, did not display discrete spawning migrations or spawning site selection; rather, these fish moved relatively short distances (< 31 mi) and spawned among many river reaches, a difference that might be influenced by spawning habitat availability (McAda and Kaeding 1991). Alternatively, fishes in the Colorado River may have historically spawned in downstream or upstream reaches that are now disconnected by dams.

Studies on the San Juan River have shown that Colorado pikeminnow in that system appear to use at least one primary spawning area near RM 131 to 132 in an area called the Mixer (Miller 1994, 1995; Ryden and Ahlm 1996), although, based on the capture of adults (Ryden and Pfeifer 1996a) and larvae in the area (Platania 1996), another spawning site near RM 75 is possible. Migrations to the Mixer spawning area at RM 131 to 132, similar to those seen in the Green River system, have also been documented. Ryden and Ahlm (1996) documented the migration of a large female from the area of RM 74 to the Mixer spawning area in 1994, a net upstream movement of over 65 mi.

Water temperature, discharge, and photoperiod are possible spawning and/or spawning migration cues. Vanicek and Kramer (1969) suggested water temperature was the main spawning cue because spawning initiation varied up to a month from year-to-year, but gonadally mature fish were taken at water temperatures of about 21E C, approximately 1 month after water temperatures exceeded 18E C in all years of his study. Hamman (1981) was able to induce spawning at 18E C with carp pituitary injection but noted spontaneous spawning at 20 to 21E C. Haynes et al. (1984) suggested that receding flows and water temperatures of 20 to 22E C correlated with spawning. Nesler et al. (1988) developed a regression model for back-calculating ages of larval and YOY Colorado pikeminnow based on growth and fish of known ages. They used this model to predict spawning times in the Yampa River based on size of captured larvae, and indicated that flow spikes appeared to be a cue for Colorado pikeminnow spawning. During radiotelemetry studies in the Green River system, radio-implanted Colorado pikeminnow began spawning migrations as spring runoff began to recede and water temperatures increased to 14EC (Tyus 1990). Spawning migrations began from late May to early June in both the Yampa and Green rivers (1981 to 1988). Actual spawning occurred as flows receded on or near the spring solstice and approximately 38 days after peak flows. The water temperature at time of spawning was found to be over 19EC and averaged 21 to 23.4EC (Tyus 1990). However, spawning aggregations of adults occurred sooner in low water years than in high water years, suggesting that temperature may override any effect of discharge or that these cues may act in concert (Tyus 1990). Recent Colorado River studies using back-calculated spawning dates suggested that temperature is a primary factor for spawning (Trammell and Chart 1998).

Recent studies by Bestgen et al. (1998) in the Green and Yampa rivers indicated that the timing of the initiation of Colorado pikeminnow spawning was fairly constant from year-to-year, occurring from June 13 to July 1 in the Yampa River during the 7 years of their study. Temperature at the initiation of spawning was more variable, from 16 to 19E C. The spawning period lasted for about 34 days in the Yampa River. Based on larval collections from both the Yampa River and lower Green River, spawning sites and aging of larvae with otoliths, Bestgen et al. (1998) also noted that spawning initiation occurred at lower temperatures than other researchers had reported (16 to18E C versus 18 to 20E C). This information suggests that photoperiod, or time of the year, may be more important than temperature or flow for cuing spawning.

A total of 48 larvae, YOY, and age-1 Colorado pikeminnow have been collected in the San Juan River since 1987 for SJRIP and earlier studies funded by the Bureau (Holden and Masslich 1997). Back-calculated spawning dates for 34 of the larvae and small YOY, using the model from Nesler et al. (1988), showed some consistency in spawning time (Figure 3.1). Calculated spawning time generally occurred in mid- to late-July, but ranged from July 8 (1993) to August 14 (1992). Flow was considerably different between years as shown in Figure 3.1, with fairly high flows (> 2,000 cfs) occurring during predicted spawning times in 1987, 1994, and 1995, and low flows (< 2,000 cfs) during 1988, 1992, 1993, and 1996. During all years, spawning occurred near the end of the descending limb of the hydrograph. Average river temperature during the predicted spawning time was around 16E C in 1987, over 22E C in 1988, 1992, 1993, 1994, and 1996; and between 17E C and 21E C in 1995. This analysis tended to support the results of Bestgen et al. (1998) in that temperature during predicted spawning times varied. Since initiation of spawning was not verified in the San Juan River, it is not known how that factor may compare with the Yampa River site.

Miller (1994, 1995) followed radio-tagged Colorado pikeminnow adults to spawning areas in the San Juan River in 1993 and 1994. Spawning appeared to occur in mid-July during both years in the general area of RM 131 to 132, similar to the timing determined as shown in Figure 3.1. Temperatures during the spawning times were about 22E C in 1993 and 18E C in 1994, within the range seen in similar studies on the Yampa and Green rivers. Two specific sites within this area were thought to be used for spawning.

In summary, recent research has differed in what is considered the primary factor cuing Colorado pikeminnow spawning. Photoperiod, temperature, and flow likely all play a role, and each in turn may be the primary factor during different types of spring and summer flow and weather conditions.

Breeding condition of Colorado pikeminnow is discernable by nuptial tubercles on the dorsal surface of the head and back and on paired fins of males (Seethaler 1978, Tyus 1991a). Hamman (1981) reported tubercles appearing on the head, operculars, and pectoral and pelvic fins on males when temperatures reached 15E C, and tubercles over the entire surface of males (except the abdominal area and caudal fin) when temperatures reached 20E C in a hatchery raceway. At 18E C, males produced seminal plasma with active sperm. In addition to tuberculation, males also became bronze in color, whereas females remained lighter (Tyus 1990). Hamman (1981) reported that females did not demonstrate breeding condition (distended abdomen, cloaca enlarged) until shortly before spawning (water temperatures of 20E C). Females developed some nuptial tuberculation; however, this was not common. Tyus (1990) also found females to be generally larger than males.

Hamman (1981) reported that hatchery-reared males matured at 5 years of age (317 to 376 mm total length (TL)) and that hatchery-reared females matured at 6 years of age (425 to 441 mm TL). Vanicek (1967) reported sex ratios to be nearly 1:1 for 5- and 6-year-old fish after which males outnumbered females. The sex ratio reported by others suggests males greatly outnumbered females and that the ratio of males to females is closer to 4:1 (Seethaler 1978, Hawkins 1991). It is not clear whether this ratio is real or an artifact of sampling bias favoring males, since females have been

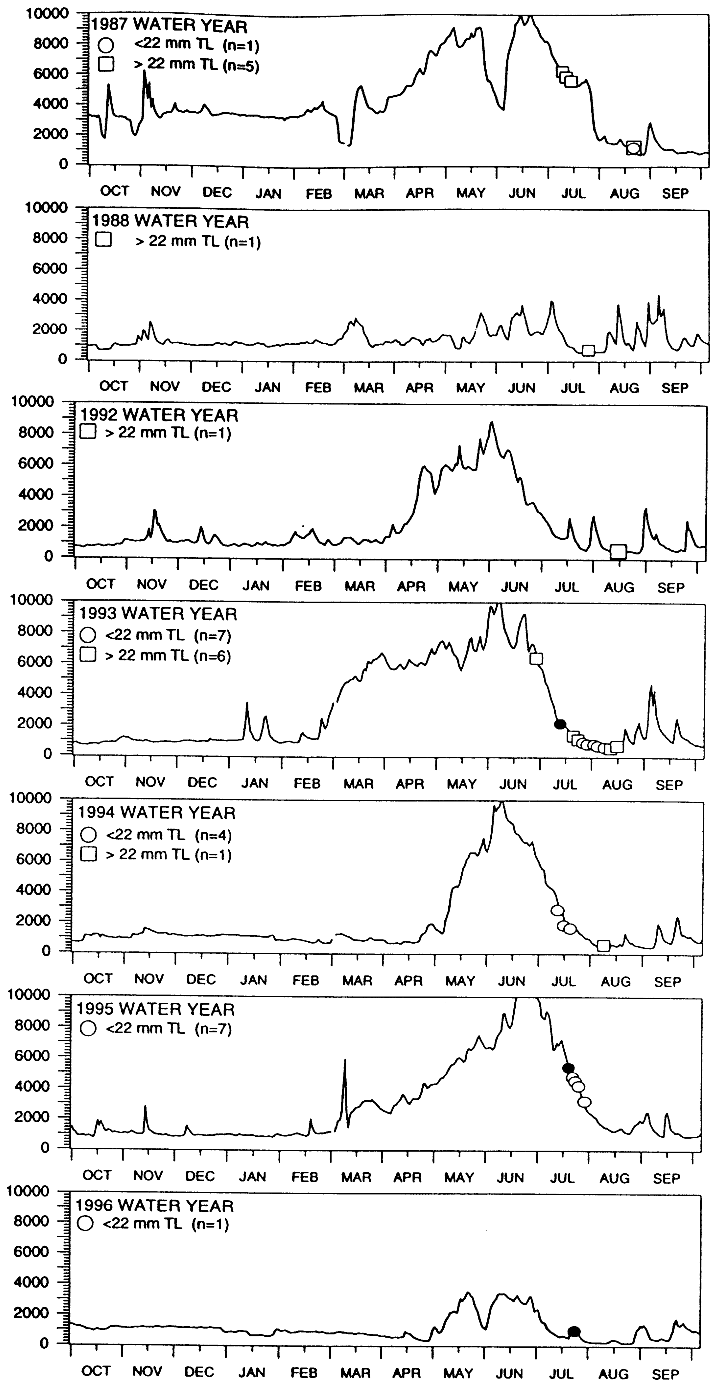


Figure 3.1. **Back-calculated dates of *Ptychocheilus lucius* spawning based on larval and juvenile specimens collected in the San Juan River, 1987 to 1996. Hollow dots indicate *P. lucius* < 22 mm total length (TL); solid dots indicate *P. lucius* < 22 mm TL collected in drift nets; squares indicate *P. lucius* > 22 mm TL. Symbols may represent multiple individuals.**

noted to grow faster, occupy deeper holes, and to be generally less active than males, especially prior to spawning (Seethaler 1978, Tyus 1990).

A spawning behavior scenario was developed based on observations of hatchery spawning (Hamman 1981); spawning habitat selection noted in field studies (Seethaler 1978, Archer and Tyus 1984, Tyus 1990); and spawning behavior of a congener (a closely related species), the northern pikeminnow (*Ptychocheilus oregonensis*) (Beamesderfer and Congleton 1981). The Colorado pikeminnow is believed to migrate to pool/riffle areas near the spawning sites. Here, they appear to use deep pools, eddies, or mixing zones to rest or stage before actually spawning. Males may gather near females in these pools until the females are ready to spawn, at which time the fish move into nearby riffles, chutes, and shallow runs with cobble substrates. After and between spawning bouts, it is believed the fish return to pools and eddies to rest. Tyus (1990) noted that radio-tagged fish aggregated in river reaches near spawning sites, staged in resting areas for hours or days, and then moved onto spawning riffles for 30 minutes to 3 hours before returning to resting areas.

Tyus (1990) described spawning areas in the Yampa and Green rivers as river reaches less than 12.4 mi long with large, deep pools and eddies, and submerged cobble, gravel, boulder, and sand bars. He noted, however, that substrates in the Yampa Canyon spawning area were predominately cobbles with some gravel and sand, whereas substrates in the Green River spawning area were mainly boulder, sand, and silt. Through radio-tracking, spawning was inferred to occur on cobble or boulder bars with the fish intermittently resting in nearby pools (Tyus 1990). Lamarra et al. (1985) more-specifically examined the substrate of "Cleopatra's Couch," the Yampa River spawning site. They noted that the actual spawning locations contained very clean cobble, with little or no organic material in interstitial spaces. They concluded that clean cobble was important to spawning habitat quality because the eggs were likely deposited in the spaces between cobbles.

Miller (1994, 1995) noted similar habitat use and movements with radio-tagged spawning Colorado pikeminnow in the San Juan River. Observations at the Mixer spawning area indicated that the fish used lower-velocity pools as resting areas and moved to swifter chutes and riffles for apparent spawning. Additional detail on those observations is provided in Chapter 4.

Bliesner and Lamarra (1996) compared the cobble size and amount of substrate embeddedness of the suspected Mixer spawning areas in the San Juan River (Miller 1994, 1995) with those in the Yampa and Colorado rivers. They found that although substrate size varied slightly, the general size and cleanliness of the spawning areas were similar. Colorado pikeminnow spawning areas had some of the cleanest cobble in all three rivers, as noted by the relatively large interstices between cobbles.

Relatively intensive formation and maintenance studies were conducted on the Colorado pikeminnow spawning bars in the Yampa, Green, and Colorado rivers. In all three rivers, the shape and size of the cobble spawning bars, location of sidechannels, and the distribution of coarse sediments over the bars were primarily a function of large, infrequent flood events rather than the annual spring runoff (O'Brien 1983, Harvey et al. 1993). In the Yampa River, even the supply of cobbles and boulders to the bar was dependent on large floods. Without large floods and the upstream supply of coarse sediments, cobbles would be redistributed more uniformly throughout pools and runs. In all three rivers, large flood events reworked the bars and created sidechannels along the banks with higher elevation bars in the center of the channel. During the recessional limb of a large flood event, a center channel across the bar may evolve that can become more pronounced at low flows. These chutes across the bar are used for spawning by Colorado pikeminnow and similar bar formation has been noted at the Three Fords Rapid site on the Green River, and the Yampa River spawning site, as well as in the Colorado River at potential spawning areas (Pitlick and Van Steeter 1998).

The role of large, infrequent flood events, at or above bankfull discharge (or in the case of the Yampa River even higher, on the order of the 25-year to 100-year return period flows (O'Brien 1983, Harvey et al. 1993)), can be threefold: (1) large floods provide new coarse sediments to the river channel; (2) large floods shape, distribute, sort, imbricate and rework the cobbles bars; and (3) large floods create the sidechannels serving as Colorado pikeminnow spawning sites. Colorado pikeminnow spawning habitat viability in these three rivers is closely linked to these rare flood events because extreme flood events keep portions of the cobble bar from becoming inactive. With upstream flow regulation and nonnative vegetation encroachment, portions of the Green and Colorado rivers' cobble bars have experienced vertical accretion and bank attachment, thereby reducing the active channel width (FLO 1996, Pitlick and Van Steeter 1998).

In summary, considerable information about Colorado pikeminnow spawning behavior and site selection was gathered from the Green, Yampa, and Colorado rivers. Many similarities between these sites exist. Data from the suspected Colorado pikeminnow spawning areas in RM 131 and 132 of the San Juan River suggest that similar spawning site characteristics are also selected by Colorado pikeminnow in that spawning area.

Eggs

It is assumed that eggs are deposited in cobbles and gravels within riffles and chutes during spawning events. Clean interstitial spaces in the spawning substrate likely allow eggs to fall between the substrate, preventing them from being washed downstream. Eggs are adhesive either to gravels or to other eggs in clumps (Toney 1974). Seethaler (1978) traced the developmental stages of fertilized Colorado pikeminnow eggs naturally spawned in raceways at Willow Beach National Fish Hatchery, Arizona. He noted embryo and eye formation after 1 to 2 days and hatching at 5 days in temperatures of 21.7 to 23.9E C. Toney (1974) noted that eggs were 2 mm in diameter, and newly hatched larvae were 6.5 mm in length.

Hamman (1981) noted hatching beginning 96 hours after fertilization and ending 144 hours after fertilization during a wild Colorado pikeminnow spawning event in raceways. From approximately 25,000 spawned eggs, an estimated 7,500 larvae hatched, a survival rate of 33% for a natural spawn in an artificial environment. These larvae ranged in size from 6.5 to 7 mm in length. Hatching success is likely lower in the wild.

Marsh (1985) found that Colorado pikeminnow embryo survival was significantly reduced by low (5, 10, and 15E C) and high (30E C) water temperatures, with greatest survival occurring at temperatures of 20 and 25E C, respectively. Colorado pikeminnow experienced total mortality at 15E C. Colorado pikeminnow spawn later (mid-summer) than any other native species in the Colorado River system, which may indicate why their eggs and larvae are the least resistant to cooler temperatures.

Larvae

For this report, larval Colorado pikeminnow were defined as fish less than 23 mm TL. Seethaler (1978) described the development of young Colorado pikeminnow, from hatching to approximately 50 mm TL (168 days after hatching). By approximately 23 mm TL, all fins were formed, and the fish were beyond the larval stage. Seethaler (1978) broke down larval development into protolarval (feeding endogenously; less than 8 mm TL), mesolarval (feeding exogenously; 8 to11 mm TL), and metalarval stages (fin buds forming, 11 to 23 mm TL).

Bestgen (1996) examined the effects of constant and fluctuating temperature regimes on larval Colorado pikeminnow growth, survival, and starvation resistance. Overall, growth was greatest at highest temperature (30E C) and highest food abundance. Although larvae were relatively starvation resistant (time to 50 % starvation was 17.5 to 20 days after feeding was stopped), food abundance was a greater survival factor than temperature. Temperature may be more important for providing the growth conditions that allow larvae to outgrow predation risk than for promoting direct survival. In addition, temperature preferences were higher for larvae than later young life stages, which may contribute to habitat segregation in early life stages.

Seethaler (1978) reported that at 8-mm long, larvae began to form mouths. When larvae reach 8.3 mm TL, they had resorbed the entire yolk sac. At 9.1 to 9.4 mm TL, the mouth was fully formed. Vanicek (1967) noted that cladocerans, copepods, and chironomid larvae were the main food items for Colorado pikeminnow less than 25 mm TL. Grabowski and Hiebert (1989) analyzed stomach contents of 15 Colorado pikeminnow less than 20 mm TL that were collected from backwaters in the Ouray section of the Green River in 1987 and 1988. Chironomid (predominately *Chironomus* sp.) larvae were the most abundant food item (91% frequency of occurrence). Other food items included organic material; but no phytoplankton or zooplankton were identified and no stomachs were empty.

Bestgen (1996) concluded that food abundance was more important than temperature regime (within 18 to 30E C) in optimizing growth and survival of larvae. Larvae were relatively starvation resistant, but survival and growth were greatest when food abundance was highest, regardless of temperature (from 18 to 30E C).

Haynes et al. (1984) and Nesler (1986) determined through seining and drift net surveys that larvae emerge from substrates soon after hatching and drift passively downstream with the current. Green River system Colorado pikeminnow larvae have drifted up to 100+ mi downstream from spawning areas before becoming entrained in low-velocity nursery habitats, such as backwaters (Tyus and

Haines 1991). This was not the case in the 1960s shortly after Flaming Gorge Dam was closed (1962) when Vanicek (1967) found Colorado pikeminnow larvae and juveniles in large numbers only 20 mi below the Yampa River spawning site. In the late 1960s, water temperatures from Flaming Gorge Dam became much colder at the confluence of the Green and Yampa rivers where larval pikeminnow once stopped drifting, and colder temperatures may be the reason this area is no longer used as nursery habitat. In the Colorado River above Lake Powell, McAda and Kaeding (1991) captured larval Colorado pikeminnow in nearly all river reaches sampled, suggesting that spawning was displaced throughout that section of river and that larval drift distances depend on spawning location and downstream habitat availability. Therefore, Colorado pikeminnow larvae drift from spawning areas, but the distance they drift likely depends on factors such as habitat availability and flow levels.

Bestgen et al. (1998) examined timing and success of reproduction and its relationship with hydrology and temperature. They found that high drift abundance within a year was most closely associated with increased turbidity, increasing discharge, or darkness. All of these indicated a possible antiphototactic response of increased drift (possibly a predation-avoidance response or loss of orientation) or displacement of newly hatched larvae from interstitial spaces by higher- or more-turbid flows. Differences in abundance of drifting larvae between years appeared to be related to discharge, with lower abundance of drifting larvae during very low and very high years. It is not known if low-abundance years were because of the number of spawning adults, mortality of eggs, production of young, or other factors.

During the 7-year research effort, a total of 14 larval Colorado pikeminnow were collected in the San Juan River (Platania 1996, 1997). Eight of these larvae were collected with seines in 1994 and 1995 in Reaches 1 and 2, and another was collected with a seine in 1994 at about RM 122. The other five larvae were collected in drift nets, the standard larval fish sampling tool. Of the five larvae collected in drift nets, four were collected at RM 53 near Mexican Hat, Utah, thus suggesting that a spawning area may occur in the lower portion of the river. The other larva was collected at RM 128, 4 mi below the spawning sites at RM 131 and 132. Although numbers collected were small, this information suggests that larval Colorado pikeminnow in the San Juan River drift from the spawning areas, and may drift considerable distances to Reaches 1 and 2 to find suitable nursery habitat, similar to behavior seen in other rivers.

Juveniles

Juvenile Colorado pikeminnow grow relatively rapidly during their first few years. Vanicek (1967) showed that age-0 (YOY) Colorado pikeminnow grew to about 50 mm TL, age-1 to about 100 mm TL, and age-2 to near 200 mm TL in the upper Green River. Young-of-the-year Colorado pikeminnow stocked in the San Juan River in November 1996 averaged 60 to 70 mm TL, somewhat larger than wild YOY collected in the San Juan River, which averaged about 25 mm TL in September and 35 mm in October. The stocked YOY had grown to near 200 mm by May 1998, a faster growth rate than that noted by Vanicek (1967). The faster growth rate may have been in part because of starting life in the river at a considerably larger size than wild young.

A number of authors have reported that YOY Colorado pikeminnow were found in a variety of habitat types, but were found most frequently in backwaters (Holden 1977, McAda and Tyus 1984, Tyus and Haines 1991). Holden (1977) suggested that deep compared with shallow backwaters had higher abundance of YOY pikeminnow, but Haines and Tyus (1990) did not note a difference in abundance with depth. Other habitats used include low-velocity shorelines, small low-velocity channels, and eddies. It was determined through marked and recaptured individuals that YOY fish were able to negotiate the main channel to reach lower-velocity habitats (McAda and Tyus 1984). Most discussion of habitat for the post-larval, immature life stage of Colorado pikeminnow focuses on backwaters because they appear to be important nursery habitat for this life stage until the fish are approximately 100 mm TL.

At approximately 100 mm TL, Colorado pikeminnow appear to leave backwaters and other low-velocity habitats for higher-velocity channel margin habitats. This size of young Colorado pikeminnow is not often collected, so this habitat shift is based on scattered observations by several researchers in the Green and Colorado rivers. The mechanism for this ontogentic habitat shift is not clear, but may be related to a diet shift or predation avoidance. Trammell et al. (1993) noted a lack of stocked fingerling Colorado pikeminnow recaptures by the end of the second year. Although the authors expected high mortality, the low number of recaptures during the second year after stocking could have resulted from a habitat shift at this age and/or a size-selective bias in sampling gear. This information concurred with other studies that noted the difficulty in catching age-1+ Colorado pikeminnow, even though these fish may be recaptured later as adults (Trammell et al. 1993).

As immature Colorado pikeminnow obtain lengths of 300 to 400 mm TL, habitat again appears to change as the fish use a larger variety of habitats and appear to move more than when they were younger. Nineteen immature (< 435 mm TL) age-1+ nonspawning Colorado pikeminnow that were tagged and recaptured or tracked exhibited upstream or downstream migrations, and net movement ranged from short (12 mi) to great distances (196 mi) (Tyus 1990). Large migrations of juveniles may have represented some immature spawning instinct or other life history strategy; however, it is unclear from current studies why nonspawning or immature fish migrate.

Because of the relatively low number of young Colorado pikeminnow in the San Juan River and the apparent low availability of backwater habitat, Lentsch et al. (1996) initiated a study in 1996 to investigate stocked YOY Colorado pikeminnow habitat use. In November 1996 and August 1997, 50,000 YOY Colorado pikeminnow were stocked at Shiprock, New Mexico, and 50,000 were stocked at Mexican Hat, Utah. Periodic sampling from November 1996 to April 1998 resulted in the capture of nearly 3,000 of these stocked YOY. About 60% of the recaptured YOY were collected from backwaters (the primary habitat sampled), 15% from pools, and 13% from pocket water (see Chapter 2 for an explanation of these habitat types). The other 12% of the fish were collected from a variety of other low-velocity habitats. This study tended to support the conclusion that San Juan River backwaters were a selected young Colorado pikeminnow habitat, but that a variety of other habitats were also important. It should be noted that at low-flow levels, YOY were predominately found in secondary channels, which at that time provided the majority of low-velocity habitats in the system.

Age-1 fish from the November 1996 stocking were found during October 1997 in a variety of shoreline habitats, including shoals and eddies. While these areas typically had a higher velocity than the areas where the YOY were captured, they still would be classified as low-velocity habitats by Bliesner and Lamarra (1994, 1995). The captures of larger (age-1+) juveniles in the San Juan River supported the hypothesis discussed above that at about 100 mm TL, young Colorado pikeminnow start using higher-velocity habitats than they used during their first year of life.

Vanicek (1967) found that insects, especially chironomids, were the most important food items for Colorado pikeminnow between 25 and 100 mm TL (the approximate size range of age-0 Colorado pikeminnow). As the fish increased in size over 100 mm they became more piscivorous, primarily at sizes above 200 mm TL (Vanicek 1967, Seethaler 1978). Jacobi and Jacobi (1982) reported that fish remains comprised 85% of the stomach contents for 101 age-0 Colorado pikeminnow (22 to 59 mm TL) collected, 20% of the stomachs were empty. McAda and Tyus (1984) reported that smaller Colorado pikeminnow (22 to 40 mm TL) consumed mainly aquatic invertebrates, while larger fish (41 to 59 mm TL) consumed more fish (mainly red shiner (*Cyprinella lutrensis*)). Grabowski and Hiebert (1989) also noted that Colorado pikeminnow were highly piscivorous at about 20 to 40 mm TL. In size groups between 20 and 80 mm TL, 30 to 40% of the diet was comprised of fish remains, mostly red shiner. The most abundant item consumed was chironomid larvae, which made up most of the remaining diet (approximately 43%). Other benthic invertebrates occurred in stomachs at a lower frequency. Stomachs were only empty in June and November, which may indicate that feeding increases throughout the summer and decreases as temperatures cool into the winter. Feeding frequency is probably a function of interrelated food availability and temperatures increasing throughout the summer and decreasing with the onset of winter.

The information provided above suggests YOY Colorado pikeminnow have become more piscivorous at a smaller size since the early 1960s when Vanicek (1967) conducted his work. It should be noted that since Colorado pikeminnow spawn relatively late in the year compared with the other native fishes (see sections on other species later in this chapter), relatively few larval native fish were available in late summer before the advent of nonnative species. The fish that Vanicek (1967) analyzed were collected in 1964 through 1966, prior to the red shiner invasion of the upper Green River, which occurred after 1968 (Holden and Stalnaker 1975a). Therefore, more insects were likely found in the stomachs of YOY in the upper Green River prior to 1968 since larval fishes (native species as well as red shiner) were not available. More recent researchers have studied food habits with the availability, and generally the high abundance, of red shiner larvae in late summer, and they appear to have become a common food item of YOY Colorado pikeminnow.

Adults

Adult Colorado pikeminnow in the Green River were collected from all habitat types but most frequently from low-velocity areas including runs, eddies, backwaters, and pooled canyon mouths

(Holden and Stalnaker 1975a, Tyus 1990). Size and sex may influence habitat selection; it was noted that larger female adults were captured primarily from deep holes and smaller males were captured primarily from eddies, runs, and more transitional habitats (Seethaler 1978). During spring (pre-runoff and runoff) adults tend to use backwaters, flooded mouths of washes, and other low-velocity habitats that are warmer than main channel habitats. As the water warms and flows recede, they use eddies and other low-velocity habitats associated with the main channel. During the fall and winter they continue to use lower-velocity shoreline habitats. Detailed information on San Juan River seasonal habitat use by Colorado pikeminnow adults is provided in Chapter 4. A similar annual pattern of habitat use was found in the San Juan River with extensive year-round use of eddy habitats that are typically found along shorelines.

Predominately piscivorous, adult Colorado pikeminnow were the top predator in the Colorado River system before the introduction of nonnative fish species. Although little is known about Colorado pikeminnow feeding behavior, their mouth shape suggests that they are roving predators with lie-in-wait tactics (Moyle 1976, Pimental et al. 1985). Osmundson et al. (1997) noted that as Colorado pikeminnow reached maturity, they demonstrated a net movement to upstream reaches compared with immature individuals that demonstrated greater gross movement but lacked directional movement. The authors hypothesized that mature adults moved to and remained in these upper reaches because these reaches provided a greater abundance of prey, such as native flannelmouth sucker (*Catostomus latipinnis*), bluehead sucker (*Catostomus discobolus*), and roundtail chub (*Gila robusta*). Upon arrival into these upstream reaches, the individuals displayed less overall movement and maintained better body condition than the individuals in the lower reaches where potential native prey was less abundant.

Miller and Rees (1997) reported that during the late summer and fall base-flow period, Colorado pikeminnow in the Yampa River exhibited two distinct activities during daytime and nighttime. Eddies and low-velocity habitats in the main channel were normally used during a more sedentary resting period during daylight hours. There was an apparent feeding behavior and active movement into shallower and faster habitats during nighttime hours. In 1996, an extremely low base-flow year, the fish remained within a habitat unit (pool or run) where they were observed during both daylight nighttime hours. In 1997, an extremely high base-flow year, the fish showed behavior similar to that in 1996 (Miller and Rees 1997). The fish were most active after sunset and exhibited what appeared to be foraging behavior. Several fish that moved to adjoining habitats spent several hours apparently foraging in riffle habitats before moving to a lower-velocity habitat. Some of the fish moved within a single habitat unit while other fish were observed to move to another habitat unit during this apparent foraging behavior. Two of the fish observed in 1997 moved through several habitat types during the 24-hour observations. On these occasions, the fish returned to their starting locations within 24 hours. These observations suggest that an entire habitat complex may be selected by Colorado pikeminnow, rather than just the resting habitat where they are most frequently collected.

RAZORBACK SUCKER

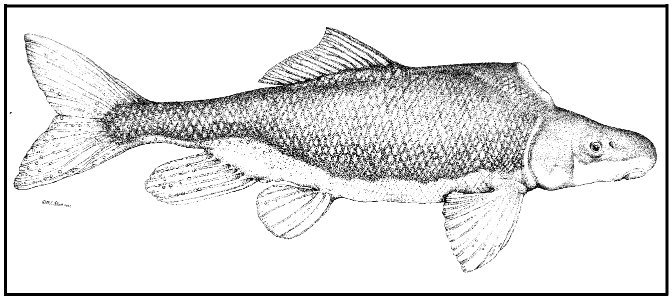


Plate 3.2. Razorback sucker (*Xyrauchen texanus*).

Razorback sucker is endemic to the Colorado River Basin and once ranged from near the estuary to the upper mountainous tributaries in Colorado and New Mexico. Similar to Colorado pikeminnow, their numbers have declined as dams altered basin habitat. Unlike Colorado pikeminnow, razorback sucker remain in some reservoirs and have survived in them for many years. However, until recently no reservoir population was shown to have natural recruitment (Holden et al. 1998).

As its name implies, the razorback sucker has a prominent keel just behind its head. It was very abundant in some parts of the basin in the 1800s (Minckley 1973), and it was reported in the San Juan and Animas rivers in the late 1800s (Jordan 1891) as far upstream as Durango, Colorado, but abundance in this system is not well understood. Several specimens were reported in a pond beside the San Juan River in 1976, and one was collected from the river near Bluff, Utah, in 1988 (Platania 1990).

The largest Upper Basin population of razorback sucker at present occurs in the Green River, with a smaller population in the Colorado River. Reservoir populations include a large Lake Mohave group and a smaller Lake Mead group, both in the Lower Colorado River Basin (Lower Basin). Recruitment is a major concern for this species, and most populations are comprised of old adults and have no, or relatively little, recruitment.

Spawning

Since populations of adult razorback sucker are found in some Lower Basin reservoirs, as well as in Upper Basin riverine habitats, life history information has been gathered in both reservoir (lentic) and riverine (lotic) habitats, and both sources of information were used in this section.

Minckley (1973) stated that razorback sucker in riverine environments make annual spawning "runs" to specific river areas. The annual springtime collection of adult razorback sucker below instream diversions, in gravel pit ponds, and downstream of large reservoirs (Valdez et al. 1982, Mueller 1989, Bestgen 1990), as well as annually repeated adult razorback sucker migrations to specific areas of the Green and Yampa rivers (Tyus and Karp 1989, 1990, Modde and Irving 1998), support this statement. Razorback sucker spawning in Upper Basin riverine environments occurs later than and is not as extended as in Lake Mohave and other Lower Basin reservoirs (Bestgen 1990). In riverine habitats, ripe razorback sucker have been collected from mid-April to mid-June, but within any year, they were collected only over a 4 to 5 week period (Valdez et al. 1982; Tyus 1987; Osmundson and Kaeding 1989; Tyus and Karp 1989, 1990; Bestgen 1990). In contrast, razorback sucker spawning in Lower Basin reservoirs extends from January to April or early May, and the spawning period does not change substantially from year-to-year.

When spring flows increased enough to allow access into bottomland areas or to create backwaters at the mouths of tributaries or dry washes, adult razorback sucker moved from colder main channel habitats into these warmer (2 to 4E C warmer) habitats, a behavior called “staging,” before spawning (Tyus and Karp 1990, USFWS 1997). However, staging may be difficult for adult razorback sucker in the San Juan River. Because of the San Juan River’s high-gradient, overbank flows that occur in some reaches tend to quickly channelize and form secondary channels, as opposed to forming flooded lowlands (R. Bliesner, Keller-Bliesner Engineering, personal communication), and mouths of tributaries that form backwaters are rare. Razorback sucker also move into backwaters and flooded tributary mouths following spawning, apparently to recover and feed (Modde and Irving 1998). Razorback sucker in riverine environments spawn at temperatures ranging between 9 and 20E C (mean = 14 to 16E C), on the ascending limb of the hydrograph (Tyus 1987, Tyus and Karp 1989, 1990, USFWS 1997). Modde and Irving (1998) tracked adult male razorback sucker with radiotelemetry and concluded that increasing flow was more important in aggregating the razorback sucker to spawn than temperature.

Razorback sucker prefer to spawn over predominantly rock or gravel substrates (Snyder and Muth 1990). Although considered broadcast spawners, razorback sucker produce discrete, identifiable redds in reservoirs (Bozek et al. 1984), which may suggest a tendency towards a brood-hiding guild. In rivers, adult razorback sucker in spawning condition have been collected in shallow, swift runs over gravel, cobble, and sand substrates at depths of 1.0 to 3.0 ft, velocities of 1.3 to 3.3 feet per second (fps) with substrate component diameters between 0.75 to 1.95 in. (McAda and Wydoski 1980). Adult razorback sucker were also observed spawning in the mouth of a side canyon wash (riverine habitat) below Hoover Dam at a depth of 3.9 to 6.5 ft, at velocities of 0.0 to 1.21 fps, and over a substrate of newly deposited gravel and cobble (Mueller 1989).

Riverine populations of razorback sucker tend to use the same spawning areas year after year, but few spawning areas have been identified in the Green and Colorado river systems. In the upper Green River, a spawning area exists at the mouth of the Yampa River, and another near Jenson, Utah (called the Escalante site) (Tyus and Karp 1990). Another spawning area is suspected to exist in the lower Green River near the town of Green River, Utah. Similar to the Colorado pikeminnow situation, no well-defined spawning areas are known in the Colorado River, but infrequent captures of razorback sucker in that area make identification of spawning areas difficult. Modde and Irving (1998) noted that some male razorback sucker in the upper Green River used more than one spawning site over a period of 3 years, including use of both the Yampa River site and the Escalante site.

Because of the low numbers of razorback sucker in the San Juan River, the SJRIP initiated experimental stocking of subadults into the river in 1994. In 1997, a more-formal plan for augmentation was developed and implemented. This provided subadult fish for research during the remainder of the 7-year research period. Between May 3 and 5, 1997, eight ripe stocked male razorback sucker were collected from the San Juan River. Four of these ripe males were collected in a short reach of river, one fish at RM 100.5 and three fish at RM 100.2. The three individuals collected at RM 100.2 were in an area of approximately 10 square feet (ft^2). Another three adult razorback sucker were observed, but they were not collected in this same aggregation. The temperature at collection locations for these eight fish ranged from 11 to 19E C. All eight adult male fish were collected over midchannel cobble riffles and run/riffles, or along the river's margins over cobble shoal/runs. Depth at these locations was 3.0 ft or less.

Male razorback sucker outnumbered females (2.5:1) at Green River spawning grounds (Tyus and Karp 1990). Total fecundity among 10 Green River razorback sucker (466 to 534 mm TL) ranged from 27,614 to 76,576 ova/female(McAda and Wydoski 1980). Recalculations performed by Minckley (1983) placed the mean relative fecundity of these 10 female razorback sucker at 1,166 ± 490.6 ova/centimeter (cm) of standard length (SL) (range = 600 to 2,000). Total fecundity of an additional five ripe females (391 to 570 mm SL) examined by Minckley (1983) ranged from 74,600 to 144,000 ova/female, with the mean relative fecundity being 1,812 ± 90.5 ova/cm SL (range = 1,680 to 1,908). Ovary mass of these five females averaged 10.1 % (range = 9.2 to 11.5%) of somatic body mass.

Eggs

Water-hardened razorback sucker eggs, which range in diameter from 2.3 to 2.8 mm, are initially adhesive and are deposited into interstitial spaces between gravel or cobble substrates during spawning (Bestgen 1990, Snyder and Muth 1990). Egg hatching time is highly variable and dependent upon water temperature. At 10E C average hatching time was 19.4 days (Bozek et al. 1984), while at 15 to 17.2E C hatching time averaged from 5 to11.1 days (Toney 1974, Minckley and Gustafson 1982, Bozek et al. 1984), and at 20E C hatching time averaged 6.8 days (Bozek et al. 1984). Embryo hatching success and survival is also highly variable and dependent upon water temperatures. At 10E C survival ranged from 0 to 39 % (Bozek et al. 1984, Marsh 1985), while at 14.4 to 17.2E C survival ranged 15 to 95% (Toney 1974, Bozek et al. 1984, Marsh 1985). Survival ranged from 35 to 45% at 20E C (Bozek et al. 1984, Marsh 1985) and was 29% at 25E C (Marsh 1985). No survival was reported at temperatures of 5 and 30E C (Marsh 1985).

Reasons for low survival of razorback sucker eggs include, but may not be limited to, predation and egg suffocation. Three nonnative fish species present in the San Juan River (channel catfish, common carp (*Cyprinus carpio*), and green sunfish (*Lepomis cyanellus*)) were documented as predators on the razorback sucker eggs (Minckley 1983, Brooks 1986, Marsh and Langhorst 1988, Marsh and Brooks 1989, Tyus and Saunders 1996). Suffocation may occur when adult razorback sucker spawn over sediment-laden substrates (Bestgen 1990). Also, silt deposition because of wave action and storms can bury eggs deposited into interstitial spaces during spawning (Inslee 1982, Bozek et al. 1984). Flushing and maintenance of spawning habitat during the increasing hydrograph could increase the chances of successful razorback sucker egg retention, hatching, and survival.

Larval and Early Juvenile Life Stage

Larval razorback sucker hatch at 7 to 10 mm TL and begin to feed at the time of yolk sac absorption, (about 10 to 12 mm TL) (Snyder and Muth 1990). By 2 weeks of age, larval fish enter the drift, primarily at night (USFWS 1997). Recent studies in the Green River suggested that flooded bottomlands were a primary nursery habitat for larval razorback sucker and that with adequate spring flows, the larvae drift into these habitats (Modde 1996, Modde et al. 1996). In Lake Mohave, larvae spent most of the day in substrate interstitial spaces and emerged at night (probably to feed), at which time they were collected in water up to 4.9 meters (m) deep (Bozek et al. 1984). During recent Lake Mead studies, larvae were collected around floating breakwaters at depths of over 80 ft (Holden et al. 1998). In 1950 about 6,600 larval and early juvenile razorback sucker (10 to 35 mm SL) were seined from shallow margins of the Colorado River at Cottonwood Landing, Nevada, from water that was only a few inches deep but much warmer (21.1 to 24.4E C) than that in the main channel (15.5E C) (Sigler and Miller 1963).

Estimated mean daily gain in TL for otolith-aged larval Green River razorback sucker less than 35 days old (post-hatching) and reared in water temperatures of 15 to 28E C, was 0.3 mm/day (Muth et al. 1997). Diet of larval razorback sucker (11 to 18 mm TL) in Green River nursery habitats (1993 to 1996) consisted mainly of small chironomid larvae supplemented by zooplankton (mostly cladocerans and rotifers) and algae (e.g., diatoms), particularly in fish < 14 mm TL (Muth et al. 1997). Early instar Ephemeroptera are probably consumed as well, as was seen in larval bluehead sucker and flannelmouth sucker (Bestgen 1990). In lentic habitats, larval razorback sucker feed on midwater phytoplankton and zooplankton that are unavailable in turbid rivers such as the San Juan River (Marsh and Langhorst 1988, Bestgen 1990).

In recent years there has been a lack, or near lack, of recruitment in wild razorback sucker populations. Studies on Lake Mohave summarized by Minckley et al. (1991) concluded that larvae did not survive primarily because of predation by nonnative fishes. In Lake Mohave, razorback sucker as large as 30 mm TL occurred in predator-free environments, while razorback sucker exposed to predation did not exceed 10 to 12 mm TL (Brooks 1986, Marsh and Brooks 1989, Tyus and Saunders 1996). In addition, odonate nymphs also preyed upon razorback sucker larvae in Lake Mohave studies (Horn et al. 1994). Modde et al. (1996) suggested that low recruitment in the Green River was likely because of poor nursery habitat over many years (few flooded bottomlands) and high predation by nonnative fishes. Two nonnative fish species present in the San Juan River, green sunfish (*Lepomis cyanellus*) and red shiner, were offered larval razorback sucker during 4-minute trials (Tyus and Saunders 1996). Red shiner consumed 50%, while green sunfish consumed 90% of the larval razorback sucker offered. Two other experiments demonstrated that razorback sucker larvae exhibit very little defensive behavior in the presence of predators and are unlikely to survive in habitats supporting high densities of nonnative fishes (Loudermilk 1985, Johnson et al. 1993). In addition, razorback sucker are one of the first fish to spawn in the Colorado River system each spring, making their larvae available as prey early in the season when few other fish larvae are available.

Tests conducted with arsenate, selenate, selenite, and two mixtures of numerous inorganic contaminants simulating mixtures reported for sites along the San Juan River between Farmington and Shiprock, New Mexico, demonstrated that larval razorback sucker were significantly more sensitive to these contaminants than were larval Colorado pikeminnow (Hamilton and Buhl 1997). The major toxic component in the mixtures was copper. High hazard ratios obtained during this study suggested that inorganic contaminants could adversely affect larval razorback sucker in the San Juan River at sites receiving elevated inorganics from sources such as nonpoint discharges and irrigation return flows. Concentrations of these contaminants may increase or decrease in the mainstem San Juan River depending upon the source of a given contaminant.

Although fairly large numbers of larvae were found in both lentic and lotic environments, very few YOY or larger juveniles (30 to 150 mm TL) were collected in the last 40 years, as noted above. In riverine environments, eight juvenile razorback sucker (90 to 115 mm TL) were reported in backwaters near Moab, Utah, by Taba et al. (1965). Two others, each about 38 mm TL, were collected in Glen Canyon on the Colorado River before its inundation by Lake Powell, one in a backwater and one in a creek mouth (Smith 1959, Modde 1996, USFWS 1997). In 1991, two juvenile razorback sucker (36.6 and 39.3 mm TL) were collected from two separate backwaters in the lower Green River (Gutermuth et al. 1994), and two more (29 and 59 mm TL) were found in the upper Green River in 1993 (Modde 1996). The most recent collection of yearling razorback sucker occurred in 1995 and 1996 at Old Charlie Wash, a flooded bottomland along the Green River. Modde (1996) reported that 28 juveniles (74 to 125 mm TL) were recovered when the wetland was drained in 1995, and 45 juveniles (44 to 83 mm) were recovered in 1996. Minckley et al. (1991) noted that in Lower Basin reservoirs, only four small juveniles were reported (those from Lake Mohave in 1987) even though thousands of larvae were collected annually.

Based primarily on the size information gathered by Modde (1996) and on growth rates from reared wild-caught larvae in Lower Basin ponds (Burke 1995), young razorback sucker grew from 50 to 150 mm their first year, and were 200 to 300 mm TL or more by age-1. Young razorback sucker in warm, food-rich habitats appeared to grow faster than those in cooler habitats, but individuals within the same cohort of larvae reared in the same aquaria showed considerable growth variation during the first year. The information gathered in both the Upper and Lower basins in recent years suggest that predation by nonnative species is a major contributor to young razorback sucker mortality, but habitats that have extensive cover and high levels of food (i.e., flooded bottomlands in the Green River) allow some young to escape predation.

Late Juvenile Life Stage

Similar to yearlings, very few larger juvenile razorback sucker (150 to 400 mm TL) were collected in recent years, so little is known about the life history of this size fish. As noted above, late juvenile razorback sucker were not collected from Lake Mohave, but from 1973 to 1986, a number were found associated with irrigation canals along the lower Colorado River (Minckley et al. 1991). During recent studies on Lake Mead, five subadults were collected (318 to 381 mm TL), one in 1994, two in 1997, and two in 1998 (Holden et al. 1998). None of these Lower Basin captures provided information on life history except for the fact that in some habitats (Lake Mead and the lower Colorado River canals), young razorback sucker escaped predation and may have recruited to the adult population. These captures suggest that perhaps improved habitat conditions, such as more abundant food and extensive cover, may help young razorback sucker escape predation.

Two experimentally stocked juvenile razorback sucker were recaptured in the San Juan River from which information on habitat use was determined. The first (231 mm TL), recaptured on March 9, 1995, was seined from a pool at the downstream end of a midchannel cobble island complex at RM 94.2, near Montezuma Creek, Utah. The pool was 1.4-ft deep, 4-ft wide, and 15-ft long, had a slight flow-through on the upstream end, and was 3 degrees warmer (9E C vs. 6E C) than the main channel. The second razorback sucker (216 mm TL), recaptured October 21, 1997, was seined from a large backwater at RM 77.3 by the UDWR. The backwater was several feet deep, had a silty substrate, and was 1E C warmer than the main channel (E. Archer, Department of Fisheries and Wildlife, Utah State University, personal communication). Additional information on habitat use was collected from radio-tagged razorback sucker in the San Juan River, and that information is discussed in detail in Chapter 4.

The diet of juvenile razorback sucker is also not well known. Stomach contents collected from eight young juveniles 90 to 115 mm long contained "algae and bottom ooze" (Taba et al. 1965). It is likely that the "bottom ooze" was ingested while feeding upon benthic invertebrates or algae.

Adult Life Stage

Adult razorback sucker have been aged at up to 44-years old (McCarthy and Minckley 1987). Studies by Hamman (1985) on hatchery-reared razorback sucker have shown that males can reach adulthood at age-2, or less than 350 mm TL, while females can reach adulthood at age-3, or greater than 390 mm TL. The juvenile razorback sucker collected recently in Lake Mead (318 to 384 mm TL) did not show signs (e.g., tuberculation, ripeness) of sexual maturity, while mature adults captured at the same time had obvious secondary sexual traits (Holden et al. 1998). This suggested that wild fish may not mature as quickly as hatchery- or pond-reared fish. In the Upper Basin, adult razorback sucker occupy habitats during the course of a year ranging in temperature from near 0E C (ice-covered) to 25E C (Bestgen 1990). In the Lower Basin, occupied habitats were somewhat warmer, ranging from 10 to 32E C (Dill 1944). Optimal summer temperatures for adult razorback sucker were 22 to 25E C (Bulkley and Pimentel 1983).

Most of the pertinent information that applies to adult razorback sucker year-round habitat use in the San Juan River and habitat use in other Upper Basin rivers during spawning seasons is presented in Chapter 4 of this report. Bestgen (1990) stated that razorback sucker were known to use backwaters, sloughs, and oxbow lakes. None of these habitat types were particularly prevalent in the San Juan River. Winter habitat observations in the Green River documented that adult razorback sucker were fairly sedentary and exhibited no distinct diel movement patterns (Bestgen 1990). Winter radiotelemetry in the San Juan River seemed to indicate that there was a threshold temperature somewhere between 0 and 3E C that determined razorback sucker activity during daylight hours. At warmer temperatures, razorback sucker moved into main channel run habitats, presumably to feed, for short periods of time during the day before returning to slow or slackwater habitats along the river's margins (Ryden and Pfeifer 1996b).

Sigler and Miller (1963) stated that the diet of adult razorback sucker consisted of "algae and midge larvae." Other studies identified immature Ephemeroptera, Trichoptera, and Chironomidae as well as algae, detritus, and inorganic material from adult razorback sucker digestive tracts (summarized in Bestgen 1990).

OTHER NATIVE FISHES

This section discusses the other common native fish species found in the study area. Not included here is the cool-water species, mottled sculpin (*Cottus bairdi*), which is found primarily in the upper portion of the study area. These accounts are briefer than those presented for the two endangered species, partially because less is known about these species and also because the flow recommendation emphasis is on the two endangered species.

Flannelmouth Sucker

Endemic to the Colorado River Basin, the flannelmouth sucker has been extirpated from most of its former range in the Lower Basin, especially the area below Hoover Dam (McAda 1977). It is the most abundant native species in the San Juan River (Ryden and Pfeifer 1996a) as well as all Other Upper Basin rivers (Holden and Stalnaker 1975).

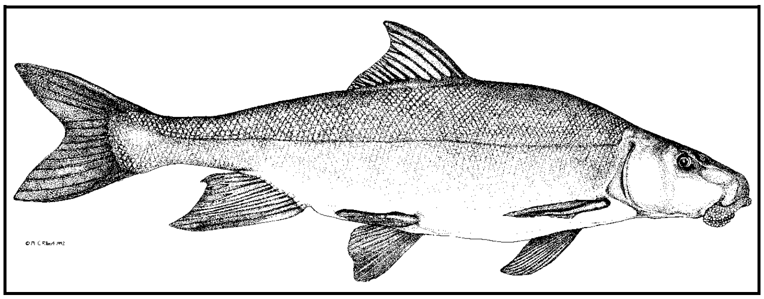


Plate 3.3. Flannelmouth sucker (*Catostomus latipinnis*).

Flannelmouth sucker spawn in spring and early summer, typically during May and June, and on the ascending limb or peak of the hydrograph—although timing can vary spatially within and between river systems as hydrologic and temperature regimes vary (Valdez 1990). They are broadcast spawners, and there is no parental guarding of eggs. Eggs are demersal and initially adhesive (Muth and Nesler 1993). Ripe females were not captured past early June. Although spawning was not actually observed, "ripe male and female flannelmouth sucker were captured over the same gravel bars used by razorback suckers. . . ." The fish were collected in water about 3.0 ft deep and moving about 3.25 fps. Substrate ranged in size from 0.75 to 1.95 in. in diameter. Assuming spawning occurred at this exact location, such habitat approximately corresponds to riffle-run or run habitat in the San Juan River (Bliesner and Lamarra 1996). In the White River, during May and early June, Lanigan and Berry (1981) found large, ripe flannelmouth sucker in water less than 3 ft deep, near sand bars. No indication of spawning habitat was provided. Muth and Nesler (1993) similarly reported flannelmouth sucker spawning in gravel/cobble bars or riffles, with depths generally <3.75

ft. Spawning was not directly observed in the San Juan River; however, the larval drift period for this species was completely bracketed in 1994 from June 20 to July 1 (Archer et al. 1995).

Flannelmouth sucker larvae in the Colorado River were found in the midchannel as passive drift and along quiet shoreline areas (Carter et al. 1986). From June to July in the San Juan River, this species was common in the drift from Four Corners to Mexican Hat, Utah, but was typically more common at the former site (Platania 1996). Larvae were likely also present in backwaters and other low-velocity habitats along the shoreline; however, the study design from 1991 to 1997 did not sample low-velocity habitats in June and July. In the San Juan River, larval drift of flannelmouth sucker was observed during August and appeared to be related to displacement by storm events (Platania 1996).

Age-0 flannelmouth sucker, like the early life stage of many fish species, were commonly found in low-velocity habitats such as backwaters, shorelines, and pools in the Colorado River (Valdez 1990). In the San Juan River, they were most abundant in backwaters and flow-through backwaters in the upper portion of the river between Hogback Diversion and the Four Corners area in the spring (Buntjer et al. 1993). The abundance of age-0 and age-1 fishes tended to decline from spring to fall (Buntjer et al. 1993, 1994; Archer et al. 1995, 1996; Propst and Hobbes 1996), following spawning. This was likely because of mortality and a shift in habitat use from low-velocity habitats to other less-efficiently sampled habitats with faster current. By early spring, these young flannelmouth sucker still occupied habitats such as backwaters and pools but in relatively low numbers (Buntjer et al. 1994).

In the San Juan River, the abundance of juvenile flannelmouth sucker tended to increase in the lower reaches downstream of Aneth, Utah (Ryden and Pfeifer 1996a). Juvenile distribution was fairly well correlated with shoreline slackwater habitats in the spring, particularly in the lower canyon reaches, and moderately correlated with cobble-type habitats in the fall when overlayed with aquatic habitat distribution. It is not known whether this observation is an artifact of sampling efficiency, actual habitat use, or both, but flannelmouth sucker occurrence appeared to be correlated with these habitats.

McAda (1977) reported that adult flannelmouth sucker were collected in all habitat types in the Upper Basin, including riffles, runs, and pools, but were most abundant in pools. In the San Juan River, they were captured in a wide variety of habitats, including riffles, runs, pools, and eddies; however, no telemetry data exist to document actual habitat use. During post-runoff base-flow conditions, the distribution of juvenile and adult flannelmouth sucker was only moderately correlated to cobble-type habitats (e.g., riffles and riffle/runs), probably because of their extensive use of other habitat types such as runs and pools. Winter habitat use by flannelmouth sucker has not been well studied, although habitat use is likely varied, similar to other times of the year (Holden and Stalnaker 1975a).

Bluehead Sucker

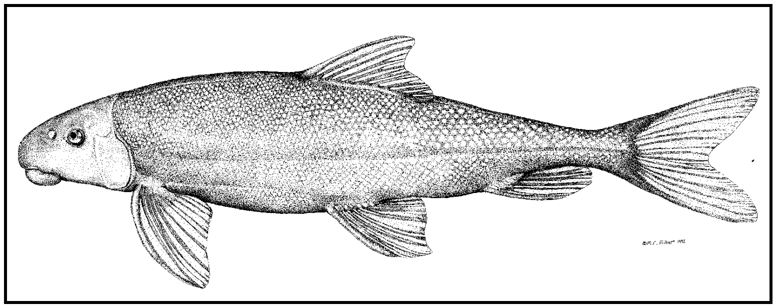


Plate 3.4. Bluehead sucker (*Catostomus discobolus*).

Bluehead sucker is native, but not endemic, to the Colorado River Basin, and is also found in parts of the Walker River in Nevada (Valdez 1990), the Bear and Weber river drainages in Utah and Wyoming, and the upper Snake River Drainage in Idaho and Wyoming (McAda 1977). Bluehead sucker inhabit the relatively cooler, clearer waters of the upper and middle portions of rivers and streams, preferring faster flowing water over rocky substrate (Holden and Stalnaker 1975a, McAda 1977, Woodling 1985). The high use of these habitats is probably largely related to feeding. These fish possess a rigid upper lip with a cartilaginous ridge, designed for scraping cobble for diatoms and other potential food sources (Woodling 1985).

Bluehead sucker in the Green River usually spawn in mid-June to mid-July, typically during the descending limb of the runoff period, at temperatures above 15E C (Holden 1973, McAda 1977). Like flannelmouth sucker, these fish are broadcast spawners with demersal, initially adhesive eggs (Muth and Nesler 1993). Spawning was observed over a gravel bar during early May in a small Arizona tributary, Kanab Creek, by Maddux and Kepner (1988). Females were typically accompanied by no more than two males during the spawning act, which occurred in water ranging from 3.5 to 11.3 in. deep (0.6.24 in.) with a constant velocity of about 1.15 fps. Substrate consisted primarily of loose gravel (0.2.57 ± 2.48 in. diameter). Studies on the San Juan River indicated that such habitat resembles what was classified as a cobble shoal, where mean column velocities ranged from 0.66 to 1.31 fps and depths ranged from 3.9 to 5.85 in. (Bliesner and Lamarra 1996). No direct observations of bluehead sucker spawning were made in the San Juan River; however, the overwhelming relative abundance of YOY within the reach of the Mixer (a reach of relatively complex and dynamic habitats located 10 mi or so upstream of the Four Corners Bridge) to Hogback Diversion (Archer et al. 1996), indicated that the bulk of spawning activity occurred in this reach or further upstream. The majority of adults were found from the Mixer upstream to Farmington, New Mexico (Ryden and Pfeifer 1996a).

Bluehead sucker larvae were common in the midchannel as passive drift and along shoreline areas with slow current shortly following the spawning period (Carter et al. 1986, Valdez 1990). In the San Juan River, the period of peak drift for this species (late July) tended to be several weeks later than for flannelmouth sucker, because of their later spawning period. This species tended to occur much less frequently in the drift of the lower (Mexican Hat, Utah) than the upper (the Mixer) sampling sites in the San Juan River (Platania 1996), which may indicate a limited downstream drift. However, considering that the majority of adults resided in the upper reaches of the river, larvae could have still drifted extensively and data collected in other systems would indicate that they do drift (R. Muth, USFWS, personal communication; T. Chart, UDWR, personal communication). Bluehead sucker larvae were also captured along the shorelines about 2 mi downstream of Clay Hills

Crossing (RM 0) in the San Juan River during August 1995 but were infrequent (0.4% of total) in the catch (Schaugaard et al. 1996).

Age-0 to age-1 bluehead sucker inhabited quiescent habitats along river margins such as backwaters and eddies (Valdez 1990). They were regularly collected in backwaters and flow-through backwaters in the San Juan River during the runoff months of June and July (Buntjer et al. 1993, 1994) and in a variety of habitats such as backwaters, flow-throughs, and secondary channels from summer to fall. However, their abundance declined sharply during the course of a summer (Buntjer et al. 1993, 1994; Archer et al. 1995, 1996; Propst and Hobbes 1996). Like flannelmouth sucker, little published information exists for winter habitat use by these younger fish. Backwaters, flow-throughs, pools, and other low-velocity habitats were still occupied during early spring (March/April), but at very low densities (Buntjer et al. 1994). These fish used swifter habitats (e.g., riffles and runs), in greater numbers as they increased in size.

Juvenile and adult bluehead sucker tended to be most common in the upper reaches of Upper Basin tributaries and typically occurred in habitats with rocky substrate, usually riffles, at all times of the year (Holden and Stalnaker 1975a, McAda 1977, Valdez 1990). Ryden and Pfeifer (1996a) conducted electrofishing surveys on the San Juan River between Farmington, New Mexico, and Clay Hills Crossing, Utah, and indicated that bluehead sucker tended to be most abundant in the area upstream of the Mixer. The distribution of juveniles and adults was virtually identical to that of adults during base flow and highly correlated with cobble-type habitats, particularly riffles in the upper half of their distribution. This was likely related to feeding, although improved capture efficiency in shallower, cobble-bottomed habitats may also be a factor. The distribution of these fish remained largely unchanged during higher spring flows. It appeared likely that they occupied similar cobble habitats during spring although higher velocities and greater depths may have been more common.

Roundtail Chub

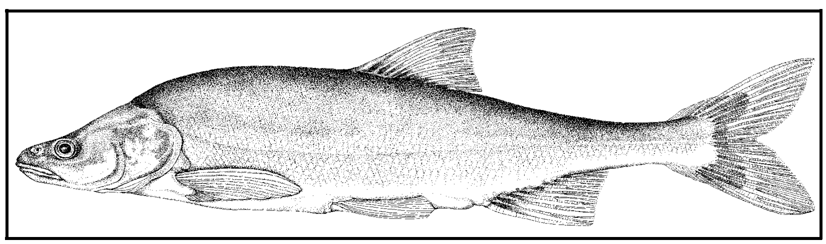


Plate 3.5. Roundtail chub (*Gila robusta*).

Found throughout the Colorado River Basin, the roundtail chub historically was common in most tributaries of the Upper Basin (Vanicek 1967, Holden and Stalnaker 1975a and b, Joseph et al. 1977). Holden and Stalnaker (1975b) reported that roundtail chub was abundant or common at all sites sampled in the Yampa River and at most sites in the Dolores River. McNatt and Skates (1985) found roundtail chub common at most sites in the Green River and Yampa River at Dinosaur National Monument, and Olson (1967) stated that during 1965, roundtail chub was common in Navajo Reservoir collections on the San Juan River. Recent collections on the San Juan River found relatively few roundtail chub, but larger populations were found in several tributaries (Miller et al. 1993, Miller 1995). Therefore, it appears that a roundtail chub population does not currently exist in the San Juan River mainstem and that the few individuals collected likely came from tributaries.

Little information is available describing the details surrounding the specific spawning activities of roundtail chub. Because of the high turbidity commonly associated with the Colorado River and its tributaries, the exact spawning procedure and habitat used by roundtail chub have not been observed. Most roundtail chub that were ripe when collected were found occupying shoreline eddies when captured (Vanicek and Kramer 1969, Karp and Tyus 1990). Vanicek and Kramer (1969) reported that exact spawning sites or deposited eggs were never observed; however, all ripe fish were collected in eddies or shallow pools with boulder or cobble substrate. Although no observations indicated that eddy habitat was used for spawning, Karp and Tyus (1990) stressed the importance of this habitat during spawning whether it was used as a spawning, feeding, or staging area.

Roundtail chub in the Upper Basin began spawning when water temperatures reached about 18.3E C (Vanicek and Kramer 1969, Joseph et al. 1977). In most Colorado River tributaries, this temperature increase coincided with a decrease in discharge after peak runoff. Karp and Tyus (1990) indicated that spawning of roundtail chub in the Yampa River at Dinosaur National Monument occurred between mid-May and early July. Minckley (1973) suggested that an average-sized female roundtail chub would produce about 2,000 eggs. Muth et al. (1985) stated that roundtail chub females produced about 39,500 to 41,350 eggs per kilogram (kg) of body weight. The eggs hatched 7 to 15 days after spawning, depending on water temperature. Young roundtail chub began feeding about 10 days after they hatched (Minckley 1973). During the first 54 days after hatching, the mean daily growth rate was 3 mm for cultured fish (Muth et al.1985). Carter et al. (1986) suggested that roundtail chub actively drifted during the mesolarval stage of development. Drifting activity occurred primarily after mid-July and appeared to increase with warmer water temperatures.

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

Roundtail chub over 200 mm TL consumed a greater variety of prey items than smaller individuals. Adult roundtail chub were reported to feed on filamentous algae, aquatic invertebrates, terrestrial invertebrates (especially grasshoppers and ants), fishes, and plant debris (Vanicek and Kramer 1969, Joseph et al. 1977). Minckley (1973) indicated that adult roundtail chub may have also consumed their own eggs as well as the eggs of other fish species. Olson (1967) reported that the diet of roundtail chub was similar to that of Navajo Reservoir rainbow trout. The diet of both species in the reservoir was primarily plankton with some aquatic insects.

In large rivers, adult roundtail chub may reach 400 to 450 mm TL; however, adult size in the smaller tributaries can be less than 200 mm (Joseph et al. 1977). Karp and Tyus (1990) collected ripe males that ranged from 292 to 419 mm TL, and ripe females from 343 to 380 mm TL. Vanicek (1967) reported that most roundtail chub became sexually mature by age six; however, Muth et al.(1985) reported that spawning females were collected ranging in age from 5 to 7, and spawning males ranged from age-5 to age-8. Prior to spawning, male and female roundtail chub typically developed breeding tubercles. These tubercles were usually uniformly scattered over the surface of the male; however, they were mostly restricted to the head and caudal peduncle of the female. Both sexes developed an orange-red coloration on the ventral surface and ventral fins (Muth et al.1985) which was more pronounced on males.

At present, there is concern regarding the status of roundtail chub in the Colorado River Drainage. Historically, the roundtail chub may have been the most abundant carnivore in the Upper Basin (Holden and Stalnaker 1975a). Recently, a decrease in range and abundance was documented at several locations (Vanicek et al. 1970, Minckley 1973, Joseph et al. 1977, Kaeding et al. 1990). Joseph et al. (1977) suggested that declines in roundtail chub populations were often correlated to the introduction and establishment of predatory nonnative fishes. It is likely that roundtail chub is preyed upon by native and nonnative predators sharing their habitat. Reduction of roundtail chub populations was documented in the San Juan River downstream from Navajo Dam (Joseph et al. 1977), and in the Green River downstream from Flaming Gorge Dam (Vanicek and Kramer 1969, Karp and Tyus 1990). Low numbers of roundtail chub in the San Juan River may be attributed to the change in water temperature induced by Navajo Dam; however, rotenone was used to eliminate nongame species from approximately 70 mi of the river during 1961, which may have made a large, long-lasting impact on the local population (Olson 1962). Roundtail chub was also eliminated from the reservoir portions of the rivers, including the area of Navajo Reservoir and Flaming Gorge Reservoir.

Vanicek and Kramer (1969) provided evidence suggesting that roundtail chub growth rate decreased in the Green River downstream of Flaming Gorge Dam because of a decrease in summer stream temperature. Absence of certain year-classes suggested that successful spawning did not occur during some years in the Green River between Flaming Gorge Dam and its confluence with the Yampa River (Vanicek and Kramer 1969). Vanicek et al. (1970) found that almost no roundtail chub occurred in the Green River within about 20 mi of the Flaming Gorge Dam. Following inlet modification of Flaming Gorge Dam to provide warmer release flows, roundtail chub again started spawning successfully in the Green River above the mouth of the Yampa River (Holden and Crist 1981). Karp and Tyus (1990) indicated that the change in temperature and flow regime caused by Flaming Gorge Dam may have been responsible for a decline in roundtail chub populations in the Green River upstream from its confluence with the Yampa River, but they also suggested that a negative interaction between roundtail chub and channel catfish occurred and resulted in a competition for food and predation by channel catfish on roundtail chub.

There is some speculation that human-induced changes to the Colorado River Drainage may have contributed to the breakdown of reproductive isolation mechanisms that have evolved between roundtail chub and other chub species (Kaeding et al. 1990). Karp and Tyus (1990) collected one specimen that was considered to be a roundtail x humpback hybrid. Morphology of many individuals ranges from more humpback-like to more roundtail-like with a full range between (T.

Chart, UDWR, personal communication). Kaeding et al. (1990) reported that hybridization is possible between roundtail chub and humpback chub, and also between roundtail chub and bonytail chub. Spawning of roundtail chub and bonytail chub is concurrent in time but thought to be spatially separated (Vanicek 1967). Kaeding et al. (1990) additionally suggested that the difference between roundtail chub and humpback chub microhabitat selection for spawning was an important mechanism contributing to the reproductive isolation of each species. Because so little is known about specific spawning requirements of roundtail chub and other chubs in the Colorado River Drainage, further research must be conducted to develop or confirm theories regarding the spawning success and recruitment of roundtail chub.

Speckled Dace

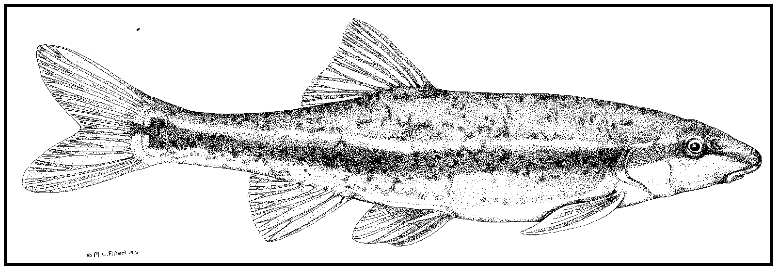


Plate 3.6. Speckled dace (*Rhinichthys osculus*).

Speckled dace, *Rhinichthys osculus*, is perhaps the most ubiquitous and, in many lotic systems, the most common native fish species west of the Rocky Mountains (Minckley 1973, Wallace 1980, Tyus et al. 1982). Its range extends from southeast Arizona (Minckley 1973) and southwest New Mexico (Sublette et al. 1990) north through the Great Basin (Sigler and Sigler 1987) and Pacific coastal states (Moyle 1976) to south-central British Columbia (Scott and Crossman 1973). Across its range, it occupies a variety of streams ranging from small desert streams (Barber and Minckley 1966) to large rivers such as the Colorado (Tyus et al. 1982) and Columbia (Wydoski and Whitney 1979).

In the San Juan River Basin of New Mexico, Colorado, and Utah, speckled dace was widespread and comparatively common (Miller 1994, Ryden and Pfeifer 1996a, Propst and Hobbes 1996). In San Juan River secondary channels, speckled dace was the most common native fish species in summer and autumn fish collections (Propst and Hobbes 1996). Although it was found in a variety of habitats, it was most common in riffles and runs with moderate to rapid velocity water over gravel and cobble substrates (Gido et al. 1997; Gido and Propst, in press).

Speckled dace is a stout, round minnow that is flattened slightly ventrally. It possesses a triangular shaped head with small eyes, subterminal mouth, and pointed snout. Head length is roughly equal to body depth. Coloration is typified by an olivaceous or gray back and sides with scattered spots above the midline. The species usually possesses a dark lateral band extending from the tip of the snout through the caudal peduncle. Adults are 45 to 100 mm TL (Wallace 1980, Sigler and Sigler 1987). Minckley (1973) described breeding males ". . . with brilliant red on bases of paired fins and on body above those fins, on and near anal fin base, the lower caudal lobe, the mouth, and near the upper part of gill cleft."

Deacon et al. (1987) noted that speckled dace preferred water temperatures around 15.8E C and had a low tolerance of water temperatures higher than 30E C. Lowe et al. (1967) suggested that low tolerance of reduced oxygen, along with high temperatures, were the reasons why speckled dace was only found between elevations of 5,905 and 6,890 ft in Arizona.

John (1963) described the reproductive cycle of speckled dace as bimodal, with discrete peaks of spawning in early spring and late summer. Spring spawning was associated with increased water temperatures, day length, and spring runoff. Spawning in late summer was associated with higher flows during or following rain events. A single flood was not adequate to stimulate spawning in early summer, but would in late summer. John (1963) therefore hypothesized that photoperiod is the determining factor in regulating the reproductive period of speckled dace. Nests or spawning sites were typically located in areas with gravel substrate, slow or no velocity, and little if any vegetation (John 1963). Several males, up to 60 in one site, would occupy a nest, persistently working over the gravel with their mouths. This activity, and the constant turbulence associated with so many males swimming in one area, produced an area clean of silt, plant material, and debris. Females would only enter the area periodically prior to actual spawning to "test" the spawning substrate. Males would converge on the female and "a vibrating swarm" would accompany the female's vigorous tail lashing (John 1963). Once spawning was initiated, a female would enter the nest site repeatedly, depositing a few eggs at a time (John 1963). The "swarm" of males would again converge on the female and apparently release sperm simultaneously. After the female left the nest site, eggs that did not immediately fall below the first layer of gravel were immediately preyed upon by the males. Spawning activity would continue in one area for up to 5 days, during which several females would use the nesting site. Eggs were located on the under surfaces of stones or in the interstitial spaces of the finer gravel below (John 1963). In the laboratory, hatching occurred within 6 days at 18 to 19E C. Larval fish remained hidden in the interstices of the gravel for up to 8 days or when the free-swimming stage was reached (John 1963). Winn and Miller (1954) and Snyder (1981) described the larval stages of speckled dace.

John (1963) concluded that female speckled dace typically matured in their second year (age-1), but that smaller age-1 fish were immature. Further studies by John (1964) revealed that speckled dace live 3 or 4 years at most. Females are typically larger and mature later than males.

The diet of speckled dace was comprised almost entirely of aquatic insects (Greger and Deacon 1988, Angradi et al. 1991); however, detritus and plant material were also collected from digestive tracts of speckled dace (Schreiber and Minckley 1981, Williams and Williams 1982). Feeding was most active at night (Van Eimeren 1988).

Speckled dace are an important component of the native fish community in the San Juan River. Commonly collected in both primary and secondary channels (Propst and Hobbes 1996, Ryden and Pfeifer 1996a), speckled dace were probably an important food item for Colorado pikeminnow and roundtail chub.

NONNATIVE SPECIES

The decline of western native fish species was identified by Minckley and Deacon (1968) as, in large part, because of the introduction and establishment of nonnative species in association with habitat alteration. Channel catfish and common carp, two of the most abundant large-bodied nonnative fishes, were introduced in much of the Colorado River Basin during the late 1800s or early 1900s. Other abundant forage species, such as red shiner and fathead minnow (*Pimephales promelas*), were introduced later, after sport fisheries were established in reservoirs that were constructed in the mid-1900s. However, the successes observed in the introduction and establishment of a variety of nonnative species were realized at the expense of native species. Habitat alterations within the Colorado Basin, because of the construction and operation of dams, allowed for the wide dispersal of nonnative species in concert with the decline of natives. Interaction between native and nonnative fishes has been recognized as an obstacle to the conservation of native species and has been the focus of a variety of management efforts (Nesler 1995, Lentsch et al. 1996) in the Colorado River Basin. Mechanical removal of nonnative fishes is a standard practice in SJRIP sampling. Minckley and Meffe (1987) provided evidence for the importance of unregulated rivers in the maintenance of native fish communities, even in the presence of nonnative forms. As noted above, populations of native fishes, especially the endangered forms, were still strongest in the Green River—the system that was the least altered hydrologically. The mechanisms for species replacement vary, but predation by nonnative species was documented as a major factor in the decline, as well as a major deterrent to the reestablishment of native Colorado River fishes (Marsh and Langhorst 1988, Marsh and Brooks 1989).

Understanding the biology and habitat requirements of nonnative species and the associated impacts on native species in San Juan River studies was necessary to determine if flow recommendations could be used as a management tool to decrease nonnative species numbers. This section discusses the life history of the four abundant nonnative fish species in the San Juan River; red shiner, fathead minnow, channel catfish, and common carp. Specific information from SJRIP studies related to distribution, abundance, habitat use, and related factors of these species in the San Juan River are provided. Life history details have generally been developed through literature review.

Red Shiner

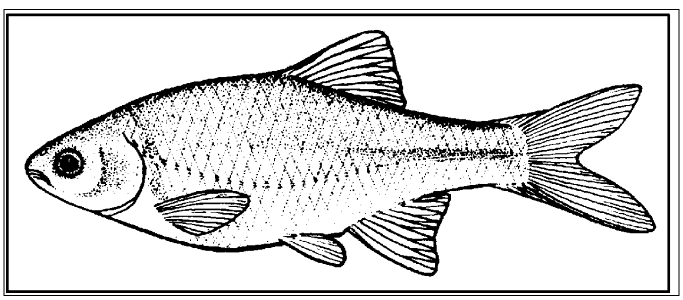


Plate 3.7. Red shiner (*Cyprinella lutrensis*).

Red shiner is native to streams of the south-central Mississippi and western Gulf Coast drainages in the United States and northeastern Mexico (Matthews 1980). In New Mexico, the native range of red shiner encompasses the Rio Grande, Pecos, and Canadian drainages (Sublette et al. 1990). In Colorado, it is native to all drainages east of the Continental Divide (Wordling 1985). Red shiner was first documented in the Colorado River system in the 1940s in the Lower Basin reaches below Lake Mohave (Hubbs 1954). Since then, this nonnative cyprinid has become widely distributed throughout the American Southwest. The species was probably introduced to the San Juan River system during the 1950s or 1960s (Sublette et al. 1990), and it is now common in the river between the Hogback Diversion in New Mexico and Lake Powell in Utah (Archer et al. 1996, Propst and Hobbes 1996, Ryden and Pfeifer 1996a). Red shiner occupies a broad range of habitats, including primary channel shoreline habitats, low-velocity areas associated with the primary channel (e.g., backwaters and embayments), and the array of habitats found in secondary channels (e.g., pools, low-velocity runs, and riffles).

Red shiner is a deep-bodied, laterally compressed minnow with small eyes, a terminal, oblique mouth, and a blunt, rounded snout. This species is well adapted to survive in highly turbid streams with extreme flow variability. Red shiner is highly tolerant to changes in dissolved oxygen, pH, and salinity (Matthews and Hill 1977). Temperature, water velocity, and depth most influenced habitat selection by red shiner in Oklahoma (Matthews and Hill 1979). Matthews and Hill (1980) reported that the species avoided temperature extremes in winter and summer, preferring backwaters or slow-moving deeper water (1 ft) where temperatures were most stable. Throughout the 682 mi north-south span of the red shiners' native range, Matthews (1986) found no significant differences or clinal variation in critical thermal maximum between or among populations. However, it was noted that red shiner was probably the cyprinid most tolerant to high water temperatures. Red shiner was collected in New Mexico from a very warm spring (39.5E C) (Brues 1928).

Reproduction of red shiner was extensively studied (Minckley 1959, Saksena 1962, Taber 1969, Pflieger 1975, Farringer et al. 1979, Gale 1986). Most commonly, spawning occurred from April to October, usually peaking during June and July. Gale (1986) observed fractional spawning over a 2-month period (June to July), wherein several clutches of eggs were produced by a single female. Farringer et al. (1979) suggested the incidence of at least two discrete spawning periods in Oklahoma and Texas. Red shiner nests were found in riffles, sunfish nests, submerged roots, and crevices. Substrates varied from gravel to silt. Males defended a territory where they aggressively chased females. After a usually lengthy courtship (several hours), a male and female passed 1.5 to 2.0 in. over a "nest" where the female and male expelled gametes simultaneously. The fertilized eggs fell into the nest substrata. Gale (1986) described the eggs as yellowish and adhesive with a maximum diameter of less than 0.05 in. Clutch size averaged 585 eggs (Gale 1986). Gale (1986) observed up to 19 clutches from one female. After fertilization the eggs were abandoned and hatched in about 105 hours. Snyder (1981) and Fuiman et al. (1983) described morphology of red shiner larvae.

Farringer et al. (1979) examined scale annuli and suggested that some red shiner may live through two winters and that sexual maturity is reached at age-1 or near 30 mm SL. Laser and Calander (1971) suggested that most red shiner in a population are age-0 and age-1, and that only a few fish reach age-2.

Red shiner is omnivorous and feeds on smaller fishes, insects, algae, crustaceans, and a variety of microorganisms and plant material (Hale 1963, Greger and Deacon 1988, Ruppert et al. 1993).

The red shiner is a habitat generalist, capable of numerically dominating fish assemblages in western Great Plains streams (Matthews and Hill 1977). Red shiner demonstrates a high adaptability to environments with greatly fluctuating physiochemical factors (Matthews and Hill 1979). In the Colorado River Drainage, which has been highly modified by anthropogenic activities, red shiner has become well established in several river systems, often becoming the numerically dominant species (Ruppert et al. 1993, Gido et al. 1997, Propst and Hobbes 1997).

The decline of many native western fishes has been attributed, at least in part, to red shiner (Minckley and Deacon 1968). Although the particular mode by which red shiner displaces or negatively interacts with native fishes is uncertain and appears to vary among native species (and life stages of each) and geographic location, predation (Ruppert et al. 1993; Brandenburg and Gido, in press), resource competition (Douglas et al. 1994), and greater fecundity (including extended reproductive season) (Gale 1986) have been suggested. Data to support each mode have been presented. Regardless of how red shiner impacts native fishes, it has been documented that where red shiner is common, native fishes (at least some species) have declined.

Red shiner was the most abundant nonnative fish species in San Juan River secondary channel habitats (Gido et al. 1997; Propst and Hobbes 1997; Gido and Propst, in press). In these studies, red shiner often comprised 50% of the total number of fishes collected, whereas native fishes usually comprised less than 20%. Although spring runoff typically reduced red shiner abundance, red shiner density usually attained pre-runoff levels after the reproductive season.

Fathead Minnow

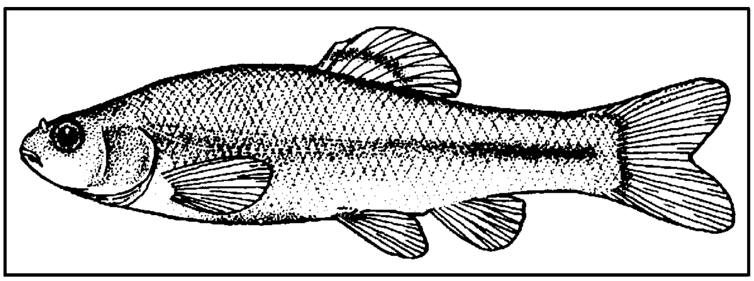


Plate 3.8. Fathead minnow (*Pimephales promelas*).

Fathead minnow is native to the central and upper Mississippi-Missouri-Ohio River Drainage (Lee and Shute 1980). It has been broadly distributed outside its native range, particularly west of the Rocky Mountains, as a bait and forage fish (Carlander 1969, Minckley 1973, Woodling 1985, Sublette et al. 1990). Its hardiness and tolerance of a variety of environmental conditions are one reason it is a popular bait fish and contribute to its widespread establishment outside its native range (Carlander 1969). Fathead minnow was probably first introduced to the San Juan River Drainage in the 1950s or 1960s (Sublette et al. 1990). It is now common throughout the warmwater reaches of the San Juan River (Archer et al. 1996, Propst and Hobbes 1996, Ryden and Pfeifer 1996a).

Fathead minnow is a stout-bodied minnow with a small head and eyes, a small, oblique, terminal mouth, and a blunt, rounded snout. Coloration is typified by an olivaceous back with predorsal dusky stripe behind the head. The sides fade to tan or brown, sometimes with a dusky lateral band. Pflieger (1975) described breeding males as ". . . mostly black with a broad, yellowish bar encircling body behind head and a similar bar beneath dorsal fin; large tubercles developed on chin and in 3 rows on snout; forward part of back with a fleshy pad."

Fathead minnow has been collected in rivers, streams, lakes, and ponds, preferring low-velocity habitats (Becker 1983, Robison and Buchanan 1988). The species is highly tolerant of low oxygen, high temperatures, and turbidity. It was reported by Kochsiek and Tubb (1967) that fathead minnow can tolerate high salinity (>8,000 ppm) for up to 48 hours. In streams with intermittent flow, fathead minnow is often the most abundant fish species collected, mostly in isolated, stagnant pools (Pflieger 1975, Cross and Moss 1987, Sublette et al. 1990). More commonly collected in low-velocity habitats, fathead minnow is often associated with submerged or floating algae (Becker 1983, Sublette et al. 1990).

Spawning of fathead minnow has been reported from April through early autumn (Markus 1934, Prather 1957, McCarraher and Thomas 1968, Scott and Crossman 1973, Andrews and Flickinger 1974, Becker 1983, Robison and Buchanan 1988), depending on geographic location. It has been hypothesized that water temperature, photoperiodicity, or both may influence initiation of spawning by fathead minnow (Andrews and Flickinger 1974). Andrews and Flickinger (1974) hypothesized that day length may be more important in initiating spawning and that water temperature becomes most important as the reproductive season progresses. Spawning begins in the spring or when the water temperature is approximately 15.6E C and continues through the summer and autumn until water temperature is again below 15.6E C (Prather 1957, McCarraher and Thomas 1968). Male fathead minnow select a nesting site, usually under an object, digging out a cavity if necessary (Andrews and Flickinger 1974). One male will spawn with several females while defending a nest from all other males. McMillan (1972) reported "snout-butting" between male combatants. After a complex courtship best described by Burrage (1961), a male maneuvers a female into the nest, then stimulates her to expel eggs while the male simultaneously releases sperm. The male will tend the nest until the eggs hatch (Markus 1934, Pflieger 1975). Fathead minnow females were observed depositing eggs on the undersides of rocks, timber, concrete, tile, and even metal (Markus 1934, Benoit and Carlson 1977). Gale and Buynak (1982) determined that fathead minnow is a fractional spawner. Five pairs of fathead minnow produced 16 to 26 egg clutches with 9 to 1,136 eggs per clutch (Gale and Buynak 1982). One female produced more than10,000 eggs during a reproductive season. Gale and Buynak (1982) reported no post-spawning mortality. However, Markus (1934), among others, reported post-spawning mortality of both sexes. Mature eggs are orange, demersal, and buoyant, with a maximum egg diameter of less than 0.05 in. (Becker 1983). A secretion by the male adheres the eggs to the underside of the nest cavity (Cross 1967, Smith and Murphy 1974). Eggs hatch in 4.5 to 6 days (Hasler et al. 1946), and larvae remain near the nest until yolk-sac absorption (Becker 1983). Larval morphology and development has been extensively documented (Fish 1932, Markus 1934, Andrews 1970, Snyder et al. 1977, Snyder 1981, Heufelder and Fuiman 1982, Fuiman et al. 1983).

Growth was rapid in some populations with individuals reaching adult size during the first summer (age-0) if an abundant food source is available. However, in most instances, maturity was not reached until the second summer (age-1) or even the third year (age-2) (Becker 1983). Age-3 fish were rare (Carlson 1967, Held and Peterka 1974, Chadwick 1976).

Fathead minnow was observed to feed primarily in soft-bottomed substrates. The majority (80 to 95%) of their diet consisted of algae and other plant material with the remainder comprised of microscopic organisms and smaller aquatic insects (Coyle 1930, Starrett 1950).

Fathead minnow was one of the most important commercially propagated fish species in the United States (Becker 1983, Robison and Buchanan 1988). Miller (1952) reported use of fathead minnow as a bait fish in the lower Colorado River system by the early 1950s. Fathead minnow is commonly found in bait shops in and around the San Juan River Basin. An easily propagated, widely produced species, it may be surmised that control or enforcement to prevent inadvertent introductions into nonnative waters is almost impossible.

The impact of fathead minnow on native fish populations in the San Juan River is unknown. Fathead minnow commonly occupy habitats used by some life stages of several native fish species. Archer et al. (1996) found fathead minnow common in backwater habitats associated with the San Juan River. In secondary channel habitats, Gido and Propst (in press) reported that all life stages of fathead minnow (larvae, juvenile, and adult) occupied the same mesohabitats as native fishes (primarily flannelmouth sucker and bluehead sucker), but that there was temporal segregation in the use of these mesohabitats. Although they did not find direct evidence of competition, it may nevertheless occur.

Channel Catfish

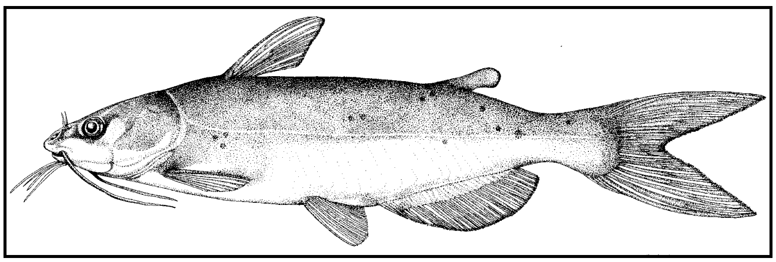


Plate 3.9. Channel catfish (*Ictalurus punctatus*).

Channel catfish is native to the central United States, south central Canada, and portions of the Atlantic coast and Mexico (Sublette et al. 1990). It is the most widely cultivated warmwater species in North America (Sublette et al. 1990). It is not known when channel catfish was first introduced into the San Juan River, but this species was stocked in the Colorado River Basin as early as 1892 (Allen and Roden 1978 as cited by Tyus and Nikirk 1990). It is found in a wide range of warm to cool water habitats and in large rivers, ponds, and reservoirs. In the Yampa River, channel catfish occupy the same habitats as the endangered fishes at all times of the year (Irving and Karp 1995). Channel catfish is omnivorous, consuming a variety of food items including insects, fishes, and plant material (Koster 1957). Spawning occurs during late spring and early summer (Sigler and Sigler 1987, Sublette et al. 1990). Channel catfish reportedly can live almost 40 years (Moyle 1976), though most probably live no more than 10 to 12 years (Sigler and Sigler 1987). Tyus and Nikirk (1990) reported a maximum life span of 22 years in the Green and Yampa rivers.

Spawning occurs during late spring and early summer when water temperatures are about 21 to 29E C (Sublette et al.1990). In the San Juan River, channel catfish spawn during late June through early August, typically on the descending limb of the hydrograph. In the Green and Colorado rivers, spawning overlaps with Colorado pikeminnow (T. Chart, UDWR, personal communication). Males can spawn several times in a year, while females spawn only once (Lentsch et al. 1996). Based upon radiotelemetry data, there did not appear to be any seasonal pattern of movement associated with spawning in the San Juan River. Spawning nests are built (and guarded) by males in holes, undercut banks, or other protected areas such as rubble or boulders (Sigler and Sigler 1987, Sublette et al. 1990). The eggs are demersal, adhere into a compact gelatinous mass, and are about 3.5 mm in diameter (Sublette et al.1990, Lentsch et al. 1996). Incubation time is 6 to 10 days at 15.5 to 27.8E C, and larvae hatch at 6 to 9 mm TL (Lentsch et al. 1996). Young channel catfish remain in the nest for 2 to 5 days until the yolk-sac is absorbed (Sigler and Sigler 1987). Males defend both eggs and young for varying periods of time after hatching (Koster 1957, Sigler and Sigler 1987). Age at first spawn varies from 18 months to 8 years (Carlander 1969, Sigler and Sigler 1987), though most probably mature at age-3 to age-5 years (Sigler and Sigler 1987). In the San Juan River, channel catfish probably first spawn at age-4 when they are typically 300 to 325 mm TL.

After emerging from the nest, young channel catfish school for up to several weeks, then disperse (Sublette et al. 1990, Lentsch et al. 1996). Larval catfish have been collected during August (Buntjer et al. 1994) in drift collections indicating that spawning can occur during post-runoff. Though larval channel catfish may “drift” in the San Juan River, it appears their abundance in drift collections is often related to downstream displacement from storm events (Buntjer et al. 1994, Platania 1996). In the Illinois River, Arkansas, Armstrong and Brown (1983) hypothesized that drift of larval channel catfish was related to diel periodicity of feeding.

Young-of-the-year and age-1 channel catfish were commonly found in areas of low velocity, including backwaters (Holden and Stalnaker 1975a, Conklin et al. 1995). In the San Juan River, they were abundant in backwater and flow-through habitats in the middle reaches of the river between Aneth and Mexican Hat, Utah (Buntjer et al. 1993, 1994). There were no documented collections of YOY and age-1 channel catfish in the mainstem of the San Juan River upstream of the San Juan Generating Station (RM 166.1) near Waterflow, New Mexico. The appearance of YOY channel catfish in low-velocity habitat collections varied by year between late July and August (Buntjer et al. 1993, 1994; Archer et al. 1996), indicating variable spawning times. Channel catfish increased in abundance throughout the summer in backwater and flow-through habitats and were usually most abundant in autumn (Buntjer et al. 1993, 1994). Summer and fall habitat requirements were similar to those reported for spring and vary temporally depending upon the annual spawning period.

In the San Juan River, juvenile channel catfish abundance typically increased with increasing distance downstream, with the highest catch rates occurring between Aneth and Mexican Hat, Utah (Buntjer and Brooks 1996). Juveniles (< 300 mm TL) in the San Juan River were commonly collected over sand/silt substrates along cobble bars and in slow run habitats associated with riffles (Brooks et al. 1994). Conklin et al. (1995) indicated that juvenile catfish (< 300 mm) in the Platte River, Nebraska, preferred both low-velocity backwater areas and faster main channel runs. Sigler and Sigler (1987) reported that young catfish remained in riffles in association with obstacles as barriers to high water velocities. Channel catfish YOY typically occurred year round in low-velocity shoreline habitats in the San Juan River, including backwater and flow-through habitats (Buntjer et al. 1993, 1994; Archer et al. 1996). Their abundance in these habitats in the winter was typically lower than in late summer and fall collections. Conklin et al. (1995) found similar habitat use by young channel catfish year round but did not discuss seasonal differences in abundance.

Catch rates for adult channel catfish generally increased with increasing distance upstream between Clay Hills Crossing (RM 3.0) and the San Juan Generating Station (RM 166.1) (Buntjer and Brooks 1996). In the San Juan River, adults were collected in all habitat types, often in association with flannelmouth sucker and bluehead sucker (Brooks et al. 1994). Spring radiotelemetry data showed channel catfish most frequently used run habitat in association with lower-velocity areas including slackwaters, eddies, run/riffles, sand shoals, and sand shoal/runs. As flows peaked during June 1997, two individuals that predominately used main channel habitats throughout the year moved into previously dry channels, presumably seeking refuge from high water velocities or perhaps food. In addition, there were positive electivity values for both eddies and slackwaters, further suggesting that adult channel catfish were seeking refuge from high flows during spring runoff. In the Yampa River, adult channel catfish occupied the same habitats as Colorado pikeminnow at all times of the year (Irving and Karp 1995).

Summer radiotelemetry data indicated habitat use patterns that were similar to those observed during spring in the San Juan River. Adult channel catfish most frequently used run habitat in association with low-velocity areas including slackwaters, eddies, and riffles. One fish occupied flooded vegetation during peak flows in June 1997. Fall habitat use was similar to summer use with respect to frequency of use of run habitat and associated habitat complexity. Adult channel catfish most frequently used run habitat in association with eddies, riffles, run/riffles, and cobble shoals. The distribution and abundance of juvenile and adult channel catfish were correlated with cobble-type habitats during fall base-flow conditions. On average, adult channel catfish occupied less complex habitats in summer and fall than in spring. Though no juvenile channel catfish were implanted with radio transmitters in the San Juan River, a study done in the Platte River, Nebraska, indicated similar habitat use by season for juvenile channel catfish (Conklin et al. 1995). Conklin et al. (1995) found juvenile channel catfish preferred low-velocity backwater areas and faster main channel runs, and were most frequently associated with sand and a combination of sand and silt substrates. In addition, they were generally found in areas associated with the river banks, particularly near exposed roots and brush piles.

Winter radiotelemetry data revealed that adult channel catfish most frequently occupied run habitat in association with eddies, slackwaters, and run/riffles, similar to both fall and summer habitat use. The average habitat complexity of areas occupied by channel catfish in the winter was also similar to both summer and fall. However, unlike summer and fall, and similar to spring runoff, during winter adult channel catfish were seeking areas of lower velocity.

Common Carp

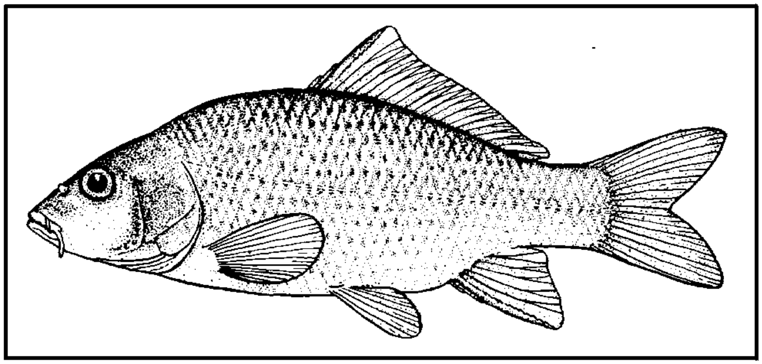


Plate 3.10. Common carp (*Cyprinus carpio*).

Common carp is native to Europe and Asia, and was first introduced in the United States in 1831 (Sublette et al. 1990). The introduction of common carp in the San Juan River likely occurred in the early to mid-1880s (Holden and Stalnaker 1975a, Sublette et al. 1990). Common carp are capable of adapting to a wide variety of environmental conditions (Minckley 1973, Lentsch et al. 1996), but seek warm, shallow, vegetated, low-velocity habitats (Sublette et al. 1990). In the Upper Basin, they are abundant in sheltered habitats, including backwaters, shorelines, and along tamarisk-lined banks (Valdez 1990). Common carp is truly omnivorous, consuming aquatic invertebrates, algae, organic debris, plants, and occasionally fish eggs (Cooper 1987, Sublette et al. 1990). Spawning occurs from April to late August (Carlander 1969, Sigler and Sigler 1987). Common carp can live 47 years in captivity (Carlander 1969) though the average life expectancy is 9 to 15 years (Sublette et al. 1990, Lentsch et al. 1996).

Spawning occurs in a wide variety of habitats in water temperatures of 10 to 30E C (Lentsch et al. 1996) with 17 to 23E C generally considered optimum (Carlander 1969, Sublette et al. 1990). In the San Juan River, carp likely spawn from late-April through August, peaking some time in June or July. In the Yampa River, carp spawn from mid-May through mid-August with peak spawning between early-June and early-July (Lentsch et al. 1996). Spawning usually involves one female and a group of males (Minckley 1973). Females may spawn twice in a season, releasing most of their eggs in the first spawn (Carlander 1969). The slightly adhesive eggs (0.9 to 2 mm in diameter) are broadcast at random in shallow water along the shore, often over submerged vegetation, debris, or rubble (Koster 1957, Carlander 1969, Minckley 1973). Age at first spawn is 1 to 4 years for males and 2 to 5 years for females (Carlander 1969). In the San Juan River, few juvenile carp have been collected, making it difficult to follow cohorts through time and estimate age at first spawn. However, because trends in annual adult carp collections generally track adult channel catfish collections (Buntjer and Brooks 1996), it is possible to assume carp in the San Juan River are mature (>250 mm TL) by age-2 or age-3. Ripe males have been observed that were 250 to 350 mm TL.

Egg incubation time was 3 to 5 days at 20E C and 5 days at 15E C (Lentsch et al. 1996), but could be up to 16 days depending upon water temperature (Sublette et al. 1990). Larvae hatched at 4 to 5 mm TL (Lentsch et al. 1996) and remained attached to vegetation until they completely absorbed their yolk sacs, generally within 5 days (Cooper 1987). Though larval carp were reported as being common in drift collections in some rivers (Gale and Mohr 1978), their collection in the San Juan River drift was primarily incidental (Buntjer et al. 1994, Platania 1996).

After hatching, common carp remained near shore for a period of time, then dispersed to sheltered areas as juveniles (Minckley 1973). Young-of-the-year and age-1 carp were commonly seined in backwater and flow-through habitats in the San Juan River, though seldom in large numbers (Buntjer et al. 1993, 1994; Archer et al. 1996). Holden and Stalnaker (1975a) reported similar findings for carp in backwater habitats of the Upper Basin. Catch rates for YOY and age-1 carp in secondary channels from 1991 to 1996 were considerably higher than those reported for main channel habitats, particularly in 1993 and 1994 (Buntjer et al. 1993, 1994; Archer et al. 1996). Propst and Hobbes (1995, 1996) found common carp were most abundant in upstream reaches (above RM 115) and were the most abundant nonnative in spring secondary channel electrofishing collections. Thus, secondary channel habitats in the San Juan River appeared to be seasonally important nursery areas for YOY and age-1 carp, particularly in upstream reaches. Young carp abundance in low-velocity shoreline habitats in the winter was typically lower than in late summer and fall collections (Buntjer et al. 1993, 1994; Archer et al. 1995, 1996).

Few juvenile (<250 mm TL) carp were collected in the San Juan River (Buntjer and Brooks 1996), making it difficult to describe their distribution, abundance, or habitat requirements. In addition, there were few, if any, riverine studies in the Upper Basin that discussed juvenile carp. Conklin et al. (1995) described habitat selection for common carp in the Platte River, Nebraska, but the majority (96%) of carp collected were greater than 300 mm TL. In general, it is believed that juvenile carp seek warm, protected areas.

Catch rates for adult common carp generally increased with increasing distance upstream between Clay Hills Crossing (RM 3.0) and the San Juan Generating Station (RM 166.1) (Buntjer and Brooks 1996). During the spring in the San Juan River, adult carp were most abundant in deep, low-velocity eddies along the shore over sand and silt substrate (Brooks et al. 1994). During the summer, adult common carp were most abundant in shoreline habitats over sand and silt substrate in slow- to moderate-run habitats (Brooks et al. 1994). There is no information regarding winter habitat use in the San Juan River. However, other studies have shown that common carp move in response to water temperature and move to deeper areas in winter where water temperatures are warmer (Koster 1957, Otis and Weber 1982). Small adult carp (350 to 450 mm TL) commonly occupy open, shallow areas downstream of riffles and adjacent to run/pool complexes (Brooks et al. 1994). They were also frequently abundant in slow- to moderate-velocity run habitats. Conklin et al. (1995) observed similar habitat use (and selection) by adult carp in the Platte River, Nebraska. In the Yampa River, adult carp occupied the same habitats as the endangered fishes at all times of the year (Irving and Karp 1995).

Common carp are potential predators on the eggs and young of native fishes in the San Juan River, and they may also be potential competitors with young native fishes. Although common carp are common in much of the Colorado River Basin, only in Lake Mohave have they been observed actually eating eggs of a native fish species (razorback sucker) (Minckley et al. 1991).

CHAPTER 4: PHYSICAL AND BIOLOGICAL RESPONSE TO RESEARCH FLOWS

During the 7-year research period (1991 to 1997), flows from Navajo Dam were adjusted to provide different annual flow regimes for the purpose of examining the biological response of fish species and aquatic habitats to specific hydrologic regimes. Research releases from Navajo Dam were made every year from 1992 through 1997 (1991 was a control year with no modification to the release) to augment the unregulated flows from the Animas River and provide peak spring runoff flows mimicking a natural hydrograph in the San Juan River. Releases from Navajo Dam in 1992, 1993, 1994, 1995, and 1997 were designed to provide variation in ascending limb, descending limb, and breadth and magnitude of peak, within the limits of the available hydrology and reservoir storage volume, and to the satisfaction of downstream water rights. The peak release in each of these years was timed to match the anticipated peak of the Animas River to provide the largest practical flow through the study area consisting of the San Juan River from Farmington, New Mexico, to the confluence with Lake Powell. In 1996, the peak release was timed to extend the duration of the runoff rather than to enhance the magnitude of the runoff because of limited water supply. Table 4.1 summarizes the nature of the release hydrograph for each year.

Table 4.1. Summary of Navajo Dam release hydrograph characteristics during the research period, 1992 to 1997.

YEAR	ASCENDING LIMB	PEAK	DESCENDING LIMB	MATCHED ANIMAS RIVER PEAK
1992	6 weeks starting April 13	2 weeks at 4,500 cfs	4 weeks ending July 15	Yes
1993	Starting March 1, rapid increase to 4,500 (compare with 1987)	split peak, 45 days at 4,500 cfs, 7 days at 4,500 cfs	4 weeks ending July 13	No
1994	4 weeks starting April 23	3 weeks at 4,500 cfs	6 weeks ending July 28	Yes
1995	3 weeks at 2,000 cfs in March, ramp to 4,500 over 6 weeks starting April 1	3 weeks at 5,000 cfs	4 weeks ending July 14 (summer flow increased by 200 cfs)	Yes
1996	1 week starting May 27	3 weeks at 2,500 cfs	1 week ending June 29	No
1997	3 weeks at 2,000 cfs in March, return to 600-cfs base for 31 days, 10 day ascent starting May 12	2 weeks at 5,000 cfs	6 weeks ending July 16	Yes

The resulting hydrograph through the study area during the research years was dependent upon the Animas River flows that were not predictable, other than total volume, at the time the decisions were made concerning the type of release hydrograph. Therefore, the actual downstream hydrograph was often quite different from the anticipated condition. In addition to research flows that involved the spring peak, two low winter flow tests were also conducted. In January 1996, a 2-week low-flow test (250-cfs release from Navajo Dam) was conducted, and in the winter of 1996-97 a 3-month low-flow test was conducted. Figure 2.5 shows the resulting hydrographs at the Four Corners gage for the 1991 to 1997 research period.

Tables 4.2 and 4.3 compare hydrologic parameters for each year of research flows as measured at two USGS gaging stations (San Juan River near Bluff, Utah, and San Juan River at Four Corners) in the study area. Exceedence parameters involving timing of discharge (volume of runoff or magnitude of peak flows) were calculated using the pre-dam period of record only. Parameters using an annual volume of water (total annual discharge or exceedence of annual discharge) were calculated using the entire period of record (1929 to 1997), because Navajo Dam redistributes discharge but does not effectively change the total volume released.

The years 1993, 1995, and 1997 were considered relatively high spring flow years, although the characteristics of each peak varied (Tables 4.2 and 4.3). The years 1991 and 1996 were considered low-flow years with relatively small spring peaks, and 1992 and 1994 were intermediate runoff years (Figure 2.5). Prior to the initiation of the 7-year research period in 1991, the San Juan River experienced a series of very low-flow years because of a major drought in the western United States (1988 to 1990) (Figure 2.4). This drought period was preceded by a 5-year wet period, terminating in a very high-flow year (1987). Biological studies in the river were conducted during the period 1987 to 1990 and provided a pre-research period that adds to the variation in flows and number of years examined.

One of the primary objectives of the 7-year research project was to evaluate the physical and biological responses of the San Juan River ecosystem to these research flows. This section discusses the study results that provide much of the information used to develop the flow recommendations.

PHYSICAL RESPONSES TO RESEARCH FLOWS

Studies by Bliesner and Lamarra (1993, 1994, 1995) were designed to examine the response in the overall river geomorphology and aquatic habitat to flow using channel cross-section data, bed material sampling, suspended sediment sampling, and habitat mapping. Established channel cross-sections in certain reaches along the river were used to document channel morphology changes with different flows or a net response to the overall hydrologic regime. In addition, extensive mapping of hydraulic habitat at different discharges to represent the range of discharges encountered during the study was conducted in the field using aerial videography to determine response to different flows. A more-detailed discussion of methods used to derive the results presented in this section can be found in those reports.

Table 4.2. Summary of research flows for the pre-dam and research periods, San Juan River near Bluff, Utah.

	1929-61	1991	1992	1993	1994	1995	1996	1997
				San Juan River near Bluff, Utah				
Peak Runoff-cfs	12,409	4,530	8,510	9,650	8,290	11,600	3,280	11,300
Runoff (Mar-Jul)-af	1,263,890	573,863	1,025,622	1,681,192	887,252	1,503,533	421,001	1,278,795
Runoff (total annual)-af	1,750,643	1,084,540	1,504,916	2,271,912	1,289,521	2,011,415	797,821	1,893,403
Peak Date	31-May	16-May	29-May	30-May	06-Jun	19-Jun	16-Jun	05-Jun
Days>10,000	14	0	0	0	0	6	0	8
Days>8,000	23	0	4	13	1	19	0	22
Days>5,000	46	0	44	109	41	68	0	46
Days>2,500	82	42	79	128	64	137	37	95
Ave Daily Flow for month-cfs								
October	2,863	1,628	716	885	1,054	1,145	1,123	1,521
November	1,858	1,173	1,479	1,013	1,160	1,123	1,181	982
December	1,405	1,009	1,187	995	1,066	1,033	1,065	769
January	1,336	1,053	860	2,053	1,047	1,007	739	832
February	2,115	1,541	1,517	2,256	838	1,175	819	807
March	3,250	1,179	1,205	5,741	1,081	2,970	739	2,552
April	7,881	1,684	3,296	6,369	928	3,298	599	2,676
May	12,484	3,357	6,278	6,840	4,680	5,753	1,974	5,629
June	13,078	2,474	4,590	7,136	6,055	8,749	2,874	8,000
July	4,825	807	1,624	1,787	1,961	4,158	798	2,358
August	3,548	650	1,020	1,195	529	1,581	476	2,497
September	2,844	1,470	1,219	1,456	976	1,349	860	2,756
Frequency of exceedence - annual		67%	52%	26%	58%	33%	90%	36%
Frequency of exceedence - runoff		94%	78%	71%	78%	71%	97%	72%
Frequency of exceedence - peak		97%	81%	80%	81%	72%	100%	74%
Uniqueness		Control	early ave.	early ascent	late ave.	late peak	dry	narrow runoff
			storm @ spawn					storm @ spawn

Table 4.3. Summary of research flows for the research period, San Juan River at Four Corners, New Mexico.

	1991	1992	1993	1994	1995	1996	1997
				San Juan River at Four Corners, New Mexico			
Peak Runoff-cfs	5,160	8,900	10,300	10,000	12,100	3,540	11,900
Runoff (Mar-Jul)-af	599,459	1,074,795	1,714,328	1,039,601	1,624,927	431,913	1,319,155
Runoff (total annual)-af	1,086,676	1,512,795	2,216,819	1,448,893	2,102,228	815,795	1,844,163
Peak Date	16-May	29-May	03-Jun	05-Jun	19-Jun	18-May	04-Jun
Days>10,000	0	0	1	0	11	0	10
Days>8,000	0	3	16	13	27	0	29
Days>5,000	2	54	109	49	72	0	49
Days>2,500	46	81	128	67	135	36	98
Ave. Daily Flow for month							
October	1,449	769	827	941	1,109	1,091	944
November	1,127	1,356	911	1,210	1,077	1,139	912
December	1,080	1,088	957	1,105	960	1,088	789
January	1,173	859	1,358	1,050	918	785	772
February	1,289	1,298	1,511	781	1,076	899	713
March	995	1,173	5,463	967	2,782	766	2,279
April	1,810	3,723	6,188	1,028	3,478	607	2,567
May	3,739	6,634	7,298	5,251	6,119	2,150	5,942
June	2,580	4,844	7,701	7,836	9,367	2,925	8,407
July	801	1,444	1,776	2,170	5,187	715	2,689
August	556	927	1,348	552	1,564	492	2,298
September	1,441	997		1,142	1,193	891	2,250

Channel Morphology

Studies dealing with channel morphology and response to flows began in 1992 and are ongoing. Studies were concentrated in three areas of physical response: channel change and cobble bar and backwater formation and maintenance. Channel morphology reflects structural changes in the channel affecting both hydraulic and instream structural habitat. Cobble bars are the primary structural habitat important for spawning Colorado pikeminnow (see Chapter 3), as well as for most other native fishes. Backwater habitats are used more frequently than other habitats by YOY Colorado pikeminnow and early life stages of other native fishes. Quantity and quality of both of these habitats are affected by flow levels more so than other habitats used by the native fishes.

Channel Change

The study of the response of channel morphology to change in the hydrologic regime was accomplished by analyzing change in surveyed channel transects, assessing sediment transport during runoff, analyzing channel complexity measured by island count at a similar flow during several years, and assessing the change in bankfull capacity in modeled geomorphic reaches. The results of these analyses were used to assess channel change because of increased peak runoff flows, examine the response of particular runoff scenarios, and provide input in the selection of flow criteria important to the maintenance of habitat important to the native fishes. Transect data were not collected equally among reaches or throughout the 7-year research period because study design changed as certain information was deemed of greater need to accurately document response of channel morphology to different flow regimes. Measurement of channel complexity could not be completed at the same flow throughout the study because of the natural variability of flow. As a result, some standardization and assumptions were necessary to evaluate channel response to discharge. In general, mean bed elevation, channel complexity, and bankfull discharge were used in this analysis to detect changes in channel morphology.

In 1992, 11 river transects (RTs) were established between RM 70 and RM 169 to monitor scour and deposition within the river. In 1993, 15 additional transects were established. Eight were located in Reach 5, near the suspected Colorado pikeminnow spawning site designated as "the Mixer," five were in Reach 3 between RM 83 and RM 88 (the "Debris Field"), and two were in Reach 1 at RM 4 and RM 12.8 (Clay Hills Crossing, Utah). The Mixer and Debris Field transects were surveyed during runoff to determine local deposition and scour of coarse and fine sediments. The Clay Hills Crossing transects were surveyed before and after runoff, similar to the RT surveys. The assessment of change in mean bed elevation is made based primarily on the RTs for the main portion of the river since they are located throughout the study area and have the longest period of record. The other transects were used to assess special conditions and to supplement the conclusions reached by analysis of the RTs.

Figure 4.1 shows the series of transect surveys at RT 01 from 1992 through 1997, along with the substrate material for each survey. The cycle of scour during runoff and fill between runoff can be observed in this figure, along with the change in substrate. While the other transects have responded somewhat differently, the general pattern for most is similar.

Figure 4.2 shows the mean bed elevation with time for the RT series, assuming no change in width. Change in mean bed elevation may be in bank or bottom erosion/deposition, but it is reported as change in depth as a standardized measure representative of change in cross-sectional area. The transects show a pattern of deposition between runoff periods and scour during spring runoff. The amount of scour is linearly correlated to the volume of spring runoff (r^2=0.78, p=0.02). The correlation is stronger when the previous year's deposition is added to the relationship (r^2=0.95, n=5.0, p=0.05). The correlation to peak discharge is weaker (r^2=0.62, n=6.0, p=0.06). Examination of Figure 4.1 in conjunction with the regression results explains why the previous year's deposition is important to the correlation. The amount of scour in 1997 was nearly as great as in 1993, while the spring runoff volume was much less than in either 1993 or 1995, the other large scour years (Table 4.2). Since 1996 flows were inadequate to remove the fine sediment accumulated since runoff of 1995, there was a large accumulation of fine sediment available for scour in 1997. In fact, even with considerable scour, the mean bed elevation in 1997 did not return to the low achieved in

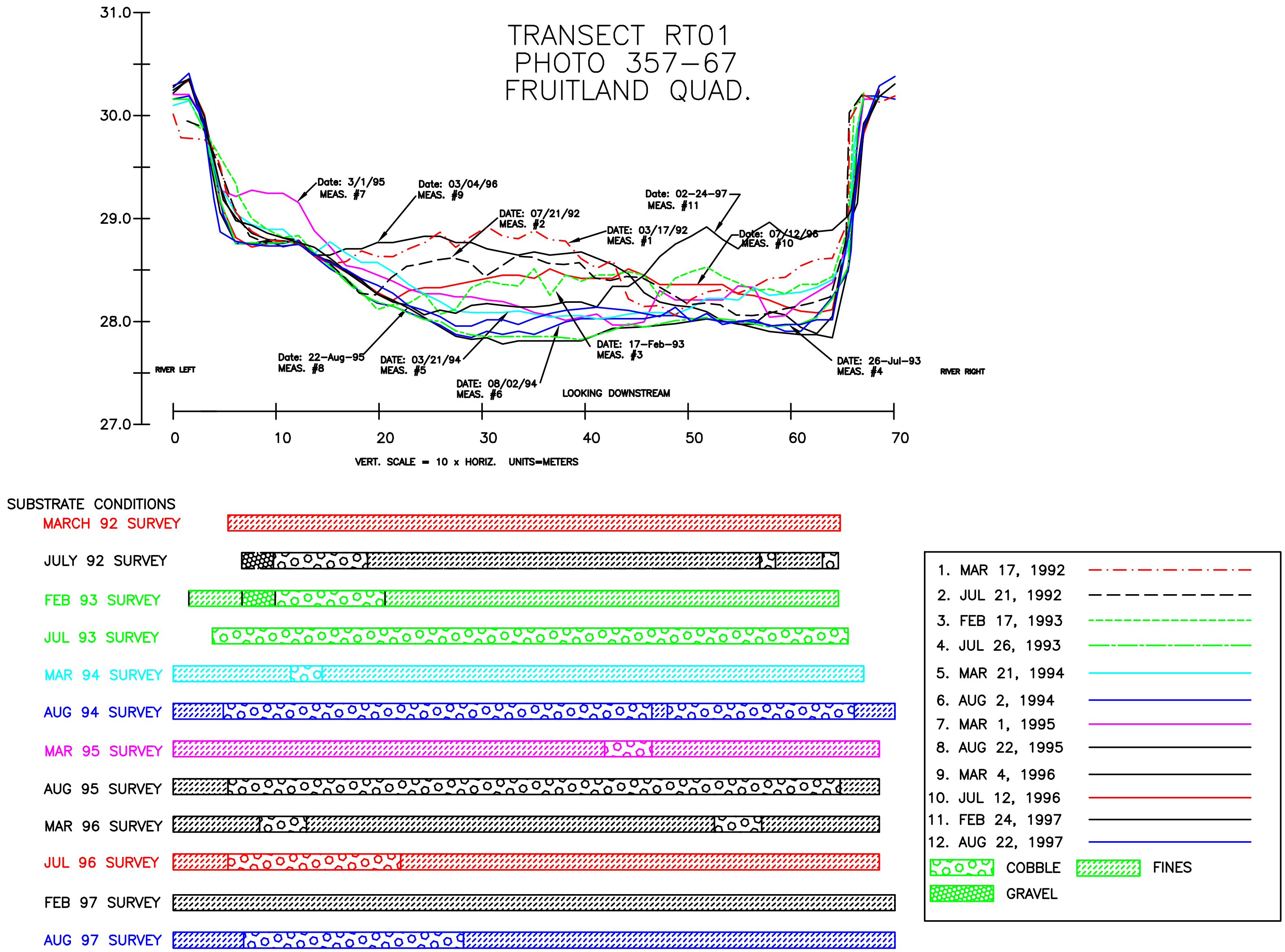


Figure 4.1. Cross-section surveys of the San Juan River at River Transect (RT) 01 for the period 1992 to 1997.

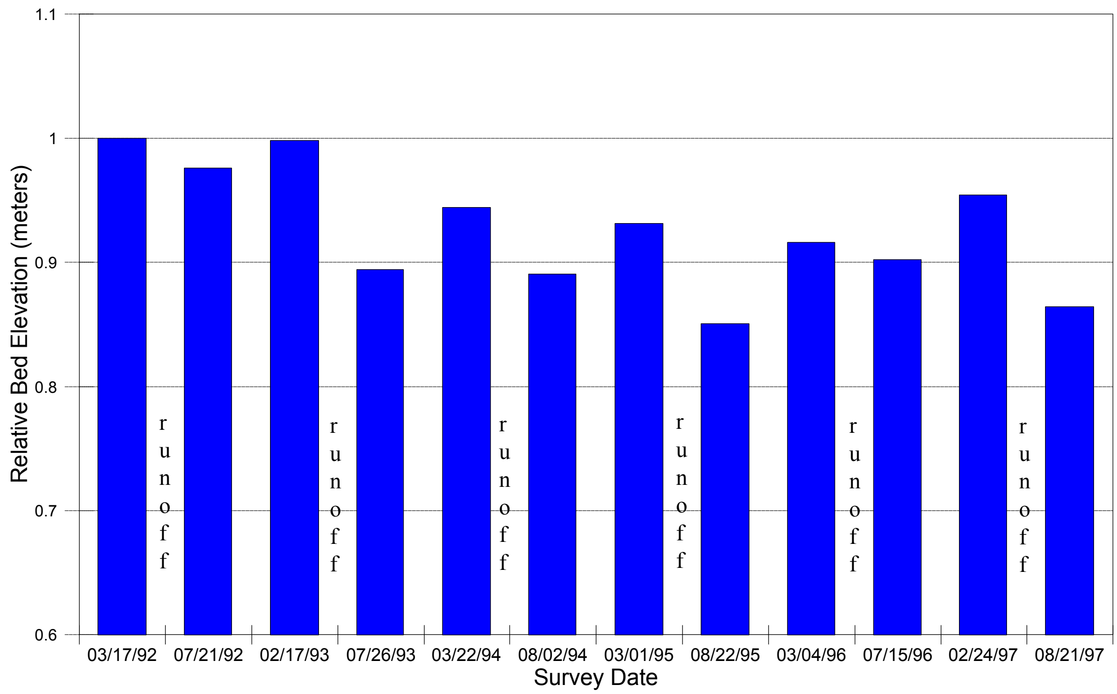


Figure 4.2. Average relative bed elevation for the 11 River Transects (RTs) for the research period.

1995. Therefore, channel bed elevation is a function of both runoff volume and previous sediment accumulation, with eventual equilibrium expected because of the altered flow regime as indicated in Figure 4.2.

Since 1992, the average bed elevation has shown a net decrease of 0.46 ft. The minimum bed elevation occurred after runoff in 1995, with a cumulative net elevation loss of 0.49 ft. Long-term channel maintenance requires a balance between scour and deposition. Since the 1996 runoff (430,000 af) did not remove the sediment accumulated during the previous year, it appears that runoff volumes as low as 430,000 af are inadequate to maintain a transport balance unless coupled with higher flows in subsequent years (e.g., 1997) in the San Juan River.

Validation of this measured change in channel cross-sectional area would be possible by completing a sediment balance for the study reach. Because of the numerous ephemeral channels and intermittent nature of flows, it was beyond the scope of these studies to complete a rigorous sediment balance. However, suspended sediment sampling was conducted periodically during the runoff period each year to examine the gain in suspended sediment because of channel scour. Sediment samples during nonstorm periods (no runoff in the ephemeral washes) were collected at several locations along the river (Bliesner and Lamarra 1993, 1994, 1995). By assessing the sediment balance during nonstorm periods, the amount of sediment removed from the channel during runoff can be estimated. For the period 1992 to 1997, the suspended sediment load in the San Juan River at the Montezuma Creek sampling site (RM 93.6) averaged 785 milligrams per liter (mg/l) greater than at the Farmington sampling site (RM 180.6) during the nonstorm-effected samples taken between March 1 and July 31, totaling 7.66 million tons of sediment over the six runoff periods. Using an average density of 83 pounds (lbs) per cubic foot based on the average sand/silt percentage (64%/36%) of 84 samples, an average channel width from the cross-sections of 336 ft and a channel length of 87 mi, the average depth of scour required to remove this volume of material would be 1.20 ft. From the measured change in cross-sections, including scour of redeposited material, the total scour for the 6 years shown in Figure 4.1 is 1.20 ft. The exact match of the two numbers is somewhat fortuitous, since the computed change based on the increase in suspended sediment is not based on a complete sediment balance and does not include bedload. However, the agreement of the two computed values for scour does indicate that the scour represented at the 11 standard cross-sections is representative of the change in this reach of river. Year-by-year analysis completed for 1995 to 1997 supports the general trend of scour variation with time as shown in Figure 4.1, but quantification is not matched as well as the average data over the full analysis period. For example, suspended sediment analysis for 1996 indicates a small net accumulation of sediment during the runoff period, while the cross-section study shows a small amount of scour.

The series of flows during the 1992 to 1997 period initially resulted in increased channel depth with subsequent stabilization. Since this flow series follows 4 low-flow years after the last large runoff (1987), the net scour seen in the early years was likely related to accumulation of fine sediment since the last large runoff year. Because most of the change is fine sediment and the elevations seemed to have stabilized since 1995, it is likely that the system is seeking a new equilibrium level and will not continue to channelize, especially since this has been a wetter-than-normal period. Further, this series of data suggest that high-flow years are not needed every year to maintain a long-term balance, and that variability in sediment balance from year-to-year is a reality in the San Juan River. While 5 years is a short period on which to base these preliminary conclusions, continuing a release pattern similar to the research flow period, adjusted for average runoff conditions, appears reasonable, provided monitoring is continued to assess long-term impacts and provisions are in place to adjust release patterns if negative trends are identified.

While there has been a net loss of cobble/gravel with time, most of the change in mean bed elevation has been because of scour of sand and silt (90% of total scour). A loss of sand and silt from substrate has resulted in an increased percent composition of cobble/gravel substrate, from about 25% before runoff in 1992 to over 50% after runoff since 1993. Depending on the volume of runoff and sediment load during runoff, the cobble substrate has ranged from 71% (1993) to 52% (1997). However, the effects of fine sediment scour during spring runoff can be easily reversed by summer storm events. The low-flow year (1996) had less fine substrate than 1997, because of a large storm occurring on the descending limb of the 1997 spring runoff prior to sampling. It appears that flow ranges similar to those experienced during the research period are adequate to maintain 50% or more cobble substrate following runoff and over 40% prior to runoff.

The patterns are similar for the Mixer and Debris Field transects (Figure 4.3), although the Debris Field (Reach 3) transects do not appear to have stabilized. Bed elevation in the Debris Field was still decreasing with each successive runoff period. The exception was a noted increase in post-runoff mean elevation within the Mixer transects in 1997 that can be explained by the formation of cobble bars within two of the cross-sections (Figure 4.3).

The two transects in Reach 1 do not follow the same pattern (Figure 4.4). This sand-laden reach is heavily influenced by the backwater effect and the fluctuation of water surface elevation in Lake Powell. These two transects showed a net increase in bed elevation between 1993 and 1997 of 1.02 and 0.46 ft, respectively, for the upstream and downstream transects. The downstream transect initially scoured until runoff in 1995 when sand deposition occurred, likely because of a rise in the level of Lake Powell. The upper transect showed a continued depositional trend. In this case, however, net deposition could be a result of transect location. A longer study period would be needed to discern the effects of the locally shifting thalweg from an actual response in overall bed elevation to the hydrologic regime.

Net scour may indicate an imbalance between the sediment load and the hydrologic regime (volume or timing) that could affect the long-term channel morphology. Since the measurements were taken during a period of modified hydrology where the peak runoff period was restored to more-natural conditions after 30 years of regulation by Navajo Dam, the pattern of initial scour, followed by apparent stabilization or at least decreased scour, was expected. The sediment transport capacity of the higher magnitude spring releases (1992 to 1997) was greater than that occurring during the period of altered spring flows (1962 to 1991).

The increased channel depth indicated by the cross-section surveys during the research period and supported by the sediment balance study suggests a trend toward channelization and channel simplification (less secondary channels). To examine the impact of the observed scour on overall channel morphology, channel complexity, as measured by changes in total number of islands within each reach, was analyzed using habitat mapping coverage in a GIS. Only Reaches 3, 4, and 5 were used in this analysis because mapping for these reaches was the most temporally comprehensive throughout the 7-year research period, and Reaches 1 and 2 have no islands because of canyon restraints. Channel complexity was analyzed in two ways: the overall correlation between discharge and number of islands, and the chronological effect of flow regime on island count during the 7-year research period. Figure 4.5 shows the relationship between the number of islands in Reaches 3 to 5 and discharge during each of the mapping periods. Two regression lines are shown. The longer line represents the full range of discharges encountered. The shorter line includes only flows below 1,200 cfs to represent low flows. It is theorized that channel complexity at low flow would show change first if channel simplification was occurring because of channel scour. As expected, the number of islands increases with increased flow up to about 6,500 cfs as more secondary channels become active. The substantial drop in number of islands between 6,500 and 7,700 cfs indicates overbank flooding at this discharge as inundated islands became mapped as flooded vegetation.

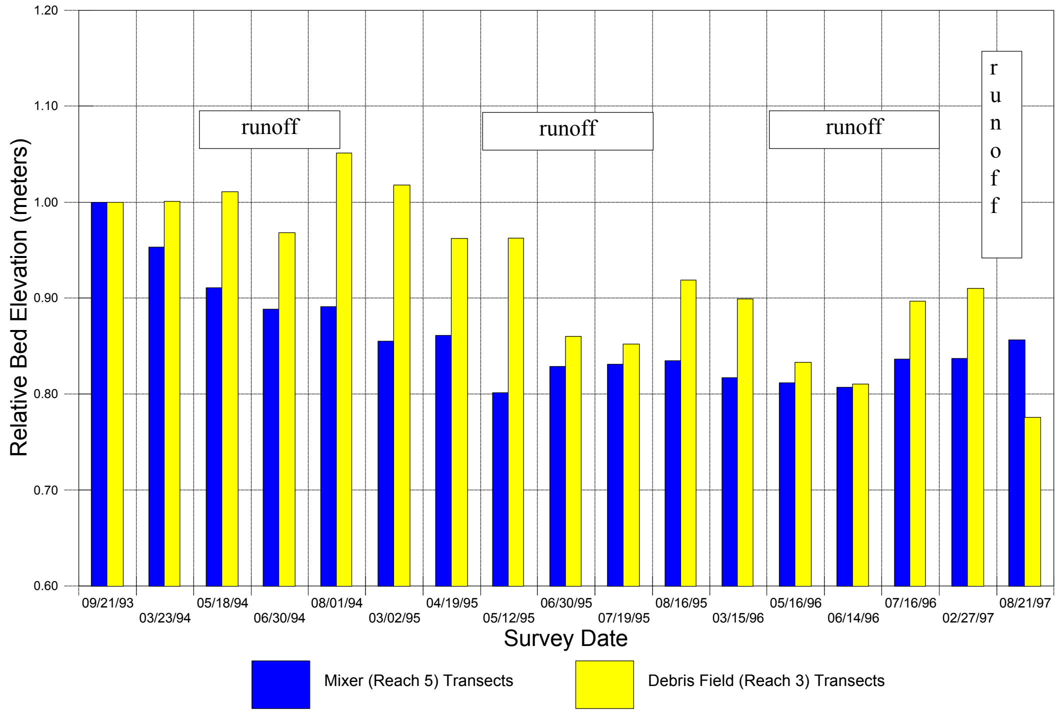


Figure 4.3. Average relative bed elevations for the Mixer and Debris Field transects.

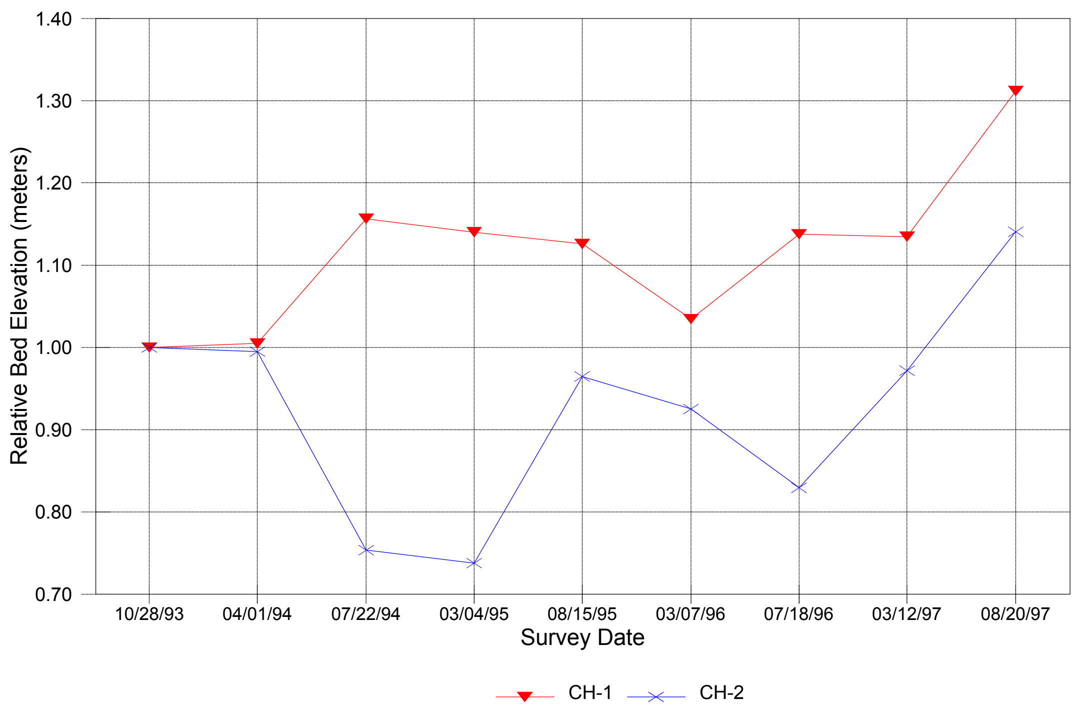


Figure 4.4. Relative bed elevation for two transects in Reach 1.

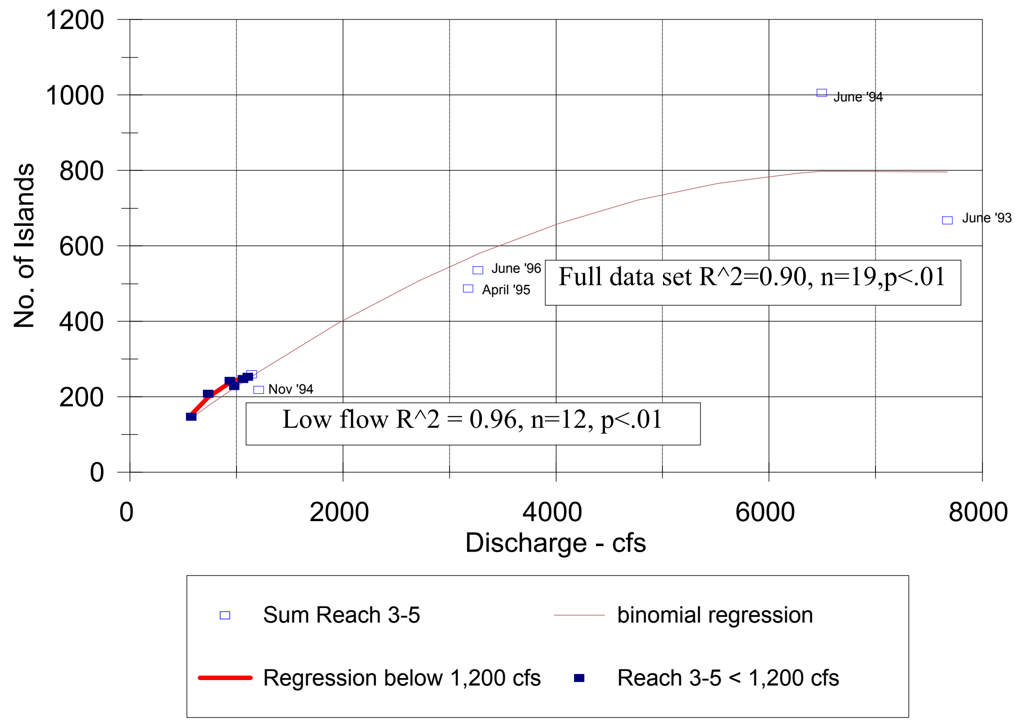


Figure 4.5. Relationship between main channel flow and island count.

To examine the chronological effect of the flow regime on the number of islands throughout the 7-year research period (a test of channel simplification), the total number of islands in Reaches 3, 4, and 5 was plotted against time as noted by the triangles in Figure 4.6. The first data set plotted represents the actual number of islands at the noted flow for each mapping, with only the mapping runs completed at flows below 1,200 cfs shown. Any variation in island count because of channel simplification for this data set is masked by the change in flow rate during mapping. To determine if a change occurred, the island counts had to be standardized to a common flow. These normalized island counts are represented squares on the second line. Normalized island counts for each year were computed as the ratio of the island counts predicted by the regression equation (represented by shorter line on Figure 4.5) for a flow of 1,000 cfs, to that ratio predicted at the flow shown in Figure 4.6 times the actual number of islands mapped at the flow shown. The analysis indicates a slight reduction in islands through 1994, an increase in 1995, a subsequent decrease in 1996, and a slight increase in 1997 with no net change over the 6-year period. The scour indicated by the decrease in mean channel elevation at the measured cross-sections would indicate an imbalance that could lead to channel simplification (loss of multiple channels and islands). For this short period of record, it appears that there was no significant loss of channel complexity associated with the channel scour observed, although there appears to have been a short-term loss that was regained during the high-flow condition in 1995.

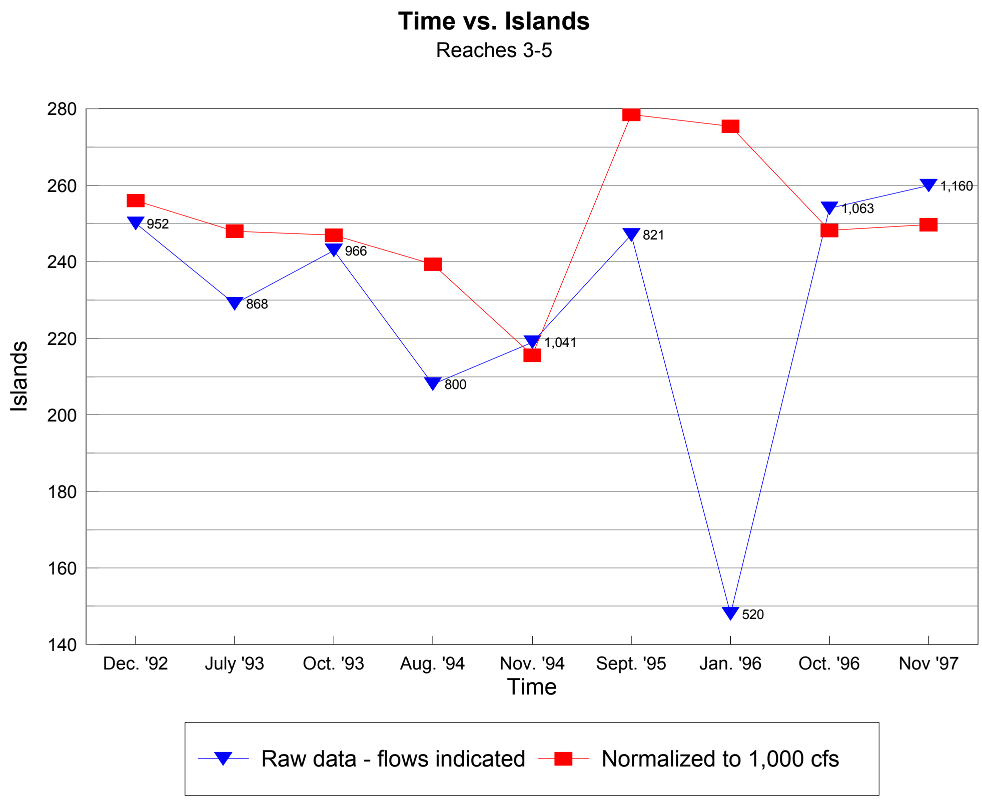


Figure 4.6. Island count in Reaches 3, 4, and 5 at base flow vs. time as a measure of change in channel complexity.

During 1995, for the first time in the 7-year research period, flows exceeded 10,000 cfs for more than 1 day, achieving a daily peak flow of 12,100 cfs with flows above 10,000 cfs for 11 days at Four Corners. The first increase in islands was exhibited in 1995. The indication from this flow series is that maintaining peak flows near channel capacity (1992 to 1994) may have slightly simplified the channel, while a larger overbank flow (1995) appears to have developed additional channels and islands, reversing the simplification. Some channel complexity may be lost because of summer and fall sediment-laden storm events that tend to berm off small flow-through and secondary channels (August 1994 to November 1994), and runoff events with peaks below 5,000 cfs (1996) may cause loss of channel complexity through the same process. The year 1997 was the only other year with flows above 10,000 cfs and the only other year to exhibit an increase in island count, although the increase is small relative to 1995. This is due in part to large summer sediment inflow between runoff and mapping that refilled small secondary channels in 1997. While analysis of the trend in island areas seems to indicate that the net effect of the research flows has not been damaging to channel complexity and that flows above 10,000 cfs are important in maintaining channel complexity, 5 years is a short period of record with which to identify long-term trends. Long-term monitoring will be required to assess the effects of restoration of a more-natural hydrograph on channel complexity.

If significant scour is occurring and it is not appreciably affecting channel complexity, sediment must be eroding from the bed and increasing channel depth with equal effect in secondary and main channels. Based on the extent of observed scour, it could be predicted that the channel capacity has increased by 7 to 10% because of bed erosion from 1992 to 1995. If channel capacity increased, then the bankfull discharge would have been about 7 to 10% greater at the end of the 7-year research period compared with that at the beginning of the 7-year research period. To determine if a change in bankfull capacity occurred, overbank flow at the beginning and end of the 7-year research period were compared. Overbank flow was considered to be the discharge at which a substantial decrease in island area and increase in flooded vegetation was noted. Figure 4.5 shows that a substantial decrease in island area occurred between 6,500 and 7,700 cfs, which corresponds to June 1993 and 1994 respectively. In addition, flooded vegetation increased an order of magnitude (3,421,680 to 37,025,160 ft^2) between 6,500 and 7,700 cfs within Reaches 3, 4, and 5. This strongly suggests that islands were overtopped in this flow range and that bankfull flow was somewhere between 6,500 and 7,700 cfs in 1993 and 1994, the early part of the 7-year research period.

In 1996, four single-channel reaches about 0.25 mi in length containing five cross-sections each were surveyed between RM 133 and RM 174. A summary of bankfull discharges for these reaches is presented in Table 4.4. In the lower three reaches, overbank flow occurred first (indicated by overbank conditions at one transect) at discharges between 7,100 and 7,500 cfs, based on calibrated HEC-RAS modeling. At RM 174, the first transect to show overbank flow occurred at 10,000 cfs. At least two cross-sections in each reach experienced overbank flow between 8,000 and 8,500 cfs for all study reaches except RM 174, which required 10,500 cfs for overbank flow at two cross-sections. Therefore, bankfull was assessed to be between 7,100 and 10,000 cfs, depending on the study reach. While this discharge is greater than that estimated based on island counts and flooded vegetation for 1993 and 1994, the ranges overlap. If a real difference exists between the beginning and ending of the 7-year research period, it could be partly explained by an increase in channel capacity because of bed scour between 1993 and 1996. However, conclusions based on such a short time period should be considered preliminary, and continued monitoring is necessary to verify an actual change in channel capacity. If channel capacity has increased, the change can be considered relatively insignificant, especially because a concurrent change in channel complexity was not detected. While modeled reaches exhibited initiation of overbank flow at between 7,100 and 10,000 cfs, consistent overbank flow occurred at between 8,000 and 10,500 cfs. The median overbank flow for the 20 cross-sections modeled was 9,000 cfs. However, the nature of the areas modeled was such that when flows were overbank on more than 25% of the area, any increase in stage (height of water) with increased flow was small. In some areas, the floodplain sloped away from the river channel, allowing the overbank flow to spread out and reenter the channel at a downstream location. In other locations a low, flat floodplain was separated from the river by a short berm, allowing a large increase in flow area for a small change in stage. Based on this information, bankfull discharge for the San Juan River was set at 8,000 cfs (25% of cross-sections overbank) as the value that appeared to fit most of the study area.

Table 4.4. Bankfull discharge from HEC-RAS modeling of four 0.25 mile (mi) reaches in the San Juan River between River Mile (RM) 133 and RM 174.

REACH DESIGNATION	BANKFULL FLOW AT ONE CROSS-SECTION (CFS)	BANKFULL FLOW AT TWO OR MORE CROSS-SECTIONS (CFS)
RM 133	7,500	8,000
RM 167	7,100	8,000
RM 169	7,100	8,500
RM 174	10,000	10,500

Since the RT series were first surveyed prior to research flows and have been surveyed twice annually since that time, an assessment of channel capacity and the change in channel capacity can be made, using the calibrated roughness coefficient from the modeled reach and applying the Manning equation:

$$Q = (w\, d^{5/3}\, S^{1/2})/n$$

Where Q = discharge, cfs
w = width, ft
d = average depth, ft
S = water surface slope, ft/ft
and n = roughness coefficient

Since water surface elevations were surveyed each time the cross-sections were surveyed, sufficient information was available to allow calculation of water surface slope. The survey with the greatest flow (1,170 to 1,950 cfs, depending on the date of survey) was selected as the calculation closest to the bankfull condition. Using the calibrated roughness coefficient of 0.027, the Manning equation was solved for slope, knowing flow, width, and cross-sectional area from the surveys. Bankfull flow at each cross-section for spring 1992 and fall 1997 surveys was then computed, assuming that the gradient did not change. The mean bankfull discharge for the RT cross-sections was computed to be 7,300 cfs (range 5,300 to 9,900 cfs) prior to modification of the flows (1992). After 6 years of research flows designed to mimic a natural hydrograph, the mean bankfull discharge was computed to be 8,200 cfs (range 5,800 to 12,600 cfs) for an increase of 12% from pre-research conditions. The 8,000-cfs channel capacity determined from the modeling studies is supported by the results of this analysis and the perceived change in channel capacity over the research period confirmed.

In summary, the bankfull discharge of the San Juan River is about 8,000 cfs and has increased by about 12% since the beginning of the research period. Bankfull flow is considered the practical upper limit for maintenance of cobble transport through low-gradient reaches and is considered in the analysis of cobble bar maintenance in the next section. Flows above 10,000 cfs appear to be important for maintaining channel complexity and floodplain integrity. Continued monitoring will be necessary to verify these values and assess impacts of the restoration of a more-natural hydrograph on channel complexity and capacity.

Cobble Bar Maintenance

To maintain spawning habitat for Colorado pikeminnow, areas of clean, loose cobble are needed, as described in Chapter 3. It has been shown in many studies that fine sediment cannot be removed from appreciable depths in a cobble bed without moving the cobble (Diplas 1994, Kondolf and Wilcock 1996). Cobble movement appears to occur over a broad range of flows in the San Juan River. In some locations, loose cobble is developed during the depositional phase of cobble bar formation at high flows, as was discussed for the Yampa River spawning site in Chapter 3. For example, a cobble bar suitable for spawning has formed at the nose of an island adjacent to a small secondary channel on river left at RM 132 during high flow conditions (see cover photo). A small chute channel was maintained at high flow between the bar and the island. At reduced flow, the chute channel becomes a run. The downstream side of the bar along the margin of this run contains loose cobble with sufficiently clean interstitial space to provide spawning habitat as evidenced by its use by spawning Colorado pikeminnow in 1993 and 1994 (Miller 1994, 1995). In other locations, adequate cobble is available through erosion as chute channels cut through an existing bar when flows recede. In either case, bars need to be periodically formed and subsequently eroded in the system to allow maintenance of clean, loose-cobble areas.

Flow conditions that move cobble in the San Juan River were determined and analyzed empirically by documenting changes in bed elevation of cobble/gravel substrate after certain flow events. In addition, interstitial depth among cobble substrate was measured immediately following runoff. Table 4.5 summarizes cobble transport results for various channel cross-sections. The top portion of the table presents data for the RT cross-sections and the bottom portion for the Mixer cross-sections. The sampling period and location of the two sites represent different hydrologic conditions. The RT cross-sections were surveyed pre- and post-runoff and represent locations upstream of channel splits, while the Mixer transects were surveyed several times during runoff in some years to assess cobble movement during shorter duration events. The latter site also represents higher gradient locations where channel morphology change was noted. Neither set of cobble transport data is highly correlated to individual hydrologic parameters, although some of the correlations are significant ($p<0.05$). The correlation improves when analyzed as a multiple linear regression including all parameters, but the correlations are not significant at the 95% level. The results of the multiple regression indicate, as expected, that larger flows (magnitude and duration) tend to move more cobble than smaller flows. Several conclusions can be made from this analysis: (1) the number of cross-sections with moving cobble was small in the first year of runoff and increased to include nearly all cross-sections after 1993 at all flow levels; (2) cobble movement was initiated at flows of about 2,500 cfs; (3) large flow events (magnitude and duration) moved more cobble, in general, than small flow events, especially in the period after 1992; and (4) data from the Mixer site were less correlated to flow conditions than those from the RT sites.

Table 4.5. Summary of cobble movement at surveyed cross-sections with hydrographic conditions.

Period	Scour Locations	Deposition Locations	Mean Scour Volume m³/m	Mean Deposition Volume m³/m	Peak Discharge cfs	Days > 10,000 cfs	Days > 8,000 cfs	Days > 5,000 cfs	Days > 2,500 cfs	Combined Results
RT Cross-sections										
Mar-Jul 92	6	4	2.3	15.6	8,900	0	3	54	81	
Jul 92 - Feb 93	8	9	5.1	5.9	3,490	0	0	0	9	
Feb - Jul 93	11	8	39.1	28.7	10,300	1	16	109	128	
Jul 93 - Mar 94	11	11	13.9	9.5	4,700	0	0	0	6	
Mar 94 - Aug 94	11	10	10.5	8.0	10,000	0	13	49	67	
Aug 94 - Mar 95	10	10	7.0	4.8	2,820	0	0	0	1	
Mar 95 - Aug 95	10	10	19.7	15.9	12,100	11	27	72	135	
Aug 95 - Mar 96	10	11	6.3	11.1	2,490	0	0	0	0	
Mar 96 - Jul 96	11	11	8.9	5.4	3,540	0	0	0	36	
Jul 96 - Feb 97	9	11	4.3	19.1	2,510	0	0	0	1	
Feb 97 - Aug 97	10	9	23.0	15.6	11,900	10	29	49	98	
Coefficient of Determination (r^2) - scour					0.55	0.20	0.47	0.59	0.51	.77
Significance of f statistic (p) - scour					.01	.17	.02	.006	.01	.11
Coefficient of Determination - deposition					0.25	0.07	0.21	0.55	0.38	.74
Significance of f statistic (p) - deposition					.12	.43	.16	.009	.04	.14
Mixer Cross-sections										
Feb - Apr 93	2 of 4	1 of 4	16.1	0.7	6,720	0	0	25	39	
Apr - Jun 93	1 of 4	2 of 4	2.1	41.2	10,300	3	16	67	67	
Jun - Jul 93	3 of 4	3 of 4	34.4	17.6	7,360	0	0	9	16	
Jul 93 - Mar 94	8 of 8	8 of 8	14.3	9.3	4,700	0	0	0	6	
Mar 94 - May 94	7 of 8	7 of 8	41.3	16.0	6,600	0	0	7	14	
May 94 - Jun 94	7 of 8	7 of 8	37.0	18.3	10,000	0	13	41	41	
Jun 94 - Aug 94	2 of 8	7 of 8	1.7	26.2	5,460	0	0	1	12	
Mar 95 - Aug 95	8 of 8	8 of 8	34.0	21.7	12,100	11	27	72	135	
Aug 95 - Mar 96	8 of 8	8 of 8	16.4	7.4	2,490	0	0	0	0	
Mar 96 - Jul 96	8 of 8	8 of 8	8.6	11.8	3,540	0	0	0	36	
Jul 96 - Feb 97	8 of 8	8 of 8	7.9	7.3	2,510	0	0	0	1	
Feb 97 - Aug 97	7 of 8	6 of 8	61.7	41.3	11,900	10	29	49	98	
Correlation coefficient - scour					0.35	0.29	0.31	0.12	0.20	.76
Significance of f statistic (p) - scour					.04	.07	.06	.28	.15	.12
Correlation coefficient - deposition					0.49	0.35	0.51	0.40	0.32	.61
Significance of f statistic (p) - deposition					.23	.04	.009	.03	.06	.22

Cobble movement does not ensure interstitial depth among cobbles adequate for successful spawning. Beginning in 1993 and continuing through 1997, measurements of interstitial depth, along with sampling of cobble particle size, were taken at several suspected or potential spawning sites in the San Juan River. Interstitial depth was measured in place on the bars over a surveyed grid as the depth from the top of the adjacent cobble to the depth at which sand fills the spaces between the cobble. Table 4.6 summarizes the results for three locations with the longest consistent record of data collection. Sampling methods have been refined with time, so earlier data only qualitatively compare to later data. However, sufficient data exist to show that some adequately clean cobble (defined as having interstitial space > 1.5 times median cobble diameter) (Bliesner and Lamarra 1995) is present, even in low-flow years such as 1996, although total area is reduced. In 1996, pre- and post-runoff sampling at the most-upstream bar suggested that transport and/or cleaning occurred, even during a low-flow year. This maintenance occurred in areas around chute channels and the resulting fans on the downstream side of the bar. Data collected in 1997 show that storm events after runoff can partially fill interstitial spaces with sand, although some clean cobble remained available. The 1997 storm event occurred during the normal spawning period for Colorado pikeminnow, so the loss of available clean cobble may have adversely affected spawning success.

Table 4.6. Summary of depth of open interstitial space in cobble bars.

DEPTH EXCEEDENCE	1993	1994	1995	1996	1997[a]
	Areal extent exceeding stated depth of open interstitial space - m^2				
RM 173.7 (potential spawning bar), cobble D_{50} = 5 cm					
1 x D_{50}	n/a	n/a	362[b]	2,204 / 3,437[c]	1,346
1.5 x D_{50}	n/a	n/a	342[b]	1,512 / 1,868[c]	571
2.0 x D_{50}	n/a	n/a	321[b]	907 / 822[c]	214
RM 132 (main spawning bar), cobble D_{50} = 6 cm					
1 x D_{50}	64[d]	126[d]	853	712	688 (367)[e]
1.5 x D_{50}	10[d]	63[d]	500	522	276(67)[e]
2.0 x D_{50}	2[d]	29[d]	317	308	172(33)[e]
RM 131 (lower red wash spawning bar), cobble D_{50} = 5 cm					
1 x D_{50}	n/a	466	222	66	157
1.5 x D_{50}	n/a	106	100	66	105
2.0 x D_{50}	n/a	29	47	33	66

[a]A large storm event occurred between July 29 and August 14, peaking twice in the 6,000-cfs range. This storm was just prior to survey in 1997, which appears to have partially filled some open interstitial space with sediment.
[b]The area surveyed was limited to chute channels (362 m^2) compared to full bar (8,000 m^2) in 1996 and 1997.
[c]The first value is pre-runoff, the second post-runoff.
[d]The area surveyed was about 10% that of later years, but was concentrated in the cleanest areas.
[e]First value is estimated based on a 20% subset survey taken in July prior to the storm event. Value in parenthesis was taken just after the storm event.

The cobble movement into and out of established cross-section sites indicates that large flow events transport more cobble, but the threshold flow for movement of cobble to begin on the bars was not determined. The lowest flow rate between surveys was 2,500 cfs, and cobble movement was evidenced (Table 4.5). Therefore, 2,500 cfs is assumed to be the minimum flow rate necessary for resculpting bars in preparation for spawning.

For long-term cobble bar formation and maintenance, the system must be capable of transporting an adequate size and quantity of cobble into the appropriate areas. In addition to assessing bankfull discharge at channel cross-sections, the study reaches were modeled to determine the discharge necessary to transport cobble through the intervening low-gradient reaches between bars. One method of determining this relationship involved examining critical dimensionless shear stress (Shield's stress), a parameter estimating the pressure applied to the bed substrate by the overflowing water velocity and depth, for the existing bed material. Incipient motion (the point at which particles begin to move) of the median particle diameter (D_{50}) of bed material is theorized to occur when the critical shear stress, $J^*_{c50,}$ is in the range of 0.02 (Andrews 1994) to 0.03 (Parker et al. 1982). This value varies from river to river and may even fall outside this range. Under conditions of incipient motion, the gravel just begins to move slightly and transport rates are very low (Pitlick and Van Steeter 1998). As the dimensionless shear stress increases, the number of bed particles in transport increases rapidly. By the time the dimensionless shear stress reaches 0.06 (Andrews 1994), a majority of the particles on the bed's surface are in motion. Appreciable transport will occur at condition of average motion, where most particles can be moved, but at a moderate rate. Andrews (1994) found transport of particles as large as the 80^{th} percentile with dimensionless shear stress in the range of 0.032 to 0.042. The three conditions of transport examined in this study are initial or incipient motion (J^*_{c50} = 0.02 to 0.03), average motion (J^*_{c50} = 0.030 to 0.045), and full motion (J^*_{c50} = 0.045 to 0.060). The range of values for each condition appears in Table 4.7 for the modeled reaches. The flows at which the conditions are met are shown in Table 4.8.

According to these calculations, all of the modeled reaches have boundary shear stresses in the range necessary for incipient motion for the average of all cross-sections at or below bankfull flow. Only one reach attained the condition (J^*_{c50} = 0.030 to 0.045) that the theory would suggest is necessary for measurable transport on average, although in all but one reach some transects were predicted to reach the condition below bankfull flow. The comparison of pre- and post-runoff surveys of the upstream cobble bar at RM 173.7 shows an increase in mean bar elevation during the 1996 runoff period and a subsequent decrease in average elevation during the 1997 runoff period. This would suggest that cobble was transported to the bar at a flow of less than 4,000 cfs (1996) and eroded from the bar during the higher flows in 1997. The bar at RM 168.4 was stable in 1996 but aggraded slightly in 1997. Given the morphological nature of the changes in the examined cobble bars, any noted cobble transport could have resulted from local scour and deposition rather than from immigration or emigration of material, but the change in the bars could have resulted from upstream transport based on the assumption of the low end of required J^*_{c50}. Based on these findings, the conditions for cobble transport in these reaches range from marginal to plausible at or below bankfull discharge, depending on the reach. However, adequate conditions exist for marginal transport only if the smaller J^*_{c50} values are applicable.

Table 4.7. Boundary shear stress conditions at various flow rates for four modeled reaches.

	CFS	RM 133.0	RM 167.0	RM 169.0	RM 173.7
D_{50} - cm		*5.00*	*6.00*	*6.00*	*4.00*
Required for beginning motion (J^*_c= 0.02 - 0.03)		**0.34 - 0.51**	**0.41 - 0.61**	**0.41 - 0.61**	**0.27 - 0.41**
Required for average motion (J^*_c= 0.03 - 0.045)		***0.51 - 0.76***	***0.61 - 0.91***	***0.61 - 0.91***	***0.41 - 0.61***
Required for full motion (J^*_c= 0.45 - 0.06)		***0.76 - 1.01***	***0.91 - 1.22***	***0.91 - 1.22***	***0.61 - 0.77***
		Boundary Shear Stress			
	1,000	0.07	0.12	0.07	0.11
	2,000	0.12	0.17	0.17	0.17
	3,000	0.18	0.24	0.25	0.23
	4,000	0.24	0.30	0.31	**0.28** 0.28
	5,000	0.29	0.35	0.36	**0.34** 0.34
	6,000	**0.34** 0.34	0.40	**0.42** 0.42	**0.38 0.38**
	7,000	**0.41** 0.41	**0.48** 0.48	**0.46** 0.46	***0.44*** **0.44**
	8,000	**0.47** 0.47	**0.53** 0.53	**0.51** 0.51	***0.48*** **0.48**
	9,000	***0.52*** **0.52**	**0.58** 0.58	**0.56** 0.56	***0.53*** **0.53**
	10,000	***0.59*** **0.59**	***0.65*** **0.65**	***0.61*** **0.61**	***0.57*** **0.57**
	11,000	***0.63*** **0.63**	***0.71*** **0.71**	***0.66*** **0.66**	0.61 ***0.61***
	12,000	***0.67*** **0.67**	***0.78*** **0.78**	***0.71*** **0.71**	0.65 ***0.65***

Note: **Bold = beginning motion**
Bold italics = average motion
Shadowed cells = full motion

Table 4.8. Flows required to meet critical shear stress conditions for cobble transport.

Modeling Reach	133	167	169	173.7
Minimum Channel Capacity - cfs	7,500	7,100	7,100	10,000
Average Channel Capacity - cfs	8,000	8,000	8,500	10,500
Cobble D_{50} - cm	5.0	6.0	6.0	4.0
Minimum flow for beginning motion - cfs	6-8,000	4-6,000	4-9,000	3-7,000
Ave flow for beginning motion - cfs	6-9,000	7-10,000	6-10,000	4-7,000
Minimum flow for ave. motion - cfs	8-12,000	6-10,000	9->12,000	7-10,000
Ave flow for ave. motion - cfs	9->12,000	10->12,000	10->12,000	7-11,000

Note: Flows above bankfull are not modeled accurately because of the inability to accurately assess the roughness of the overbank condition or define the flow channel without large amounts of additional data and the ability to calibrate the model at these higher flows. Therefore, values above bankfull presented in the table are qualitative only.

Three possible conditions found in the San Juan River supply some possible explanations for predicted transport to be somewhat less than anticipated. First, cobble diameter measurements erred on the large side; second, incipient and average motion begin at lower dimensionless shear stress values (low end of the range) in the San Juan River; and third, cobble was not adequately transported through lower gradient reaches of the system.

The first condition is likely because cobble bar sampling using pebble counts tend to be biased towards larger rocks, especially when done instream, as was the case in the turbid San Juan River. Also, the method of measurement, using the intermediate dimension of the rocks as the equivalent screen size, somewhat over estimates diameter. When combined, the diameters may be over estimated by 25%. With this level of error, the lower end of the $\mathbf{J}^{*}_{c50}$ range for average motion is achieved in each reach, but not at all cross-sections.

The second condition may be because cobble shape and the presence of sand in the system influence cobble transport. If the sand acts as a lubricant, then transport could begin at lower average values. The typical process of bar formation observed in the San Juan River consists of erosion of an upstream bar under high-gradient conditions across the bar and subsequent deposition on a bar located downstream. In addition, boundary shear stress may vary locally with varying substrate, depth, and velocity. As such, cobbles in a high-gradient reach may experience an adequate boundary shear stress for saltation or entrainment. The abundance of sand in the San Juan River may facilitate continued transport once a cobble is dislodged from the bed. This condition would tend to support using the lower end of the $\mathbf{J}^{*}_{c50}$ values.

The third condition is that cobble becomes locally available and transported from shoreline sources or that bar erosion allows short-distance movement, even though system shear stress is not adequate to move cobble through long, low-gradient reaches from upstream sources. In such a case, cobble transport is adequate in the short-term to locally maintain currently active cobble bars, and long-term sediment balance is met by continuous upstream erosion (head cutting) and subsequent downstream deposition to the extent that the higher gradient locations move through low-gradient reaches. This phenomenon, along with the formation of new secondary channels and resulting rapid, short-term transport, has been observed locally in the San Juan River.

Since the empirical data indicate cobble movement, even at low flows, and show that cobble movement generally increases with increased flow magnitude and duration, it is quite possible that some combination of the three conditions exist in the San Juan River. Sampling in 1998 will address the potential error in estimating cobble size, and cobble bars will continue to be monitored for changes with varying flow conditions.

The model studies indicate that flows in the neighborhood of channel capacity (8,000 cfs) are necessary to transport cobble of sufficient size and quantity to build bars. While effective flow, in terms of total sediment transport and channel maintenance, is typically lower than bankfull flow (Andrews 1980, Pitlick and Van Steeter 1998), the bankfull flow recommendation is for cobble transport and bar formation, and it is needed less frequently than typical effective flows. Sediment transport theory, as applied to four modeling reaches, does not support a recommendation less than bankfull for the required cobble transport, and flows above bankfull provide very little additional shear stress for the volume of water required because of large overbank flow. Therefore, bankfull flow is the recommended flow magnitude to support cobble transport in the San Juan River.

Based on the results of the studies conducted to date, it is concluded that sufficient local cobble movement exists to provide some clean cobble for spawning with flows of 2,500 cfs or higher for a duration of at least 10 days prior to spawning. The threshold flow of 2,500 cfs is determined from data in Table 4.5 indicating cobble movement at flows at or below 2,500 cfs. The 10-day duration is based on qualitative assessment of the data in Table 4.5, coupled with field observation of bar reshaping. Duration of flows at about 2,500 cfs for as little as 1 day indicate cobble movement, but there were extended periods at marginally lower flows, as these conditions typically occurred between the summer and following spring measurements. The March to July 1996 period demonstrated substantial cobble movement with 36 days above 2,500 cfs, and March to May 1994 indicated large cobble movement in the Mixer with 14 days above 2,500 cfs, although flows exceeded 5,000 cfs for this period. While no data precisely indicate the minimum required duration, the 10-day duration was selected as the minimum threshold because it falls within the results summarized above and is considered reasonable based on field observation. Longer durations at somewhat lower flows may serve the same function as indicated by the pre-runoff conditions in 1996, but there is insufficient information to conclude threshold conditions lower than 2,500 cfs.

The bankfull flow of 8,000 cfs was selected as the flow required for cobble transport and bar building based on model results of the four research reaches reported in Table 4.8, and flow calculations at the RT cross-sections; it is qualitatively supported by the decrease in island area and count at flows somewhere between 6,500 and 7,700 cfs (Figure 4.5). Examination of the cobble movement data reported in Table 4.5 suggests an 8-day duration as appropriate for the minimum duration necessary for bar-building cobble transport. This minimum duration is based on the channel cross-section data indicating measurable cobble movement with as few as 3 days at 8,000 cfs and substantial cobble movement after 13 days. The two durations were averaged to arrive at the recommended value. The flow/duration criteria were analyzed for adequacy of channel maintenance by examining historical conditions since the closure of Navajo Dam. During this time period, cross-section surveys indicated a narrowing and deepening of the channel, especially in the higher reaches (5 and 6), with a recurrence frequency of about 1 year in 4 years for flows of 8,000 cfs for 8 days. Since some channel capacity was lost under these conditions, an increase in the average frequency of bankfull flows is needed to prevent further lost capacity and possibly assist in restoring some of the capacity already lost. An average recurrence frequency of 1 year in 3 years (33%) will increase the frequency of conditions necessary for maintenance of channel capacity. Therefore, 8,000 cfs for 8 days with an average recurrence frequency of 1 year in 3 years are the conditions recommended for cobble bar construction and channel maintenance. From a sediment-transport and channel-maintenance standpoint, the full range of flows from 2,500 cfs through 10,000 cfs plays an important role. Mimicking a natural hydrograph that includes flows in this range is necessary, because just providing the conditions required at 8,000 cfs would be inadequate. Because of the short period of study, monitoring should continue, and flow recommendations should be adjusted in the future if necessary. Flows above 10,000 cfs are recommended periodically for maintaining channel complexity and floodplain integrity. The response of islands to flows shown in Figure 4.5 indicates that flows less than 10,000 cfs (1992 to 1994) may result in channel simplification with time unless combined with higher flows that develop new secondary channels and islands through overbank flow (1995). Examination of the flow record indicates a duration of 6 days at Bluff and 11 days at Four Corners, with a resulting increase in islands above pre-research period levels providing conditions that were more than adequate for maintenance of channel complexity. High flows are the most-altered portion of the natural hydrograph in the San Juan River. Historically, these flows have played a major role in floodplain development. While all the mechanisms of importance have not been identified and quantified during the research period, the general paradigm of natural flow mimicry would not be met without restoration of these higher flows to some degree. Therefore, a conservative threshold requirement of 5 days at or above 10,000 cfs was selected for purposes of natural flow mimicry and maintenance of channel complexity.

The cobble bar maintenance flow (2,500 cfs) should occur at a frequency sufficient to ensure long-term reproductive success of the species of interest. The cobble bar construction flow (8,000 cfs) is needed less frequently if bars are maintained (cleaned and reworked) on a regular interval. Data suggest that the bars can be reworked to provide clean cobble for several years without the necessity of reconstruction or replacement. Channel maintenance requirements indicate an average recurrence of 1 year in 3 years for flows above 8,000 cfs. The 10,000-cfs flow condition is not required as frequently. Historically, it had been 8 years between the occurrence of these conditions (1987 and 1995). Looking at the potential for channel complexity deterioration indicated in Figure 4.6, the required average recurrence frequency for maintenance of channel complexity and floodplain integrity was determined to be 5 years. During the pre-dam period, the 10,000-cfs flow conditions were met 39% of the time (4 years in 10, vs. 2 years in 10 in this recommendation). The reduction in channel capacity that has occurred since the closure of Navajo Dam allows a lower frequency of achieving these conditions. Given the short duration of the studies upon which these recommendations are based, future refinement of the recommendations will likely be necessary, thus requiring an adaptive management approach.

Backwater Maintenance

Backwater habitat is formed by a fluvial process of deposition and subsequent erosion of bars, and cleaning of secondary channel mouths that become backwaters at low flow in a highly turbid system like the San Juan River. A backwater is a pocket of low- or no-velocity water connected to the main river that forms in scoured areas in or behind bars, or in the mouths of abandoned secondary channels or tributaries as high water recedes. Scouring occurs during high-flow events on inundated bars, usually along shoreline areas (scour channel), at the base of ephemeral secondary channels, at alcoves at tributary mouths, or in areas of recirculation as reverse flow becomes concentrated in an upstream direction (eddy return channel). The scoured bedforms become functional as backwaters after flows recede and upper elevations of bars are exposed and secondary channels are isolated. Because of their unique physio-chemical and biological nature, which provides warmer temperatures in a food-rich environment, backwaters are important nursery habitat for Colorado pikeminnow and other native species.

The process of backwater formation and maintenance is one of bar deposition, scour of eddy returns, and secondary channel mouths and bank margin scour channels during high flows, followed by a period of low flows when the backwater is available instream habitat, with a regular interval of high flows to remove redeposited sediment in scoured areas. The latter flows are necessary to maintain the backwater's quality, but the crucial relationship is the magnitude of backwater-forming flows and subsequent maintenance flows. Late summer and fall storm events contribute large amounts of sediment to the San Juan River, yet flows are often insufficient to transport the sediment out of the system as indicated by measured sediment accumulation between spring runoff events. Backwaters that form behind bars and at the mouths of secondary channels that are dry at low flow tend to accumulate sediment during these low-flow periods, especially following summer storm events. The sediment then must be flushed with a high flow, typically spring runoff, to restore backwater depth.

During the course of the research period, no relationship was developed between spring runoff conditions and bedform structural change influencing backwater formation. Studies of bar change did not indicate a relationship between bar height and peak runoff magnitude or volume for the range of flows tested, likely because most peak flows were at or above bankfull where stage and shear stress change little with change in flow. Further, a large percentage of backwaters are associated with secondary channel or tributary mouths. Therefore, the structural studies concentrated on backwater cleaning processes.

To measure flow conditions necessary to maintain backwaters, two ephemeral secondary channels that form backwaters were selected for surveying and modeling. The first is located on river left just downstream of the Montezuma Creek Bridge (RM 93 to 93.5), and the second is approximately 1 mi upstream of Sand Island Campground (RM 77.3 to 77.5) on river left. These backwaters have formed each year during base flow (low, stable, nonstorm-effected flows between spring runoff events) conditions, indicating relative stability, although the size and depth of the backwaters have varied.

These reaches were surveyed in detail in 1996. During that year, flow conditions were inadequate to flush these backwaters (Figure 2.5). A total of 10 surveys were completed in 1997, beginning on May 13 and continuing through August 19. During that time, a correlation between secondary and main channel flow was developed to predict flow in the secondary channels. Based on six measurements over a range of discharges, the relationships developed for each channel had an r^2 of 0.99 (p=0.002). The plots of the mean depth of the backwaters and the main and secondary channel hydrographs are shown in Figure 4.7. Suspended sediment concentration was measured about twice weekly during this time to provide data for later modeling.

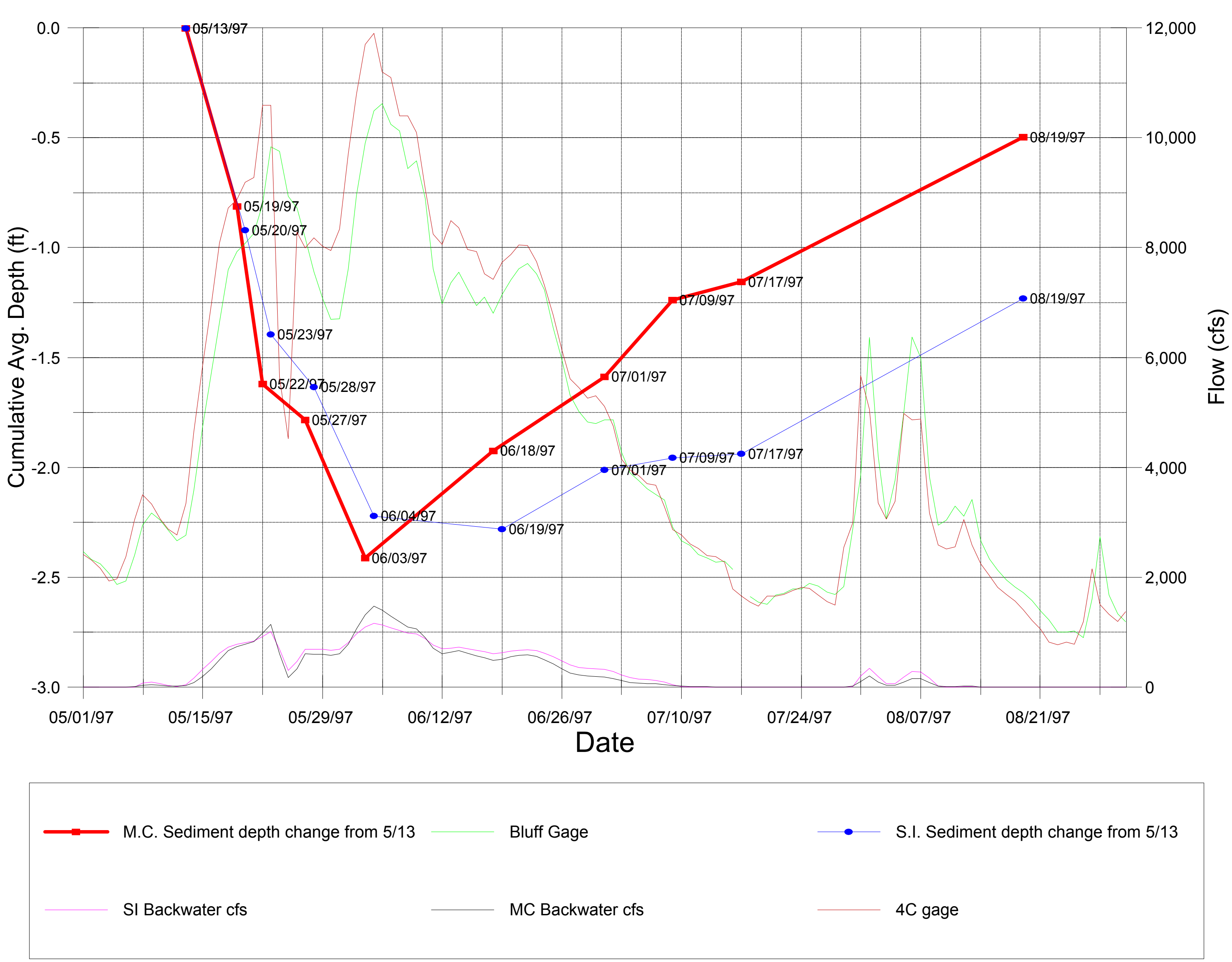


Figure 4.7. Flow and backwater depths for 1997 runoff for the Montezuma Creek and Sand Island sites.

HEC-6 was used to model sediment transport in the two secondary channels so that predictions could be made for other conditions. Survey data from May 13 and 19, 1997, were used for channel morphology in the model. Manning's *n* was determined using HEC-RAS, by varying Manning's *n* until the modeled water surfaces matched the surveyed water surfaces. This resulted in a Manning's *n* of 0.023 for Sand Island and 0.027 for Montezuma Creek. These *n* values are on the low end of the range for typical, natural channels, but they are consistent with the predominantly smooth-bottomed, relatively straight secondaries being modeled. Between May 13 and August 9, 1997 (the runoff period modeled), eight of the ten total surveys were completed in each secondary. To calibrate HEC-6, the hydrographs in Figure 4.7, with their accompanying sediment load, were routed through the channels. Parameters were adjusted until the modeled volumetric change in sediment load matched as closely as possible the measured volumetric change in sediment load. The parameter adjusted was the size distribution of inflowing suspended sediment. For Sand Island, there was one sediment size distribution for the entire time period, which was 50% very fine sand and 50% fine sand. For Montezuma Creek, the starting sediment size distribution was 71% very fine sand and 29% fine sand, which changed to 99% medium sand and 1% coarse sand on May 25, 1997. Suspended sediment size fractionation was completed to determine composition of sand and silt, not for a range of fine substrate sizes, so some calibration was necessary. Figure 4.8 shows the measured and modeled results for the two backwaters.

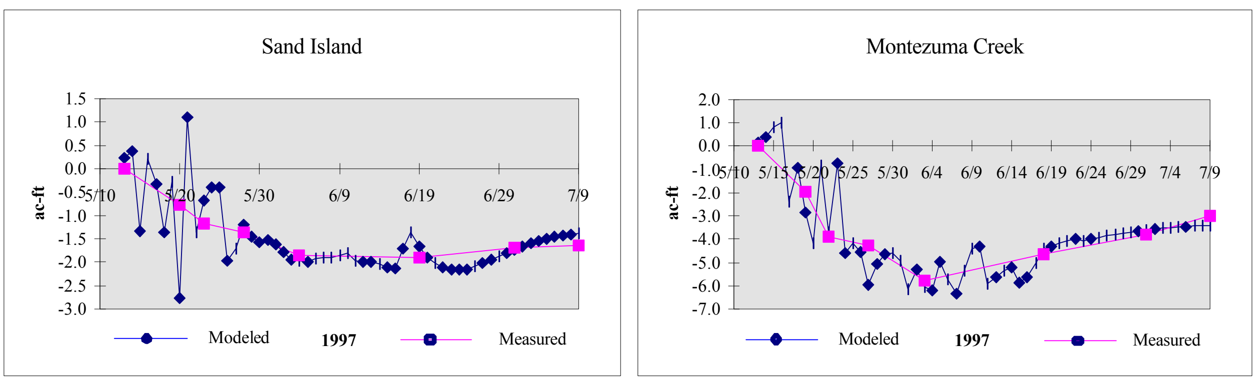


Figure 4.8. HEC-6 calibration results for Sand Island and Montezuma Creek.

For these secondary channels, the HEC-6 results for sediment inflow and outflow were extremely sensitive to even small changes in the sediment size distribution. For example, starting Montezuma Creek with 75% very fine sand and 25% fine sand instead of 71% very fine sand and 29% fine sand gave the results shown in Figure 4.9. Furthermore, the scatter in the fit in the early part of the runoff period indicated sensitivity to sediment concentration as well as particle size. The scatter about the mean was because of changes in sediment concentration at the break points. Therefore, without actual data about a more-detailed particle size distribution and daily sediment concentration, projecting these results for other flow and sediment conditions is qualitative, at best.

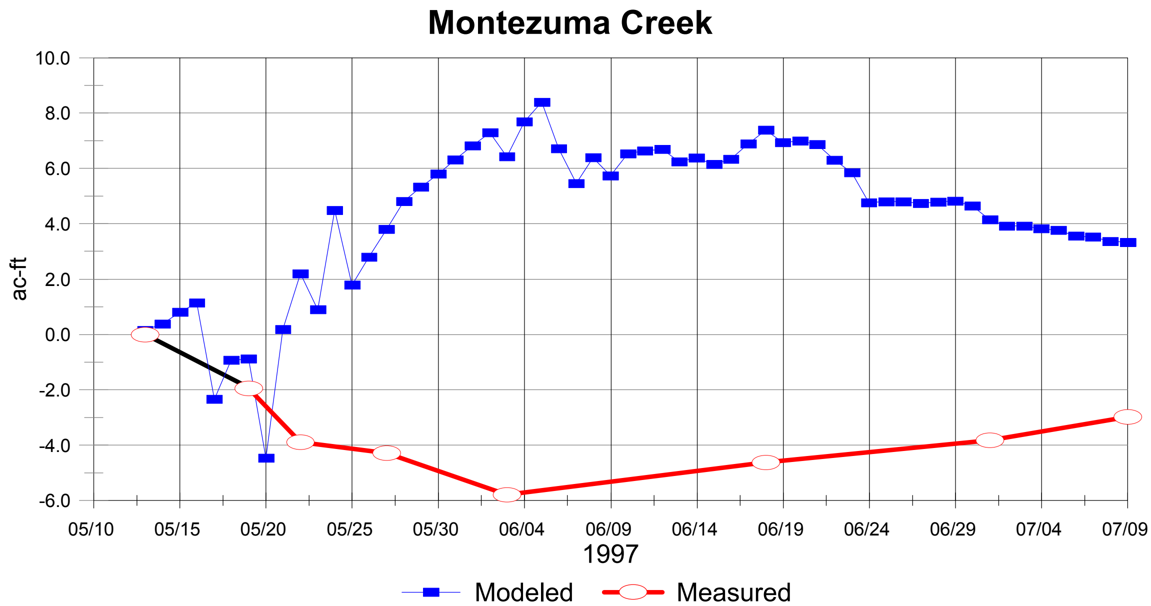


Figure 4.9. Modeling results with small change in grain size to demonstrate sensitivity.

Using the calibrated parameters, model runs were completed for 1993 and 1995 with sediment concentrations collected during those years at about 10-day to 2-week intervals. During both years, backwaters were well maintained by flows after runoff. At the end of the runoff in 1993, sediment concentration was at its lowest point of the 2 years. The model was also operated for 5 years of simulated hydrographs from river operations model output to represent five different hydrograph scenarios and four sediment concentrations. The sediment concentration patterns used represented a low-sediment concentration year similar to 1993 at Shiprock and Montezuma Creek, representing upstream and downstream differences, and a relatively high concentration pattern. These patterns were chosen to demonstrate the differences in years and reflect the normal upstream-to-downstream gain in sediment. The concentrations used are shown in Table 4.9. Disregarding storm peaks, they represent the range of expected concentrations during spring runoff in the San Juan River. The results of the modeling runs are summarized in Table 4.10. Results are shown only for Montezuma Creek. Sand Island results are similar, except the volume of removed sediment is less because the backwater was smaller. Maintenance was characterized as excellent, good, fair, or poor. Because results of the two low and two high sediment concentrations were similar, a qualitative evaluation was indicated for the two main categories only, not for the upstream or downstream conditions. In nearly all cases, the backwater was maintained at maximum depth during the runoff period, usually by peak flow conditions, and then partial refilling occurred on the descending limb. While flushing usually began at flows lower than 5,000 cfs, it became more effective at higher flows; therefore, 5,000 cfs is used as the threshold condition for effective flushing. While duration required for cleaning varies depending on the shape of the hydrograph and suspended sediment load, 3 weeks at flows above 5,000 cfs is set as the minimum condition for full cleaning as an average condition, assuming that the flow follows a typical increasing and decreasing pattern to allow for flows above 5,000 cfs for the cleaning period.

Table 4.9. Sediment concentrations (parts per million (ppm)) used in HEC-6 simulations.

	Low		High	
	Upstream	Downstream	Upstream	Downstream
	190	300	550	800
May 17 - May 31 - ppm	275	415	750	1,050
May 31 - June 10 - ppm	170	450	1,050	1,300
June 10 - June 20 - ppm	110	170	400	460
June 20 - June 27 - ppm	70	130	150	200
June 27 - July 31 - ppm	20	30	150	100

Table 4.10. Summary of HEC-6 modeling results for Montezuma Creek site.

	1997	1995	1993	1976	1970	1960	1937	1930
Nose - weeks	4	0	10	0	0	0	6	0
Ascending limb - weeks	4	10	4	5	2	4	2	4
Descending limb - weeks	4	5	4	2	6	1	6	4
Peak flow - cfs	11,900	12,000	10,000	8,900	8,800	9,500	9,200	10,000
Begin cleaning flow - cfs	4,500	4,000	4,000	3,800	3,800	3,900	4,600	4,000
Weeks to maximum cleaning	3	5	10	2	2	2	3	2.5
Results - low concentration	n/a	n/a	n/a	good	good	excell.	good	good
Results - high concentration	n/a	n/a	n/a	poor	poor	excell.	fair	poor
Results - actual concentration	good	good	good	n/a	n/a	n/a	n/a	n/a
Sediment concentration	mod.	low	low	n/a	n/a	n/a	n/a	n/a

From the empirical survey data and modeled results, several preliminary conclusions can be made: (1) main channel flows above 4,000 cfs initiate flushing, but effective flushing occurs at about 5,000 cfs, (2) if flows do not exceed 5,000 cfs, more time is required for adequate flushing, (3) shorter descending limb duration results in less refilling and better maintained backwaters after runoff, (4) short duration, steep ascending limbs to relatively high peaks (approximately 9,000 to 10,000 cfs), combined with steep descending limbs, maximize backwater maintenance for the volume of water required compared with more-extended runoff with lower peaks.

It is important to note that location in the system may influence the effectiveness of backwater-maintenance flows. The backwaters measured and modeled in this discussion are located in Reach 3 and are subject to heavy sediment inflow. Backwaters higher in the system may clean faster because they receive less sediment inflow. In 1998, two additional backwaters will be modeled in Reach 5 to assess any difference in site locale. Also, additional calibration data will be collected to refine the modeling process. As with other flow recommendations, additional monitoring is required, and future modification may be warranted.

Channel Morphology Response Summary

During the 7-year research flow period, channel cross-section surveys indicated a slight increase in channel depth and channel capacity in response to the increase in spring runoff volume and magnitude, regaining some of the cross-sectional area lost after closure of Navajo Dam. Bankfull capacity in Reaches 3 to 6 (below Farmington, New Mexico) may have increased by as much as 12%. Most of this change occurred by 1995, with relative stability since that time. Most of this increase in channel capacity is a result of removal of sand from the streambed. Relatively little net cobble loss (about 10% of the total loss) has occurred. There has been no appreciable change in channel complexity as measured by the number of islands present at base flow as a result of the research flows, although channel complexity did increase after flows exceeded 10,000 cfs for 11 days in 1995.

At some locations, cobble transport occurs at flows as low as 2,500 cfs. Cobble movement to and from cross-sections generally increased with increased flows, but movement is not highly correlated to any single hydrologic parameter. A combination of hydrologic conditions, including peak flow magnitude and days above 10,000, 8,000, 5,000, and 2,500 cfs, explains about 70% of the variation in scour and deposition of cobble at the cross-sections, although the correlation is not statistically significant at the 95% level because of the limited degrees of freedom.

Bankfull channel capacity below Farmington is about 8,000 cfs, with some overbank flows as lows as 7,100 cfs. Cobble transport modeling in the San Juan River only marginally supports observed cobble transport, but given the approximations in modeling and potential measurement error, there is not large disagreement between observed and modeled conditions. Based on the combination of the modeling results and measurement of cobble movement, flows above 8,000 cfs for a minimum of 8 days are likely necessary for reconstruction or replacement of cobble bars in the system. Flows of about 2,500 cfs for 10 days or more are adequate to develop clean cobble for spawning and should be provided regularly (at least once every two years). Bars erode slowly, so flows above 8,000 cfs are needed less regularly than the smaller reshaping flows. For channel maintenance purposes, flows should exceed 8,000 cfs for 8 days with an average frequency of 1 year in 3 years. Periodic flows above 10,000 cfs are helpful in maintaining channel complexity, providing new cobble sources for subsequent bar construction, and maintaining floodplain integrity. Frequency of these flows is less critical than that of maintenance flows, and a lower frequency is desirable if it will allow greater effectiveness of high flows. A duration of 5 days with an average recurrence frequency of 1 year in 5 years is suggested by the empirical data and is consistent with mimicry of a natural hydrograph when considering the historical loss of channel capacity. Periods of high flow following low-flow years are important to the maintenance of the geomorphology of the system.

Kondolf and Wilcock (1996) suggested that providing channel maintenance flows of magnitudes that transport both sand and gravel may not achieve the objective of reducing the sand content of the bed and may result in loss of coarse sediment from the system. Analysis of the data for the San Juan

River does not indicate either condition as a problem with the flows recommended. Percent cobble substrate has increased with time, cobble is abundant in the system, the cobble bars surveyed do not appear to be degrading, and open interstitial space is consistently maintained. Transport conditions necessary to remove fine sediment from the system occur for much longer durations and at greater frequency than those required to transport cobble. Supplying cobble mobilization flows 1 year in 3 years is only a slight increase from post-dam conditions, a period that indicated a slight loss of channel capacity. While it is not likely that the concern suggested by Kondolf and Wilcock (1996) is a problem in the San Juan River, continued monitoring will be required to identify if a problem occurs and to adjust flow recommendations accordingly.

Backwaters in the San Juan River typically flush at flows above 4,000 to 5,000 cfs. When limited flow is available, the most-effective hydrograph scenario is one of a rapid ascending limb to a relatively high magnitude peak, followed by a rapid descending limb. For full flushing of backwaters, flows should be maintained above 5,000 cfs for 3 weeks or more, assuming a relatively natural hydrograph with a peak of 1.5 to 2.5 times this level. If flows are maintained at or near 5,000 cfs, substantially longer times are needed for flushing. While backwaters are not totally lost when flushing flows are inadequate, they are diminished in size and quality. Frequency of achieving flushing conditions will be influenced by the level of sediment accumulation in the prior years and the availability of water to achieve peak flows above 5,000 cfs for 3 weeks. Peaks between about 3,000 and 4,000 cfs may actually increase the filling of backwaters during runoff and should be avoided if possible.

While the flow conditions discussed here are based upon the response of the geomorphology, they form the basis of natural hydrograph mimicry, a condition that is desirable in restoration of habitat for native fishes (see discussion in Chapter 1). Application of the rates, durations, and frequencies represented here provides for a hydrograph shape and annual variability that is similar to natural conditions.

Habitat

Studies related to habitat characterization in the San Juan River were initiated in 1991, just prior to the time when research flows from Navajo Dam were initiated. Therefore, there is no earlier reference with which to compare pre- and post-research flow periods as they relate to habitats that are needed by the native fish community. Spring runoff flows were consistently higher during the research period, and base flows were consistently lower than during the 1962 to 1990 period (Figures 2.3 and 2.4). Based on the relationships discussed above for backwater habitats (i.e., more backwaters and other low-velocity habitats at lower flow), it is likely that there were more backwaters and similar low-velocity habitats during the research flows than before because of the lower base flows. Also, fine sediments (sand) were scoured by the research flows, resulting in less sand substrate and more cobble/gravel during the research period. This likely resulted in an increase in backwaters, as well as an increase in cobble/gravel run and riffle habitat. It also is likely that the cobble/gravel substrates were cleaner (less filled with sand) overall as a result of research flows. This may have positively affected production of algae and macroinvertebrates in the river. Flow/habitat relationships developed for backwater habitat area predict that the post-dam period would have exhibited a reduction in backwater habitat area of about 21% in Reaches 1 through 5 relative to the pre-dam period. The research period averaged 7% less backwater area compared with predicted pre-dam conditions, or 14% more than the post-dam period. Therefore, low-velocity and cobble/gravel habitats, in particular, have likely improved in both quantity and quality since the initiation of mimicry of a natural hydrograph.

Habitat Quantity

The analysis of the habitat surface area/flow relationships described in Chapter 2 of this report indicates that the surface areas of habitats used by Colorado pikeminnow and razorback sucker, as well as other native species, varied significantly with the flows measured at the time of habitat mapping. For backwater habitat, the flow/habitat area relationship was also found to vary among geomorphic reaches of the river. In order to evaluate the physical response of these habitat types to the research flows that began in 1991, total area for each habitat type was normalized to 1,000 cfs and compared with runoff conditions immediately preceding each respective mapping period. Preliminary analysis indicated that shoal habitat types, slackwaters, pools, and eddies did not appear to change with different runoff conditions, while backwaters did.

Hydrologic characteristics (Figure 2.5) for each year from 1991 to 1997 were analyzed relative to their impact on backwater habitat surface areas (Table 4.11). At least one mapping session was conducted after each spring runoff period, and 4 years (1992, 1993, 1994, and 1996) included replicate data. Although an attempt was made to investigate unique features of these hydrographs, initial analysis indicated substantial autocorrelations among several characteristics. The range in autocorrelations was between 33% and 89% (Table 4.11), with days over 10,000 cfs being least auto correlated (33%), and total days over 3,000 cfs, peak flow, total runoff volume, and runoff duration having 89% autocorrelations. In total, 71% of the parameter pairs were auto correlated. These analyses suggest strongly that both the duration and magnitude of the runoff are important for providing backwater habitat in the subsequent summer/fall season.

Preliminary analysis of backwater habitat areas indicated that the flow/habitat relationships in geomorphic Reaches 1 and 2 (for location of reaches see Figure 2.1) were similar, while Reaches 3, 4, and 5 were different from Reaches 1 and 2, but had similar interrelationships. Further analysis indicated that within Reaches 1 and 2, the type of backwater (i.e., main channel or side canyon associated) was also an important factor in the flow/habitat relationship. Within Reaches 3, 4, and 5, backwater locations were associated with two different geomorphic processes categorized broadly into main or secondary channel processes. Backwaters were formed through shoreline scour of sand bars, recirculation in main channel processes, or backwaters formed at the entrance or exit of ephemeral secondary channels. These two backwater types (main channel vs. secondary channel) were analyzed separately in Reaches 3, 4, and 5.

The coefficients of determination (r^2) for backwater habitats normalized to 1,000 cfs compared with antecedent runoff conditions at the time of mapping (Table 4.11) are summarized in Table 4.12.

Table 4.11. A comparison of significant correlations (%=0.05) between the hydrologic parameters investigated for antecedent conditions relative to backwater surface areas.

Parameter	% Autocorrelated
Total Days[a] >3,000 cfs	89
Days Pre-peak >3,000 cfs	67
Total Days >5,000 cfs	78
Days Pre-peak >5,000 cfs	55
Total Days >8,000 cfs	78
Days Pre-peak >8,000 cfs	67
Total Days >10,000 cfs	33
Peak (cfs)	89
Total Runoff volume (af)	89
Duration	89
TOTAL	**71**

[a] Total days and days pre-peak are summarized between April 1 and July 31.

Table 4.12. The coefficient of determination expressed as r^2 and their associated p values for backwater habitat area normalized to 1,000 cfs compared with various antecedent hydrologic conditions.

		HYDROLOGIC CONDITIONS: DAYS[a]					
Reaches	Location	> 3,000 cfs	> 5,000 cfs	> 8,000 cfs	Peak Flow (cfs)	Total Runoff Volume af[2]	Duration (days)
1-2	main channel	0.58 (0.15)	0.15 (0.99)	0.64 (0.56)	0.60 (0.35)	0.63 (0.12)	0.44 (0.22)
1-2	Abandoned Secondary Associated	0.47 (0.28)	0.47 (0.21)	0.52 (0.38)	0.49 (0.80)	0.43 (0.35)	0.38 (0.85)
1-2	All Backwaters	0.60 (0.13)	0.16 (0.89)	0.63 (0.68)	0.61 (0.98)	0.64 (0.12)	0.39 (0.26)
3-5	main channel	0.34 (0.15)	0.12 (0.89)	0.36 (0.52)	0.23 (0.41)	0.38 (0.11)	0.04 (0.67)
3-5	Abandoned Secondary Associated	0.95 (0.002)	0.85 (0.07)	0.91 (0.005)	0.88 (0.22)	0.92 (0.009)	0.76 (0.14)
3-5	All Backwaters	0.95 (0.004)	0.89 (0.02)	0.85 (0.006)	0.91 (0.03)	0.93 (0.05)	0.81 (0.003)
1-4	main channel	0.28 (0.42)	0.22 (0.60)	0.39 (0.50)	0.43 (0.32)	0.33 (0.37)	0.55 (0.17)
1-4	Abandoned Secondary Associated	0.92 (0.05)	0.87 (0.19)	0.83 (0.16)	0.89 (0.52)	0.85 (0.16)	0.89 (0.10)
1-4	All Backwaters	0.85 (0.13)	0.73 (0.63)	0.83 (0.63)	0.82 (0.17)	0.87 (0.13)	0.84 (0.07)
1-5	main channel	0.54 (0.24)	0.31 (0.93)	0.57 (0.55)	0.68 (0.24)	0.59 (0.21)	0.61 (0.21)
1-5	Abandoned Secondary Associated	0.93 (0.04)	0.82 (0.82)	0.85 (0.18)	0.84 (0.47)	0.93 (0.06)	0.84 (0.13)
1-5	All Backwaters	0.90 (0.05)	0.73 (0.42)	0.89 (0.43)	0.86 (0.21)	0.92 (0.05)	0.81 (0.10)

[a]Between April 1 and July 31.

Note: Regressions equations are a third order polynomial with the form of $y=a+b1x+b2x^2+b3x^3$ with y = habitat area and x = antecedent conditions.

A statistical analysis of the relationship between backwater quantity and hydrologic characteristics (Table 4.12) indicated that within Reaches 1 and 2, total backwater area was generally not related to hydrologic characteristics regardless of backwater type. Although significant relationships were found, the r^2 tended to be less than 0.65 (Table 4.12). In Reaches 3, 4, and 5, main channel backwaters were not related to hydrologic conditions; however, secondary channel backwaters in these reaches were significantly related to all hydrologic characteristics (coefficients of determination 0.95 to 0.76).

In summary, the significant relationships shown in Table 4.12 indicate that hydrologic conditions significantly impact the amount of backwater habitats formed through secondary channel processes; however, because of the autocorrelations between hydrologic parameters, it is difficult to determine if one characteristic has a greater influence than any other. Because the backwaters associated with secondary channels are the dominant component of the regressions in Table 4.12, those factors that effect secondary channel modification may drive backwater habitat area. For example, results from channel morphology studies on secondary channels indicate that flows exceeding 5,000 cfs initiate secondary channel flushing. Consequently, days above 5,000 cfs may be a driving factor for backwater quantity.

Habitat Quality

Because of the importance of backwaters in the early life stages of Colorado pikeminnow and other native species in the San Juan River, the quality of backwaters was studied during late summer in 1995, 1996, and 1997. Chemical (nutrients, dissolved oxygen, pH, and turbidity), physical (depth, temperature, and substrate), and biological (detritus, periphyton, benthic invertebrates, phytoplankton, and zooplankton) factors were determined seasonally in backwater habitats. The descriptions that follow include most of the data collected during the study. During each sampling period, two to four backwaters were sampled in each geomorphic reach.

A comparison of the habitat quality data summarized for August sampling periods (Reaches 1 to 6) for each year can be seen in Table 4.13. Only August data were used in this case as this was the only month sampled each year. This sampling period is also useful as it represents backwater conditions soon after runoff and at approximately the time when Colorado pikeminnow YOY would be first present in these habitats. Sample sizes (N) indicate the total number of backwaters sampled during each sampling period. A detailed description of the sampling methodology employed can be found in Bliesner and Lamarra (1996).

Several parameters such as dissolved oxygen and pH may directly influence the distribution of fish species, while micronutrients such as nitrogen and phosphorus may indirectly influence habitat use through their interrelationship with primary production. Turbidity may influence distribution directly through avoidance of silt-laden backwaters, or indirectly by reducing light penetration and therefore primary production. Dissolved oxygen was highest in 1995, lowest in 1996, and intermediate in 1997 (Table 4.13). Mean concentrations in 1996 (4.7 mg/l) and 1997 (5.4 mg/l) may have been approaching the tolerance limit for some fish species. Orthophosphorous was significantly higher in 1995 than in 1996 and 1997, while total inorganic nitrogen was highest in 1996 and lowest in

Table 4.13. The mean and standard deviations for chemical, physical, and biological parameters sampled in backwaters during August 1995, 1996, and 1997 in the San Juan River.

CHEMICAL						
	AUGUST 1995		AUGUST 1996		AUGUST 1997	
PARAMETER	**MEAN±STD**	**N**	**MEAN±STD**	**N**	**MEAN±STD**	**N**
Ortho-P (mg/L)	0.155 ± 0.443	15	0.024 ± 0.016	20	0.016 ± 0.007	12
TIN (mg/L)	0.036 ± 0.014	16	1.07 ± 0.50	20	0.324 ± 0.167	12
Turbidity (NTU)	7.3 ± 4.6	16	330 ± 307	20	74.8 ± 50.8	12
pH (SU)	8.82 ± 0.41	10	7.99 ± 0.20	20	8.14 ± 0.13	6
Dissolved oxygen (mg/L)	6.67 ± 1.41	10	4.73 ± 1.85	20	5.38 ± 0.90	6
PHYSICAL						
	AUGUST 1995		AUGUST 1996		AUGUST 1997	
PARAMETER	**MEAN±STD**	**N**	**MEAN±STD**	**N**	**MEAN±STD**	**N**
Temperature (EC)	25.5 ± 3.3	16	25.5 ± 3.2	20	25.3 ± 3.4	12
Water Depth (m)	0.60 ± 0.55	16	0.35 ± 0.37	19	0.38 ± 0.20	12
Sediment Depth (m)	0.05 ± 0.05	6	0.30 ± 0.22	19	0.56 ± 0.29	12
BIOLOGICAL						
	AUGUST 1995		AUGUST 1996		AUGUST 1997	
PARAMETER	**MEAN±STD**	**N**	**MEAN±STD**	**N**	**MEAN±STD**	**N**
Zooplankton (#/m^3)	1140 ± 2190	16	3250 ± 5060	20	414 ± 356	12
Phytoplankton (Fg/L)	0.488 ± 0.241	16	1.34 ± 1.09	20	0.560 ± 0.622	12
Periphyton (mg/m^2)	28.6 ± 28.9	16	5.16 ± 13.8	20	0.21 ± 0.17	12
Invertebrates ((#/m^2)	1730 ± 1910	16	236 ± 237	20	272 ± 318	12
Detritus (g/m^2)	99 ± 121	16	49 ± 50	20	57 ± 89	12

1995. Turbidity was significantly higher in 1996 and 1997 than in 1995, and significantly higher in 1996 than in 1997 (Tukey's multiple comparison test, $p<0.05$). Inspection of the hydrographs during those years reveals that storm events occurred immediately prior to sampling in 1996 and 1997 (Figure 2.5). Despite these events, backwater temperature was very similar between years.

Previous investigations in other river systems within the Upper Basin have shown that greater depth is an important factor in backwater selection by Colorado pikeminnow young. This investigation found that mean water depth was significantly higher in 1995 than 1996 and 1997 ($p<0.05$) (Table 4.13). Sediment depth in backwaters was highest in 1997, intermediate in 1996, and lowest in 1995, although sample size was lower in 1995 than in subsequent years. Several factors may explain these findings. Runoff was substantially higher in 1995 than 1996, exceeding 5,000 cfs for 72 days in 1995 and never exceeding this flow during 1996 (Table 4.3). Investigations of flows necessary for adequate backwater flushing indicated that a minimum of approximately 21 days was required (see discussion this chapter). Thus, backwaters should have been completely flushed in 1995 and not flushed at all in 1996. This is also reflected in sediment depth between the two years, which was significantly lower in 1995 than 1996 ($p<0.05$). Although fewer backwaters were sampled for this parameter in 1995, all habitats occurred downstream of RM 94. It seems likely that backwater sediment depth in the upper river where sediment loading is reduced would have been similarly low. During 1997, although runoff was more similar to 1995 with 49 days exceeding 5,000 cfs, a 2-week period of several large storms preceded sampling (Figure 2.5). These storms appeared to have caused some refilling of backwaters in 1997, resulting in reduced backwater depth and greater sediment depth relative to 1995.

The same data plotted by geomorphic reach (Figure 4.10) indicate that backwater depth was similar during these three years in Reaches 4, 5, and 6, but that there were major differences in Reaches 1, 2, and 3. Hydrologic conditions prior to sampling in August 1995 (high runoff flows, lack of storms) produced deeper backwaters in the lower river. These same backwaters were not flushed in 1996 and may have experienced refilling in both 1996 and 1997 following storm events.

A major emphasis of this investigation was to document food availability for the fish community in San Juan River backwater habitats. Because these habitats represent nursery areas for larval and YOY stages of fish species, the quantity of food may be a critical component of backwater quality. A comparison of the biological parameters measured during August trips in 1995, 1996, and 1997 (Table 4.13) revealed that parameters associated with the pelagic community (phytoplankton and zooplankton), although different between years, were all at relatively low levels. Considering the impermanent nature of these habitats, this result was not unexpected. However, the biological community associated with the benthos displayed consistent differences between years. Periphyton, macroinvertebrates, and detritus (coarse organic material), all displayed significantly greater biomass in 1995 than 1996 (Tukey's multiple comparison test, $p<0.05$). Periphyton and macroinvertebrates were significantly greater in 1995 than 1997; however, detrital biomass was not significantly different ($p<0.05$).

The benthic biological data collected during August 1995, 1996, and 1997 show interesting longitudinal trends (Figure 4.11). During August 1995, which was preceded by high spring flows and no storm events, detrital biomass was highest in downstream reaches relative to the other years. Periphytal biomass in 1995 was higher than 1996 and 1997 throughout nearly the entire river, while invertebrate biomass remained at relatively high levels throughout the river in 1995, but decreased in lower reaches in a similar fashion in 1996 and 1997. Again, given the relatively high magnitude

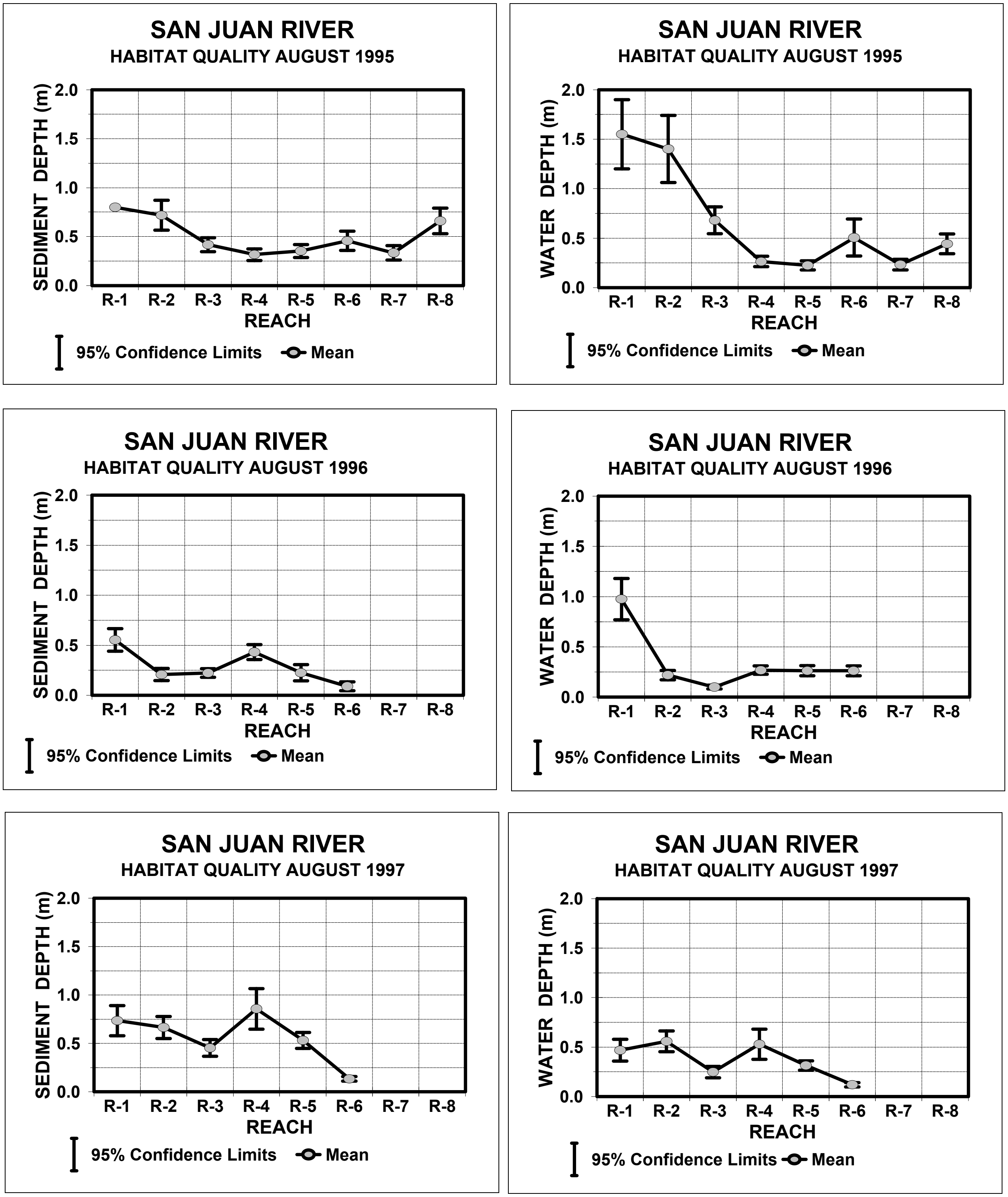


Figure 4.10 A comparison, by reach and year (1995 top, 1996 middle, 1997 lower) for sediment depth (left column) and water depth (right column) in San Juan River backwaters during August.

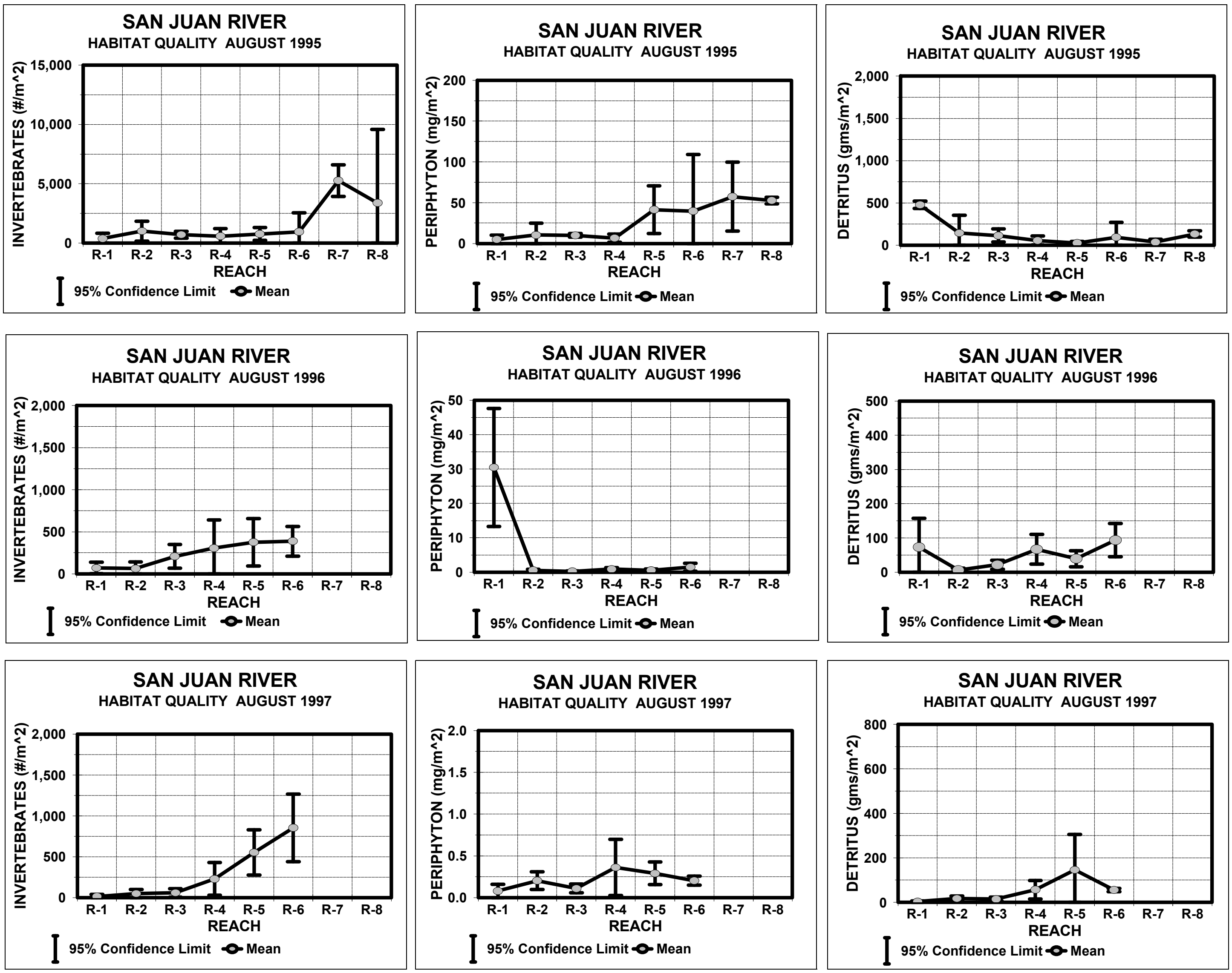


Figure 4.11. **A comparison by reach in August 1995 (upper), 1996 (middle), and 1997 (lower) of the averages for invertebrates (left column), periphyton (middle column), and detritus (right column) in the San Juan River. Please note scale differences.**

of peak runoff in 1997, it appears that storm events played a major role in the observed trends in productivity during these 3 years.

This effect is further demonstrated by comparing the November 1995 and April 1996 data sets with the December 1996 and April 1997 data. The 1995 to 1996 data represent the longest storm-free period observed during the backwater habitat quality study, whereas the 1996 to 1997 period included four storm events. Although longitudinal patterns varied, the April 1996 periphyton and macroinvertebrate densities (Figures 4.12 and 4.13) showed significantly greater biomass compared with April 1997, even though both November 1995 and December 1996 initial levels were similar. Unlike the relatively large increase in biomass of periphyton and macroinvertebrates in April 1996, the April 1997 data demonstrated a decrease in algae and invertebrate biomass from the previous sampling period.

Based on the data presented in Table 4.13 and Figures 4.10 through 4.13, it would appear that storm events had a substantial impact on backwater productivity. Habitat quality assessments by UDWR (1998) in the San Juan River also concluded that late summer and fall storm events were a major factor in low-velocity habitat quality. The magnitude of this impact depends upon the specific parameter and geomorphic reach. Although runoff conditions may be an important factor in the productivity of backwaters (especially following large runoff years) and perhaps more significantly in the creation of deeper backwaters in the lower San Juan River, storm events appear to be the dominant regulating factor. Periods of stability (lack of storms and the resulting flushing and refilling) increase trophic-level biomass, and thus food resources for native and nonnative fishes. However, it is not known if food is limited at certain times in these habitats.

BIOLOGICAL RESPONSES TO RESEARCH FLOWS

Many of the biological studies conducted under the SJRIP 7-year research effort were directed toward determining response in fish populations to research flows. Two types of studies were conducted to determine this response. The original study emphasis was to examine changes in numbers of individuals of endangered and other native species under different Navajo Dam flows. However, the rarity of the endangered species made it difficult to infer a clear biological response. As a result, a second approach was developed that focused on determining seasonal habitat preferences for different life stages of fish species of interest and subsequently determining if research flows provided adequate habitat quality and quantity at the correct time of year. Because numbers of the two endangered species were so low, individuals were stocked and studies were designed towards examining habitat use of stocked fishes. The following sections describe the studies that were conducted and the results of those studies related to the two endangered fish species, as well as other native species and the abundant nonnative fishes.

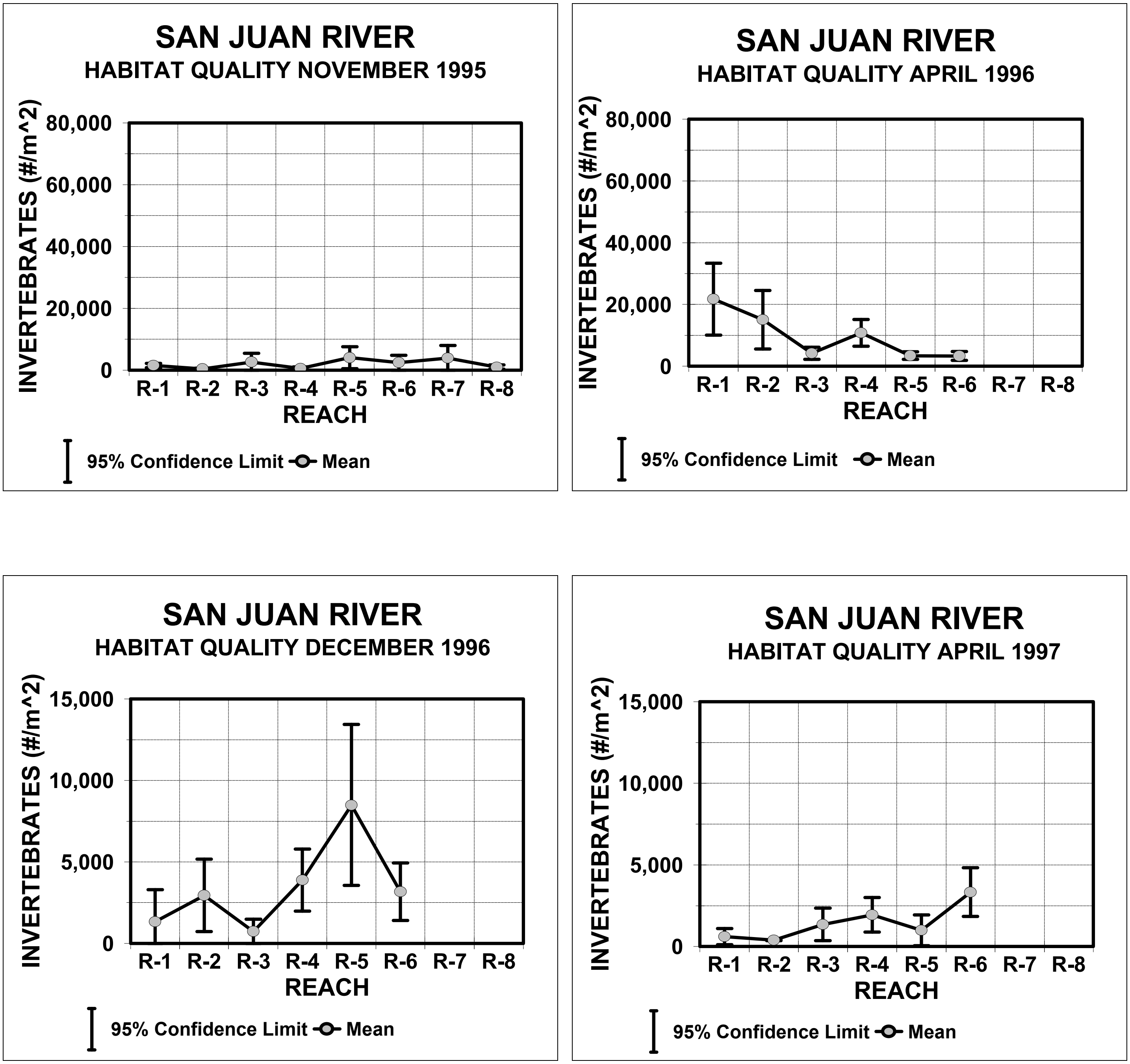


Figure 4.12. **The response of invertebrates biomass estimates during two separate time periods corresponding to a stable period (November 1995 to April 1996, above) and an unstable period (December 1996 to April 1997, below) in backwaters of the San Juan River.**

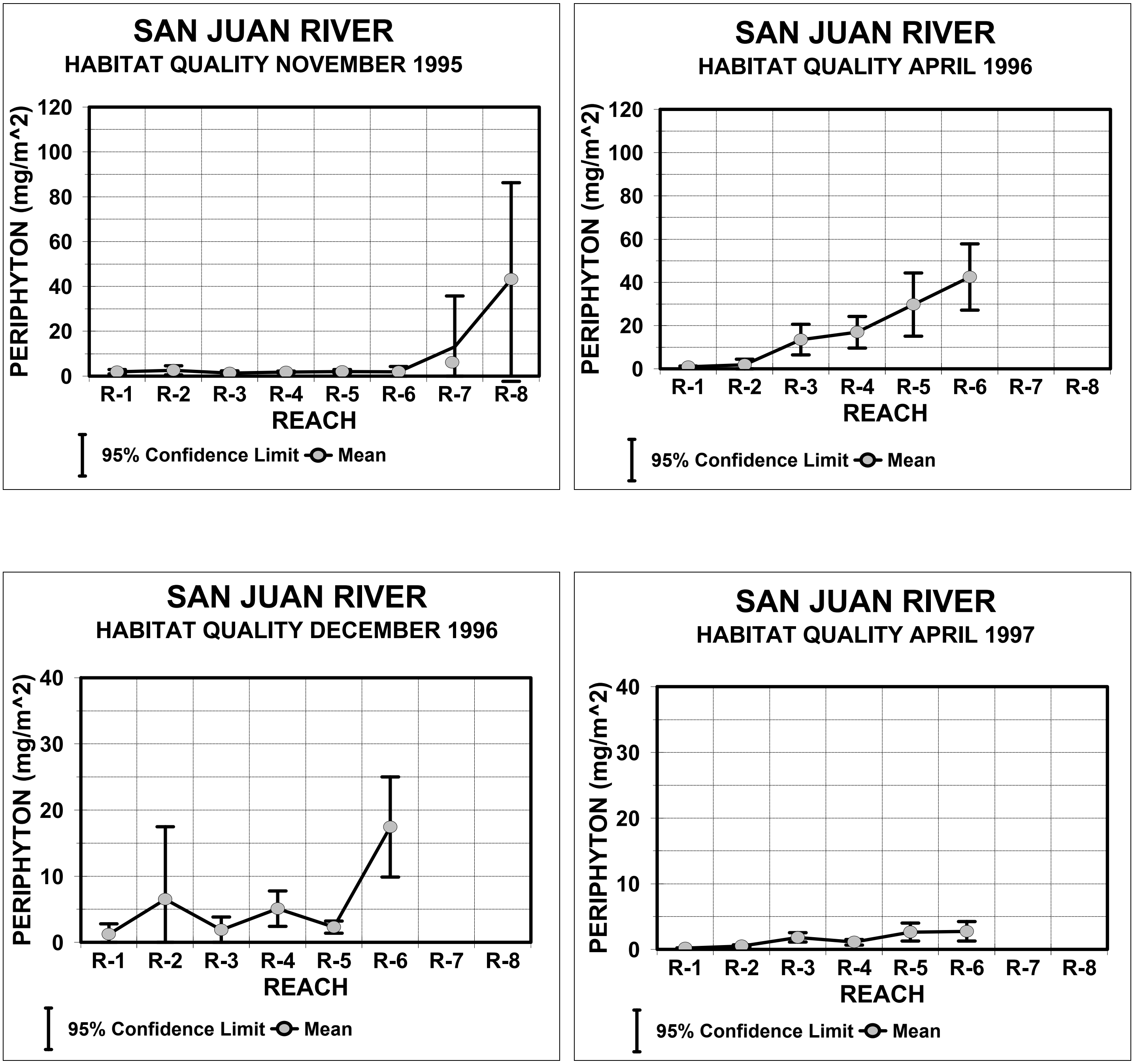


Figure 4.13. **The response of periphyton biomass estimates during two separate time periods corresponding to a stable period (November 1995 to April 1996, above) and an unstable period (December 1996 to April 1997, below) in backwaters of the San Juan River.**

Colorado Pikeminnow

Early Life Stage Habitat

For many years, late summer and fall backwater habitat sampling for YOY was used in the Upper Basin to determine Colorado pikeminnow annual reproductive success. Similar sampling in the San Juan River was initiated in 1987 (Platania 1990). This sampling was intensified in the San Juan River in August and September during the 7-year research effort (1991 to 1997) and was conducted by UDWR (Buntjer et al. 1993, 1994; Archer et al. 1995, 1996) and the Bureau (Lashmett 1993, 1994, 1995). In addition, larval drift netting was also conducted each year (Buntjer et al. 1993, 1994; Platania 1996, 1997). The initial intent of these studies was to examine Colorado pikeminnow reproductive success, and how it varied annually, as measured by the capture of YOY or larvae. Table 4.14 provides a summary of the young Colorado pikeminnow captured during the 7-year research period. Information for 1997 has not been completely analyzed at this time.

Numbers of YOY Colorado pikeminnow collected in the San Juan River between 1987 and 1996 were low and varied from year-to-year, ranging from 18 individuals in 1987 to 0 in 1989 and 1991 (Table 4.14). Sampling effort among years also varied considerably, ranging from a high of 1,390 seine hauls in 1991 to a low of 29 seine hauls in 1989 (Table 4.14). No clear relationship exists between effort and catch of YOY Colorado pikeminnow since no YOY Colorado pikeminnow were caught during the year with the highest effort (1991). The area sampled also varied among years, primarily at the lower end of the study area near Lake Powell. During most years, sampling stopped at RM 3 (Clay Hills Crossing boat takeout). During 1992, 1993, and 1994, however, sampling continued below RM 0. During those years, unique habitat conditions existed below RM 0 because of a drop in Lake Powell's elevation. Backwater habitat formed those years that had not formed previously, or existed since, because of the low level of the lake. Lake Powell rose dramatically in 1995, inundating up to about RM 7, and altering habitat up to near RM 20.

The collection locations of young Colorado pikeminnow are shown on Figure 4.14. Note that many of the collections occurred in Reach 1, the lowest reach of the river before entering Lake Powell. Of the 48 YOY collected from 1987 to 1996 (2 of the fish collected in 1994 were 1993 year-class fish collected in April), 5 were larvae caught at larval drift net stations (2 in 1993, 2 in 1995, and 1 in 1996). Of the remaining 43 YOY, 26 (60%) were collected below RM 20, the area affected by the increased elevation of Lake Powell. In 1993 alone, 4 of the 13 captures were below RM 0, and 11 below RM 3, the area sampled only in 1992, 1993, and 1994. Therefore, the portion of the San Juan River in Lake Powell appears very important to young Colorado pikeminnow but is not available consistently, which complicates comparing catch rates among years.

The general trend in the collections, when considering absolute catch, level of effort, and areas sampled, suggests that higher flow years (1987, 1993, 1994, and 1995) were better reproduction years than low flow years (1988, 1989, 1990, 1991, 1992, and 1996). A comparison of Figures 2.3 and 2.4 and Table 4.2 shows that 1987, 1993, and 1995 were high flow years, with larger than average spring runoff volume and peaks of 10,000 cfs or more. The years 1992 and 1994 were

Table 4.14. Number of young-of-the-year (YOY) and juvenile wild Colorado pikeminnow collected annually from 1987 to 1996 in the San Juan River during monitoring studies.

	YEAR									
Study	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
Platania (1990)	18	1	0	-	-	-	-	-	-	-
Buntjer et al. (1993, 1994)	-	-	-	1	0	0	2[a]	-	-	-
Lashmett (1993, 1994, 1995)	-	-	-	0	-	1	11	0	-	-
Archer et al. (1995, 1996)	-	-	-	-	-	-	-	7[b]	5[a]	0
Platania (1996)	-	-	-	-	-	-	-	-	2[a]	2[a]
# seine hauls	135	103	29	?	1,390	892	796	235	240	?

- = data not collected or available, [a] = larval fish taken in drift nets or by seining, [b]= 2 of the fish collected in 1994 were captured in April and were 1993 year-class fish

moderately high flow years with about average spring runoff volume and peaks between 9,000 and 10,000 cfs.

Using the information collected from all years, the apparent primary relationship between YOY Colorado pikeminnow collected and spring flow conditions in the San Juan River is that there is little reproductive success in the San Juan River. Further, the success is poorest in low flow years that have suppressed spring runoff. This is especially the case for a series of low flow years together, such as the period of 1988 to 1992, when only three YOY were caught during that drought period. Another inference that can be made is that high flow years with naturally shaped hydrographs like 1987, 1993, 1994, and 1995 are important for Colorado pikeminnow reproductive success. Schaugaard et al. (1995) drew a similar conclusion in comparing the 1991 to 1994 young Colorado pikeminnow collections from the San Juan River. Other researchers in the Upper Basin have demonstrated that Colorado pikeminnow had better reproductive success, as measured by capture of YOY in the late summer, after relatively high spring flows, and relatively poor reproductive success during low flow years (Holden and Wick 1982, McAda and Kaeding 1989, Osmundson and Kaeding 1991, Bestgen et al. 1998). The mechanism for this relationship is not understood but may include:

- High flows improve conditions on spawning bars and low flows do not,
- High flows increase the number and suitability of backwaters or other nursery habitats and low flows do not, and
- High flows reduce nonnative fish numbers in nursery areas and low flows do not.

Some information has also suggested that extremely high-flow years, which naturally occur relatively infrequently, are poor for Colorado pikeminnow reproductive success, as measured by collection of larvae or YOY (Bestgen et al. 1998). Thus, both very low- and very high-flow years may result in conditions unfavorable to Colorado pikeminnow reproductive success. Similar very high flows in the San Juan River would be difficult to duplicate with the regulation of Navajo Dam.

Adult Habitat

Another set of studies investigating the biological response of Colorado pikeminnow to research flows involved radiotelemetry of (radio-tagged) adults. The basic premise of these studies was to locate important habitats used by the species during important parts of their life history, such as spawning, and relate the development and maintenance of those habitats to flow.

Habitat-use data for adult Colorado pikeminnow were obtained by intensively tracking radio-tagged adult fish from June 21, 1993, through August 13, 1993 (Miller 1994), and July 5, 1994, through July 29, 1994, with additional data obtained opportunistically during February, June, and October (Miller 1995). The monitoring period included pre-spawning, spawning, and post-spawning observations. Fish were monitored from RM 75 upstream to RM 142.

Four adult fish were monitored in 1993, and five fish were monitored in 1994. Habitat-use data were analyzed following the method of Osmundson et al. (1995). To determine if adult fish selected particular habitat types, habitat use was compared with habitat availability (Swanson et al. 1974, Johnson 1980, Osmundson et al. 1995). The following description of methods used to determine habitat selection was used for Colorado pikeminnow, razorback sucker, and channel catfish. Habitat-use contacts consisted of locating a fish through radiotelemetry and monitoring its movement for at least 1 hour. During the contact period, the length of time the fish spent in each habitat type and all movements made by the fish were marked on a transparent acetate sleeve laid over a hardcopy of aerial videography that matched the flow in the river at the time of contact. At the end of a contact period, all available habitats were mapped at the fish's location and for 100 yards (yds) to either side of the most upstream and downstream contacts.

Selection for, or avoidance of, a particular habitat type was estimated by comparing habitat use to the actual availability of that habitat in the system. If there was no selection, the fish would use various habitat types in the same frequency in which they occur. For example, if 20% of the total water area is comprised of pool habitat, one would expect 20% of the fish locations to be in pools if habitat selection was random (i.e., no selection). If the fish exhibited a selection for certain habitat types by occupying that habitat in a greater portion than it is available, the habitat type is being preferentially selected, and it most likely fulfills some biological need.

To determine habitat selection, relative percentages for every individual habitat type available at each individual fish location were determined. Relative percentages of time the fish spent using each habitat type during the radiotelemetry contact were also determined. Percent availability of each individual habitat type within a given contact area was subtracted from the percent use of that habitat type by that fish species. Differences between the two percentages were then averaged for all

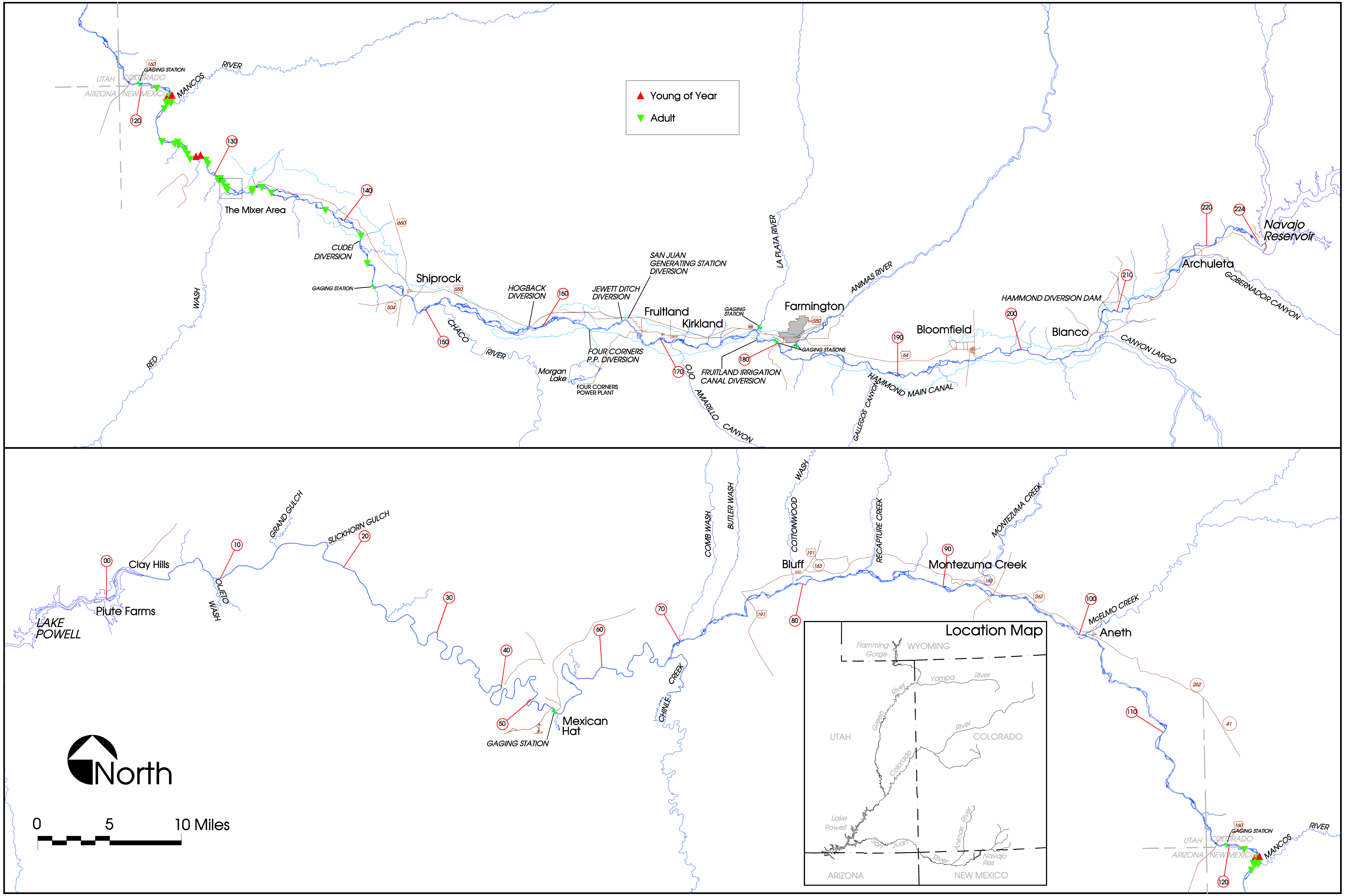


Figure 4.14. Locations of wild Colorado pikeminnow collections in the San Juan River from 1987 to 1996.

individuals in a given calendar month, riverwide, for both years (1993 and 1994) combined. This follows the "aggregate percent method" (Swanson et al. 1974) that greatly reduces biases associated with unequal number of locations among sampled fishes. In addition, analyses involving a limited number of fish observations are greatly enhanced if observations made during many months can be pooled to increase sample size (Osmundson et al. 1995). This mean difference between percent use and percent availability, termed "weight value," was then used as a measure of the degree of selection for each individual habitat type. Those habitat types with positive weight values (>0) were considered to be selected; the higher the value, the more selected. Negative weight values were interpreted simply as a lack of selection for a type rather than an active avoidance of it (Osmundson et al. 1995).

Also, it was assumed that the combination of habitats, adjacent to one another (Figure 4.15), would also play a role in the fish's site selection process. Therefore, after determining selected habitats, habitat complexity was used to determine the specific blocks of habitats that might be selected. Habitat complexity, the number of individual available habitat types within each contact area during each individual fish contact, was averaged for all contacts in a given calendar month, riverwide, for 1993 and 1994 combined. The contact area was 100 yds upstream and 100 yds downstream of the most upstream and downstream contacts made with the fish, respectively, during each contact period. The habitat complexity value for each month or season determines the number of habitat types to manage for in habitat recommendations. Main channel runs were ubiquitous, the dominant habitat type in all radiotelemetry contact areas, and were used, though not necessarily selected, by radio-tagged Colorado pikeminnow and razorback sucker during most months.

June Pre-spawning Habitat Use

In 1993, the most-used pre-spawning habitats included warmer eddies and sidechannels; water temperatures of these habitats were approximately 4E C warmer than the main channel (Table 4.15). The Mancos River confluence was used extensively prior to spawning (Miller 1994, 1995; Ryden and Ahlm 1996). Eddy habitat made up less than 1% of the available habitat; however, this habitat type was used approximately 32% of the time. The calculated selection for this habitat was approximately 60%. In 1994, the most-used pre-spawning habitats included eddies and slackwaters. Again, the Mancos River confluence was used extensively prior to spawning. Eddy habitat and slackwater habitat made up a combined total of less than 1% of the available habitat; however, these two habitat types combined were used over 40% of the time. The calculated preferences for eddy and slackwater were 30 and 70%, respectively.

July Spawning Habitat Use

Two potential spawning areas were located at RM 131 and RM 132 during the study. Three of the four radio-tagged fish were simultaneously located at an island/chute/eddy complex at RM 132 on July 12, 1993. The fish were then located in a second suspected spawning location at RM 131.15 from July 19, 1993, through July 22, 1993. A visual observation of a paired male and female was made on July 20, 1993. Radio contact was maintained for approximately 4 hours. The fish moved from an eddy area into the swifter riffle/run repeatedly during the observation. The female fish remained relatively stationary in the chute, and the male repeatedly moved from the female

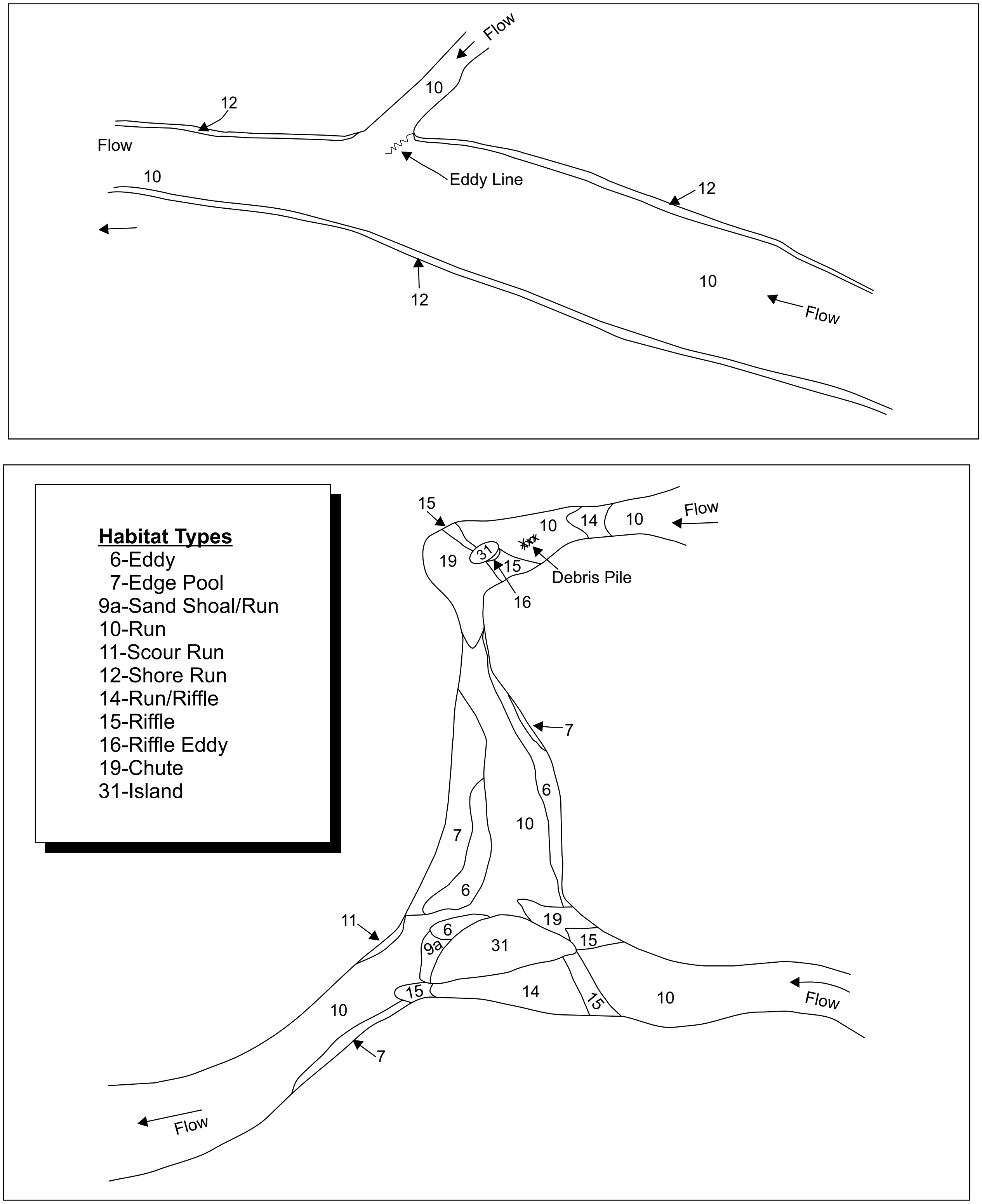


Figure 4.15. Simple versus complex habitat areas mapped from River Mile (RM) 106.9 and 129.9 of the San Juan River.

Table 4.15. Habitat selection for radio-tagged Colorado pikeminnow in the San Juan River, 1993 to 1994.

Habitat Type	Pre-spawn June	Spawn July	Post-spawn August	Fall October	Winter February
Eddy	47	32		50	50
Slackwater	30	42		19	
Pool	10	2		32	
Edge Pool	3	4			
Run/Riffle		10			
Shore Run	3	2			
Undercut Run	6				
Cobble/Shoal Run	1				
Scour Run		7			
Chute		2	52		
Riffle/Chute		<1			
Run			48		
Habitat Complexity	8	9	9	10	10

Note: Monthly selection was calculated by the aggregate percent method (Swanson et al. 1974) and is a combination of the amount of time various habitats were used and the availability of those habitats. Mean habitat complexity is the number of habitat types found in the area of river being used by the fish each month. All numbers higher than 0 suggest some selection, and higher numbers indicate a higher amount of selection for that habitat type.

downstream approximately 33 ft and then returned to the female's position (during the time both fish were in the riffle/run habitat). These fish remained in the riffle/run habitat for approximately 15 to 20 minutes before returning to the eddy. This behavior was repeated during the 4-hour observation period.

These same general locations were used in 1994. Two of the five radio-tagged fish were simultaneously contacted at an island/chute/eddy complex at RM 132 on July 6, 1994. The fish were then contacted at a second suspected spawning location at RM 131.15 on July 12 and 13, 1994. During 24-hour observation periods, these fish moved from the slower water adjacent to the chute/riffle complex into the chute/riffle complex. The fish remained in the chute/riffle complex for several minutes and then returned to the slower water habitats.

River sections with very complex habitats were used during spawning, with a complexity value of 9 (Table 4.15). Eddy and slackwater habitats were most selected, but both spawning locations had some areas of fast water habitat in close association with the slow water habitats (Table 4.15). Run, run/riffle, and chute habitats were all selected during the spawning period. The high selection for both low-velocity habitats (eddies and slackwaters) and high-velocity areas (run/riffle and chutes) at the same time is related to the spawning needs of the fish: they spawn in the fast water areas but spend time resting in adjacent low-velocity habitats.

Summer Post-spawning Habitat Use

In 1993, run and chute habitat were the most-used habitats after the fish departed from the spawning locations (Table 4.15). The fish were active in the run habitats, presumably feeding. There was little migratory behavior exhibited by any of the radio-tagged fish. There was one instance during a rainstorm (and subsequent increase in sediment) where a radio-tagged fish was displaced, presumably by the sediment inflow into the river. The fish returned to its former location within 24 hours of departure, after water clarity increased. Habitat complexity remained high during August at 9, indicating that this species tends to prefer complex river sections.

Fall Habitat Use

All fish remained separated during fall observations in October. The most-used habitat type was run habitat, although eddies and pools were the most selected (Table 4.15). Pool habitat, like eddy habitat, is available in low quantities in the observation areas. On average, 10 habitat types were present in local areas where observations were made, yet only four habitat types were used by the radio-tagged fish. All observations were made in daytime during this season. More-recent work on the Yampa River has shown that Colorado pikeminnow will use pool and eddy habitat during the day and habitats with faster velocities during the night (Miller and Rees 1997). The daytime observation data for the San Juan River may be the reason for the high habitat complexity values and low number of habitats used.

February Habitat Use

One week of observation was conducted in February 1994. Three radio-tagged fish were tracked for 5 days. Run-type habitat was the most-used during the observation period, but eddies were the most selected (Table 4.15). All fish monitored were active during observation periods, and the highest level of activity occurred midday. Water depths used during the observations ranged from 3.25 to 5.75 ft. Habitat complexity values remained high for the locations containing Colorado pikeminnow.

These radiotelemetry observations showed that adult Colorado pikeminnow selected habitats such as eddies and pools nearly year round, and that they used these habitats in complex portions of the river (areas that offer eight or more habitats). Spawning habitats also included complex portions of the river with fast chutes and riffles used for spawning and adjacent eddies and slackwaters for resting. Colorado pikeminnow also used the same general area year after year for spawning in the Green River; it appears that the Mixer (RM 131 to 132) has been an active spawning area in the San Juan River (Miller 1994, 1995; Ryden and Ahlm 1996). Therefore, flows designed to maintain the complexity of this area, and to clean the cobble chutes used for spawning, should be an important consideration in the flow recommendation process.

Young-of-the-Year (YOY) Habitat

Young-of-the-year Colorado pikeminnow use backwater habitats in the Green and Colorado rivers. Backwater habitats are relatively rare in the San Juan River, at least the backwaters that are similar to those in the Green River. The exception is the backwater morphology in Reach 1. This lowermost reach is affected by Lake Powell levels and acts as a depositional, highly alluvial reach that forms large, deep scour channel backwaters that are known to be selected by young Colorado pikeminnow. However, this reach does not consistently provide backwaters during periods of high lake level. Therefore, questions remain about the overall availability of San Juan River backwaters for young Colorado pikeminnow.

Young Colorado pikeminnow were stocked in the San Juan River to investigate habitat use (Lentsch et al. 1996). About 60% of the recaptured YOY were collected from backwaters, 15% from pools, and 13% from pocket water (see Chapter 2 for an explanation of these habitat types). The other 12% of the fish were collected from a variety of other low-velocity habitats. This study tended to support the conclusion that backwaters are a selected habitat of young Colorado pikeminnow in the San Juan River (Archer 1997), but that a variety of other habitats are also important. Young-of-the-year at low-flow levels were predominately found in secondary channels in Reaches 3, 4, and 5 that provided much of the low-velocity habitats at that time. The study also showed that the San Juan River does have sufficient habitat for the size of fish stocked.

Studies in the Upper Basin have suggested that temperature differences among backwaters and flow-through backwater habitats may influence the distribution of young Colorado pikeminnow in these habitats (Tyus and Haines 1991). During the winter and early spring, backwater water temperatures tend to be cooler than in the main channel, while in the summer the situation is reversed. Consequently, selection for backwater habitats during summer and avoidance of the same areas during winter may be primarily a response to temperature differences. Ongoing research and further analysis of data on habitat use of stocked YOY Colorado pikeminnow should provide additional insights into habitat selection of the early life stages of this species in the San Juan River.

Juvenile Habitat

Juvenile and subadult Colorado pikeminnow (yearlings and older) are less-frequently collected than YOY or adults. They have been collected from a variety of Upper Basin habitats ranging from backwaters to more riverine habitats. It appears that as young Colorado pikeminnow grow, they use more of the main channel and have the ability to move upstream and downstream and into tributaries (Tyus 1991b). Until 1997, only a few juvenile Colorado pikeminnow had been collected in the San Juan River, including two yearlings collected in a backwater in 1994 and two subadults (300 to 400 mm TL) collected in the main channel in 1996. The stocking of YOY Colorado pikeminnow in 1996 resulted in the capture of numerous yearlings in October 1997 and May 1998, and they were found in a variety of shoreline habitats, including shoals, eddies, and slackwaters. These areas typically had higher-velocity water than the areas where the YOY were captured, but still would be classified as low-velocity habitats, shoals, and slackwaters in Table 2.5. The habitats used by the yearlings tended to be low velocity but fit the general pattern seen in other portions of the Upper Basin (Tyus 1991b).

The study on stocked YOY Colorado pikeminnow showed that the San Juan River did in fact have adequate habitat for YOY and juvenile fish, and helped quantify the types of habitats that they used. Although backwaters were shown to be important, other types of low-velocity habitat were also used and appeared to provide adequate habitat for this life stage.

Razorback Sucker

Subadult and Adult Habitat Use

Because of the paucity of historical and recent razorback sucker collection information from the San Juan River (including the failure to collect wild fish during 3 years (1991 to 1993) of intensive studies on all life stages), the SJRIP Biology Committee (Biology Committee) identified the need to begin an experimental stocking program for this species in 1994. The experimental stocking program used artificially propagated, hatchery-reared razorback sucker to assess responses to research flows. The primary tests that were conducted involved determining whether the fish stayed in the river, and if so, what habitats they used during the year.

Between March 1994 and October 1996, 939 razorback sucker were stocked into the San Juan River. Experimentally stocked razorback sucker had a mean TL of 275 mm (range = 100 to 482 mm). Fifty-seven of these fish were surgically implanted with radio transmitters. These larger size-class fish were selected over smaller sizes to prevent high mortality rates because of predation by nonnative channel catfish and possibly by other nonnative predators, such as those observed in association with small size-classes of stocked razorback sucker (45 to 168 mm SL) in the Gila River (Marsh and Brooks 1989). Monitoring of experimentally stocked razorback sucker was accomplished by radiotelemetry, electrofishing, trammel netting, and seining.

Radiotelemetry tracking to determine habitat use consisted of locating a fish through radiotelemetry and monitoring its movement and habitat use for at least 1 hour. More-detailed information on methods can be found in Ryden and Pfeifer (1995). The studies provided habitat-use information for nearly all months of year.

To determine if adult razorback sucker selected particular habitat types, the same methods of data analysis were used as described for Colorado pikeminnow. This resulted in finding habitat preferences by month as well as monthly habitat complexity values.

Habitat selection for radio-tagged razorback sucker varied among months (Table 4.16), but generally occurred in complex areas of the river. During the winter base-flow periods, edge pools were the most-selected habitat, although eddies and main channel runs were also heavily used. During pre-runoff (March and April), a mixture of both fast and slow/slackwater habitats (pools, shoals, and backwaters) were used. main channel runs were not a selected habitat type in either month. Habitat selection for May showed a strong selection for eddies associated with the inside of large bends in the river channel (Table 4.16). main channel runs adjacent to these eddies were also used, and fish had a slight selection for these runs.

Table 4.16. Calculated selection for radio-tagged razorback sucker in the San Juan River, 1994 to 1997.

Habitat Type	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Oct.-Nov.
Edge Pool	26	100	44	4			24			
Run	74		28			3	14	25	15	100
Eddy			26	26		97		75		
Pool				40	21		22			
Sand Shoal/Run				30	9		12		85	
Backwater					23					
Shore Run			2		13					
Inundated Vegetation							28			
Sand Shoal					35					
Mean Habitat Complexity	7	6	8	7	7	8	6	6	5	4-8

Note: Monthly selection was calculated by the aggregate percent method (Swanson et al. 1974) and is a combination of the amount of time various habitats were used and the availability of those habitats. No data were collected in September. Mean Habitat complexity is the mean number of habitat types found in the area used by the fish each month. All numbers higher than 0 suggest some selection, and higher numbers indicate a higher amount of selection for that habitat type.

Habitat selection during the runoff period (June) was dominated by inundated vegetation (Table 4.16), which is the only time this habitat type is available. Two other low-velocity habitats, edge pools and pools, were also selected. Sand shoal/runs and main channel runs were selected to lesser degrees. All used habitats, even the main channel runs, were near shore (i.e., not midchannel) habitats. In July (descending limb of the hydrograph to post-runoff), as flows decreased, habitat use for radio-tagged razorback sucker greatly resembled use in May, with eddies being the dominant selected habitat type. As in May, main channel runs were the only other selected habitat type.

As flows receded to the summer/fall base-flow period (August to October), midchannel, fast water habitats (i.e., sand shoal runs and main channel runs) were the only selected habitats (Table 4.16). This was the only time period when habitat complexity of areas used by razorback sucker was reduced. In November, as was the case with October contacts, midchannel main channel runs were the only used and selected habitat. The one difference between the 2 months was that habitat complexity in contact locations in November was again high. November represents the last month of the calendar year before main channel water temperatures begin to drop substantially, and the winter conditions influenced razorback sucker habitat use.

Until May 1997, habitat use by razorback sucker appeared to be related to resting or feeding. However, during May 1997 electrofishing surveys, nine adult razorback sucker were recaptured. Eight of these were ripe male fish. All eight male fish were captured in aggregations of ripe, presumably spawning flannelmouth sucker, over midchannel cobble riffles and run/riffles, or along the river's margins over cobble shoal/runs. On May 3, 1997, one ripe male was captured immediately below McElmo Creek, near Aneth, Utah (RM 100.5). Approximately three-tenths of a mile below this, on the same side of the river, three more ripe male razorback sucker were captured in one net haul over a shoreline cobble shoal/run. Three other razorback sucker were observed but not captured at this location. The four recaptured fish had originally been stocked at either Hogback Diversion (RM 158.6) or Bluff (RM 79.6), and had converged near Aneth presumably to spawn. The fish recaptured at RM 100.5 was a radio-tagged male that had been located at RM 129.9 in late February 1997. One of the males recaptured at RM 100.2 was a radio-tagged fish that was last contacted at RM 93.8 on October 22, 1996. Flows were increasing in the river during the time these electrofishing collections were made. Flows at Shiprock on April 15, 1997, were 1,390 cfs; 1,770 cfs on May 3; 5,580 cfs on May 15; and 8,050 cfs on May 31, 1997.

Based on the above information, edge pool was a vitally important low-velocity habitat for adult razorback sucker during winter low-flow periods, regardless of the discharge from Navajo Reservoir. Because of high flows in the Animas River throughout the winter of 1996-97, flows in the San Juan River below Shiprock more closely resembled a "normal" winter base-flow period than they did during the January 1996 250-cfs research flow. January 1996 was the only time a true "low flow" was seen in the river downstream of Shiprock during this study. Regardless, no dramatic changes in habitat use by radio-tagged fish were observed between the two 250-cfs "low flow" periods during January 1996 and winter 1996-97. Radio-tagged razorback sucker showed little to no response to the 2-week, 250-cfs release from Navajo Reservoir in January 1995. So, at least for limited amounts of time, very low winter flows have no observable detrimental effect on larger size-class razorback sucker.

Although very few habitat types were selected during the winter, habitat complexity at razorback sucker locations was relatively high, indicating the use of complex river sections. During December's radiotelemetry contacts, use of main channel runs during warmest periods of the day was possibly because of feeding behavior. Slight weight increases of a few recaptured razorback sucker between fall 1994 and spring 1995 seem to indicate some wintertime feeding. As the weather continues to cool into January, feeding behavior would presumably tail off to a minimum. The exclusive use of edge pools during January radio contacts seems to support the idea that there was little or no activity (and probably no feeding) occurring during the coldest parts of the winter. Data collected over the last two winters appear to support that there may be a threshold temperature between 3.0 and 0.0E C that determines the shift in razorback sucker habitat use from main channel runs to lower-velocity edge pools and eddies. It also appears that turbidity may play an important role in habitat selection, because the fish used deeper habitats for cover in clear water.

During early spring pre-runoff periods, radio-tagged razorback sucker need a variety of low-velocity habitat types, the most important of which was eddies (Table 4.16). Sexually mature male razorback sucker demonstrated spawning-type behavior by aggregating on the ascending limb of the hydrograph, as was seen in other Upper Basin rivers (Tyus 1987, Tyus and Karp 1989, USFWS 1997). The majority of longitudinal movement, especially upstream movement, occurred during the summer/fall base-flow period. Although habitat selection data could not be inferred from electrofishing collections, recaptures during May 1997 provide circumstantial evidence that may suggest a shift in habitat use, if not selection, during spawning periods for individuals that have reached maturity.

During runoff (high flow) periods, radio-tagged razorback sucker moved into the river margins and used complex, low-velocity habitat areas, especially flooded vegetation. More than likely, razorback sucker were using these near-shore areas to avoid high, turbulent, main channel flows, as well as for foraging. Both immediately before and after high flows, eddies were an important and selected habitat type (Table 4.16). High habitat complexity in contact areas during runoff may have been because of the fact that as flows increase and inundate more areas, the margins of the channel became increasingly complex, rather than actual habitat selection by razorback sucker.

During summer/fall base-flow periods, radio-tagged razorback sucker selected midchannel, main channel, fast water habitats and were active throughout most of the day, probably indicating active feeding. Areas of the river used during this period were not complex until November, when a shift to more-complex areas of the river began (Table 4.16).

Overall movement of stocked razorback sucker was determined by location of radio-tagged fish, and by collection of Passive Integrated Transponder (PIT)-tagged fish. The majority of downstream displacement of stocked fish took place within several weeks of stocking. In addition, razorback sucker stocked in the spring had smaller downstream displacements than those stocked in the fall, despite being smaller fish and having to deal with high spring flows relatively soon after stocking. Given this evidence, it would appear that displacement of razorback sucker (> 222 mm TL) after stocking seems to be related as much or more to acclimation to a riverine environment as to displacement by flows. The majority of longitudinal movement following acclimation to the river, especially upstream movement, occurred during the summer/fall base-flow period.

The information gained from the stocked subadult fish has shown that the San Juan River can provide habitat for this life stage and that habitats used are not always the most abundant in the river. It also showed that, similar to Colorado pikeminnow, low-velocity habitats are important to this species. In the next few years, continued study of these stocked fish may show what habitats are used for spawning, and hopefully young will be produced so their life history needs can be assessed.

Larval and Juvenile Habitat Use

Two larval razorback sucker were collected in backwaters by larval fish seine in 1998, indicating that the fish that were stocked starting in 1994 had begun to reproduce. As discussed in Chapter 3, research in the Green River suggests that flooded bottomlands are important and perhaps necessary habitats for larvae and YOY razorback sucker (Modde 1996). That type of habitat is not found along the San Juan River, and likely cannot be feasiblely created. Whether low-velocity habitats in the San Juan River, such as backwaters and flooded vegetation, can serve as nursery habitats will be evaluated as part of the long-term monitoring program being established for the SJRIP at this time. The finding of larvae in two backwaters in 1998 is the first step in this evaluation. Since no juvenile razorback sucker have been found or stocked in the San Juan River, habitat use by this life stage is not known. Long term monitoring procedures will also monitor habitat use of juvenile fish to determine if razorback sucker can recruit to this size in the San Juan River.

Other Native Fishes

Unlike Colorado pikeminnow and razorback sucker, estimates of abundance of young and adults of many of the other native species are available, and analyses of those data related to the various flow years are provided in this section. By and large, this involved looking at various catch statistics related to the species of interest and relating catch to variables associated with flow. The GIS integrated database that was developed by the SJRIP was used to access the various flow and catch information. Specific radiotelemetry or stocking studies that resulted in development of habitat preferences were not conducted for the other native species in the San Juan River. This section discusses the results of analyses that were made to investigate responses of the nonendangered members of the fish community to the research flows from 1991 to 1997. Roundtail chub is not included in this section because, as explained in Chapter 3, that species apparently does not have a population in the San Juan River and primarily occurs in the tributaries.

Flannelmouth Sucker

Young-of-the-Year (YOY)

Flannelmouth sucker is the most-common large-bodied native species in the San Juan River. To determine reproductive response to different hydrologic scenarios during the research program, YOY catch rates (#/100 square meters(m^2)) were compared to different antecedent hydrologic conditions produced during the 7-year research period. Catch rates were determined using seining data gathered from main channel habitats by the UDWR during August and September, and from secondary channel habitats using data gathered by NMGF during August. The UDWR catch data were summarized by year for: (1) the entire reach sampled, typically Hogback (RM 158), to Clay Hills Crossing (RM 2); (2) an upper reach of the river where native YOY densities are usually highest (RM 116 to158); and (3) by geomorphic Reaches 1 through 5 (Figure 2.1). The NMGF catch data were summarized for: (1) the entire reach sampled (RM 77 to 158); and (2) the high-density reach of the river (RM 116 to 158). The UDWR sampling program focused on low-velocity main channel habitats, while the NMGF program included a greater variety of habitat types within secondary channels. Both the UDWR and NMGF used seines as the primary sampling tool.

Hydrologic data were obtained from the Four Corners USGS gaging station in New Mexico (Table 4.3). Parameters used in regression analyses included peak flow, peak date, runoff volume (March to July), and number of days runoff exceeded 2,500, 5,000, and 8,000 cfs. Exceedence flows were selected on the basis of geomorphology/aquatic habitat studies that indicated these flows influenced physical processes involved in the formation, maintenance, and quality of spawning areas and nursery habitats for Colorado pikeminnow and other native fishes. Pearson correlations were used to assess whether any relationship existed between variables ($p<0.05$). Several additional parameters were determined for UDWR trips to assess potential effects of trip-related factors on catch rates (Table 4.17). These included average trip flow, median trip date, and the number of days after peak flow that the trip occurred. River flows may influence capture efficiency by altering the physical characteristics of habitats, creating new habitats, redistributing fishes, or a combination of all of these. The timing of peak flows may influence the timing of spawning for some species, perhaps

Table 4.17. **Data pertaining to specific UDWR seining trips used in correlations.**

YEAR	TRIP	MEDIAN TRIP DATE (Julian day)	MEAN FLOW (cfs)	FLOW RANGE (cfs)	DAYS AFTER PEAK
1991	AUGUST	216	728	487-1,080	80
	SEPTEMBER	264	1,274	849-1,920	128
1992	AUGUST	226	513	490-545	77
	SEPTEMBER	261	1,395	571-2,540	112
1993	AUGUST	218	587	548-639	64
	SEPTEMBER	260	1,609	1,190-2,530	106
1994	AUGUST	220	460	335-652	64
	SEPTEMBER	258	936	659-1,370	102
1995	AUGUST	214	1,286	1,210-1,450	54
	SEPTEMBER	264	1,073	879-1,440	94
1996	AUGUST	220	274	239-345	81
	SEPTEMBER	247	461	379-525	108
1997	AUGUST	225	3,191	2,664-3,836	70
	SEPTEMBER	247	1,979	1,250-3,150	92

Note: Four Corners gage used for flow data.

by influencing river temperature or flow cues. Hence, the number of days after peak in which a trip occurred may affect catch rates as well.

Although catch rates for 1997 are indicated in Table 4.18, August catch rates for all species appeared to have been influenced by river flows that were several orders of magnitude greater than flows during previous sampling efforts (Figure 4.16). These conditions may have negatively affected catch rates by displacing fishes from preferred habitats, reducing available low-velocity habitats, decreasing sampling efficiency, or a combination of all of these. Because of these concerns, these data were not used in the hydrologic correlations that follow.

Flannelmouth sucker YOY catch rates have declined steadily from 1991 to 1996 according to the UDWR's August trip data for RM 2 to 158 (Table 4.18). A similar pattern can be seen using only the RM 116 to 158 data where catch rates are somewhat higher. Catch rates by year were more variable for specific geomorphic reaches with only Reach 4 indicating a consistent yearly decline (Table 4.18). Reach 5 (RM 131 to 154) was not included because of a change in the UDWR sampling program in 1994, which eliminated most sampling in this reach. Beginning in 1994, the UDWR ceased following the Interagency Standardized Monitoring Program (ISMP) protocol of sampling two backwaters or other low-velocity habitats every 5 mi during August trips, and began intensively sampling selected reaches to obtain more-detailed habitat information. These data were collected in RM 8 to 13 (used for Reach 1), RM 20 to 25 (Reach 2), RM 84 to 89 (Reach 3), and RM 126 to 131 (Reach 4) (see Archer et al. 1995). Thus, after 1993, geomorphic reaches were not sampled in their entirety during August trips. Analysis of the 1991 to 1993 August UDWR catch

Table 4.18. Average catch rates (number/100 m^2) with standard errors (in parentheses) and Pearson correlation coefficients (*r* values) of various hydrologic (Table 4.3) and trip (Table 4.17) parameters for flannelmouth sucker young-of-the-year (YOY) in the San Juan River (only 1991-96 data used in correlations).

CATCH RATES	UTAH DIVISION OF WILDLIFE RESOURCES DATA													NEW MEXICO DEPARTMENT OF GAME AND FISH DATA	
	RM 2 - 158		RM 116 - 158		REACH 1		REACH 2		REACH 3		REACH 4		REACH 5	RM 116 - 158	RM 77 - 158
	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	SEPT.	AUG.	AUG.
1991	23.2 (2.3)	4.6 (0.7)	38.3 (5.7)	7.1 (1.8)	12.1 (3.8)	2.1 (2.2)	3.0 (1.2)	2.2 (0.6)	21.8 (4.2)	6.4 (1.5)	21.5 (4.4)	1.8 (0.8)	5.4 (1.9)	13.3 (7.7)	16.7 (5.1)
1992	12.9 (2.8)	6.7 (1.6)	34.5 (8.4)	11.7 (4.3)	3.8 (0.8)	0.8 (0.3)	1.8 (0.5)	1.4 (0.9)	4.5 (1.1)	4.2 (0.9)	11.9 (2.5)	6.4 (1.6)	17.8 (4.8)	36.8 (16.3)	34.4 (11.0)
1993	11.5 (2.1)	13.5 (4.5)	12.9 (3.4)	24.5 (15.0)	29.5 (8.6)	7.4 (3.1)	1.6 (0.6)	3.6 (1.9)	12.1 (6.1)	12.2 (3.1)	10.4 (2.9)	20.6 (7.5)	27.9 (31.4)	47.9 (12.1)	47.3 (8.6)
1994	5.2 (3.1)	2.6 (0.9)	5.8 (5.9)	1.5 (0.8)	3.0 (0.9)	4.5 (1.3)	2.9 (1.6)	1.2 (3.1)	12.4 (12.3)	1.2 (0.3)	2.9 (1.7)	1.3 (1.0)	1.1 (0.9)	6.0 (2.0)	9.9 (4.0)
1995	0.5 (0.3)	2.0 (0.5)	1.0 (0.4)	5.8 (1.7)	0.1 (1.2)	0.0 (0.0)	0.6 (0.3)	0.3 (0.1)	0.6 (0.3)	0.5 (0.3)	1.0 (0.4)	0.8 (0.3)	12.7 (4.0)	16.7 (6.5)	16.5 (4.2)
1996	0.0 (0.1)	0.2 (0.1)	0.0 (0.4)	0.2 (0.1)	0.0 (0.0)	0.6 (0.7)	0.0 (0.0)	0.1 (0.0)	0.2 (0.3)	0.1 (0.1)	0.0 (0.0)	0.2 (0.1)	0.1 (0.1)	8.6 (4.8)	8.6 (4.0)
1997	1.6	0.0	8.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	8.0	0.0	0.0	1.7	4.8
CORRELATIONS	**UTAH DIVISION OF WILDLIFE RESOURCES DATA**													**NEW MEXICO DEPARTMENT OF GAME AND FISH DATA**	
	RM 2 - 158		**RM 116 - 158**		**REACH 1**		**REACH 2**		**REACH 3**		**REACH 4**		**REACH 5**	**RM 116 - 158**	**RM 77 - 158**
	AUG.	**SEPT.**	**AUG.**	**SEPT.**	**AUG.**	**SEPT.**	**AUG.**	**SEPT.**	**AUG.**	**SEPT.**	**AUG.**	**SEPT.**	**SEPT.**	**AUG.**	**AUG.**
Peak Flow	-0.23	0.34	-0.23	0.38	0.14	0.28	0.08	0.17	-0.15	0.12	-0.24	0.33	0.55	0.38	0.38
Peak Date	-0.52	0.06	-0.50	0.14	-0.10	0.05	-0.20	-0.14	-0.41	-0.16	-0.52	0.11	0.35	0.15	0.13
Volume	-0.17	0.58	-0.23	0.65	0.43	0.42	-0.08	0.37	-0.15	0.40	-0.16	0.61	0.78	0.61	0.62
Days > 2,500 cfs	-0.21	0.51	-0.25	0.61	0.37	0.28	-0.20	0.29	-0.23	0.34	-0.18	0.54	0.77	0.59	0.58
Days > 5,000 cfs	-0.14	0.71	-0.20	0.75	0.54	0.57	-0.04	0.49	-0.12	0.51	-0.14	0.75	0.83	0.73	0.74
Days > 8,000 cfs	-0.46	0.13	-0.54	0.22	0.08	0.18	-0.19	-0.01	-0.27	-0.02	-0.45	0.19	0.37	0.15	0.15
Trip Flow	-0.09	0.87	-0.07	0.86	-0.07	0.50	-0.10	0.82	-0.09	0.82	0.00	0.73	0.84	N/A	N/A
Days After Peak	0.44	0.14	0.54	0.06	-0.08	-0.01	0.09	0.38	0.21	0.37	0.45	-0.02	-0.13	N/A	N/A
Trip Date	0.06	0.37	0.33	0.39	-0.16	0.09	0.08	0.40	-0.21	0.36	0.04	0.17	0.44	N/A	N/A

N/A = not available
Note: Shaded cells indicate significant correlations ($P < 0.05$)

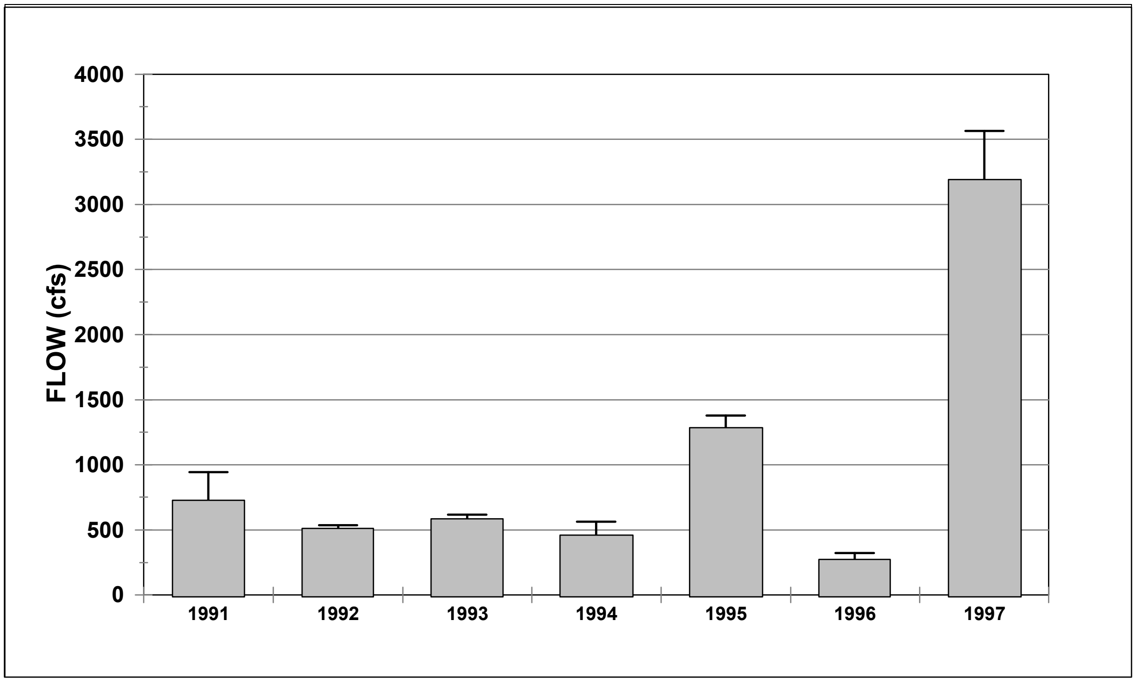


Figure 4.16. Flows during August UDWR YOY sampling trips on the San Juan River.

data, however, indicated that these detailed reaches were generally representative of the geomorphic reaches in which they occur.

There were no significant correlations with any of the hydrologic or trip parameters during August trips (Table 4.18). At a sample size of six (for each year), a significant correlation is obtained at an *r* value of about 0.81 or greater. The lack of positive correlation with hydrologic parameters is not surprising considering the apparent declining yearly catch rates for this species. The highest catch rate in any reach during any year was in Reach 1 during 1993 (Table 4.18). High flows may have displaced YOY fishes downstream to a greater degree during this year; however, catch rates by reach were uniformly low during 1995, a comparable water year in many respects. Parameters in which the 2 years differed were days exceeding 8,000 cfs and peak date. During 1995, there were 11 more days over 8,000 cfs and a slightly greater peak occurring 2 weeks later (19 June) than in 1993 (3 June) (Table 4.3). These later, higher flows may have coincided with the peak of flannelmouth larval drift that year and caused further downstream displacement of larvae. In 1995, peak drift occurred in late June (Platania 1996). When only the years 1991 to 1995 were used in the analysis, YOY abundance for RM 2 to 158 was negatively correlated with peak date (r=0.89, p=0.04).

This correlation breaks down, however, when data from 1996, a low runoff year when catch rates for flannelmouth YOY were also low, are included. It is important to note, however, that catch rates during August UDWR trips for all years were considerably lower than during the single UDWR trip that occurred in June (1991). During that survey, the average catch rate for flannelmouth sucker

YOY was 96.5 fish/100 m^2 (RM 2 to 158). It declined to 24.8 fish/100 m^2 by July (Buntjer et al. 1993), and remained at about that level in August (Table 4.18). This decline reflects the disappearance (via mortality, dispersal, etc.) of flannelmouth sucker YOY from low-velocity habitats over time. As noted in Chapter 3, flannelmouth sucker spawn primarily during May. The current YOY sampling program, however, was designed to describe reproductive success of Colorado pikeminnow, which spawns in July. Thus, using these data only, it remains uncertain whether the perceived decline in flannelmouth sucker is real or might in some way be related to the sampling program. Analysis of catch rates of juvenile and adult fish over the same time period can be used to assess this perceived decline (see Juvenile and Adult sections).

An analysis of NMGF August seining data from secondary channels revealed generally higher catch rates than the UDWR's data by year, with some near-significant relationships to flow (Table 4.18). It is again noteworthy that the UDWR seine collections occurred almost exclusively in main channel habitats (M. Buntjer, USFWS, personal communication; E. Archer, Department of Fisheries and Wildlife, Utah State University, personal communication). This *may* indicate some differences in the use of main vs. secondary channel habitats by YOY flannelmouth sucker, with possible selection for the latter during the early summer. The NMGF sampling program, however, does not concentrate effort on low-velocity habitats like the UDWR does, but samples a more-representative array of habitats within secondary channels, including swifter habitats like riffles and runs (D. Propst, NMGF, personal communication). Therefore, the NMGF and UDWR sampling programs may not be comparable in all respects.

Seine collections from the UDWR's September trips indicate temporal patterns more similar to those found in the NMGF data set, with higher, although generally nonsignificant, correlations with flow in the San Juan River's upper reaches (Table 4.18). All September collections followed the ISMP sampling protocol, and thus geomorphic Reaches 1 to 5 were sampled in their entirety. One parameter, days exceeding 5,000 cfs, produced a significant r value of 0.83 ($p=0.04$) in Reach 5. A possible explanation for the similarity with NMGF data was that during high-flow years, secondary channels may serve as temporary refugia for YOY of this species, which may then return to main channel habitats after a period of several weeks. Although this is speculative, the relatively strong year-class in 1993 indicated by the NMGF and UDWR collections appears to be reflected in catch data from electrofishing trips conducted by the USFWS. These data indicate that a relatively strong year-class of age-2 flannelmouth sucker occurred in the fall of 1995 (Figure 4.17).

Juvenile and Adult

Considering that flannelmouth sucker YOY catch rates may be declining in the San Juan River, the question arises as to whether this perceived decline is being reflected via reduced recruitment to later life stages or whether it may be related to declining reproduction because of a reduced adult population, or both. Abundance of juvenile and adult flannelmouth sucker has exhibited some decline during the 7-year research program according to fall electrofishing catch-per-unit-effort (CPUE) data collected by the USFWS (Figure 4.18). The fall trips were initially judged less likely to be influenced by flows than spring trips because fall trips generally occurred during base-flow

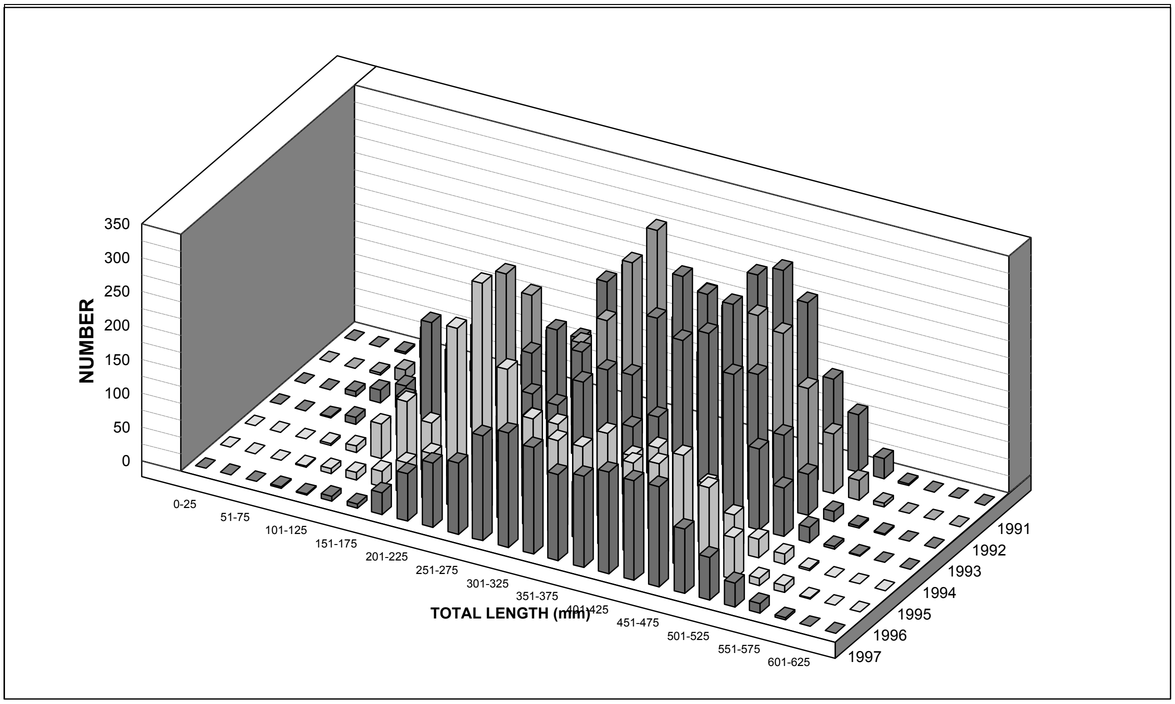


Figure 4.17. Length-frequency histogram for flannelmouth sucker collected during October USFWS electrofishing surveys on the San Juan River (RM 52 to 158). Age-2 fish in 1995 (1993 cohort) are in the 176 to 250 mm size range.

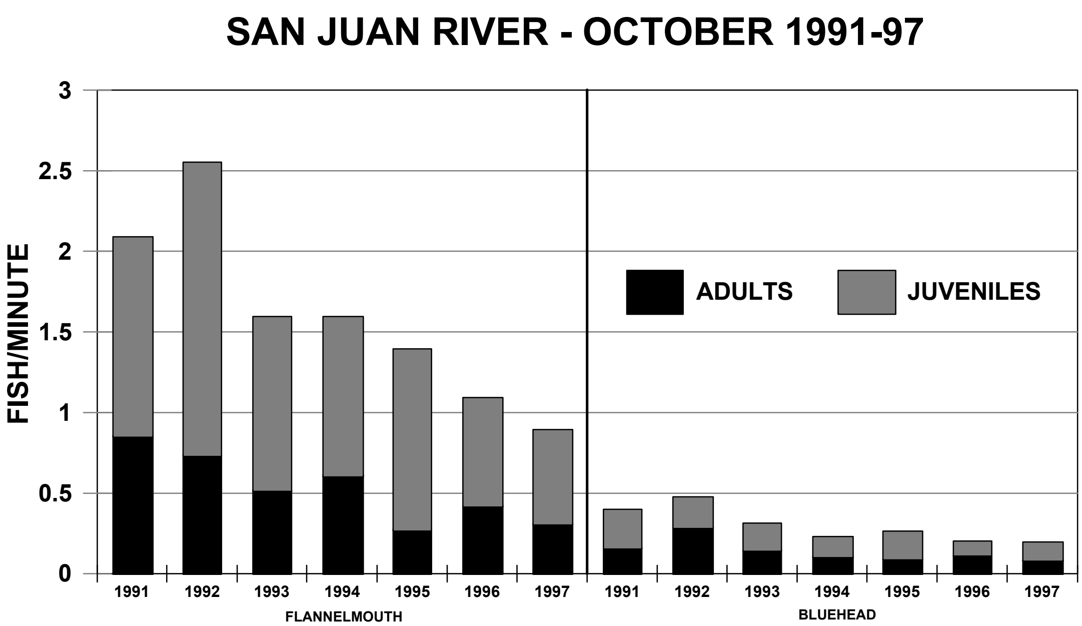


Figure 4.18. Average catch rates for juvenile and adult flannelmouth and bluehead sucker collected during October (1991-97) USFWS electrofishing surveys in the San Juan River between RM 2 and 158.

conditions, and thus flows among years should have been more consistent. However, flows have varied considerably during both spring and fall trips (Figure 4.19). Coefficients of variation (standard deviation/mean) averaged 32.5% for spring trips and 33.5% for fall trips. A linear regression analysis was performed to determine the influence of flows on total (juvenile + adult) catch rates of flannelmouth sucker during spring and fall trips after standardizing yearly effort by the river reach commonly sampled (RM 52 to 158). This analysis indicated a significant negative flow effect on flannelmouth CPUE during fall trips (Figure 4.20), but not during spring trips (r^2=0.25, p=0.39). An analysis of covariance was then performed on the fall data to determine whether there were actual differences between annual flannelmouth sucker CPUE considering the negative linear relationship between flow and CPUE (Zar 1984). There were significant differences between the slopes of the regression lines for total CPUE (F=18.03, $F_{0.05(1),1,10}$ =4.96), juvenile CPUE (F=20.46), and adult CPUE (F=7.87). This indicated that even given the apparent negative influence of flow on flannelmouth sucker CPUE (i.e., increased flows had lower CPUE), juvenile and adult CPUE still appeared to decline over the 7-year research period. A one-way analysis of variance (ANOVA) indicated that there were also significant differences in total flannelmouth sucker CPUE among the spring trips. Tukey's multiple comparison test showed that there were significant differences between almost all years; however, the trend was not a consistent decline over time. Relatively high sample sizes (n=104 to 107) likely contributed to the high number of significant differences found. In summary, flows negatively influenced flannelmouth sucker CPUE during fall electrofishing trips (i.e., higher flows resulted in generally lower CPUE), but not during spring trips. Despite this effect during fall trips, juvenile and adult CPUE appeared to decline over the 7-year research period (1991 to 1997).

These results suggested that the perceived decline in adult flannelmouth CPUE indicated by the USFWS sampling program may be real and were possibly being reflected in a decline in YOY flannelmouth sucker abundance as indicated by the UDWR nursery habitat sampling program. Conversely, the progressive decline in flannelmouth sucker YOY may be contributing to a reduction in juvenile and adult flannelmouth sucker via reduced recruitment. Future monitoring will help determine if this decline continues, or stops at some point.

A response was observed in the juvenile and adult flannelmouth sucker populations to variations in base flows during the research program. Both juvenile and adult condition (CF=(weight (g) x 10^5)/(TL (mm))^3) increased during stable base-flow conditions during fall to spring periods in 1993-94 and 1995-96 (Figures 4.21 and 4.22). During this period, the San Juan River is often characterized by storm events resulting in marked increases in discharge and suspended sediment loads. These events can reduce primary and secondary productivity (i.e., periphyton and benthic invertebrates) in the river in the short-term (1 to 2 weeks), an effect that can be prolonged when these perturbations occur with greater frequency. Primary and secondary productivity increased in a variety of habitats (i.e., riffles, runs, backwaters) following longer periods of stable flows (see Habitat Quality discussion above). Flannelmouth sucker appeared to be responding positively to this increased food supply. The marked response in both juvenile and adult fishes was evidence that it was not caused by ripening of adults during the pre-spawning period. There was no correlation

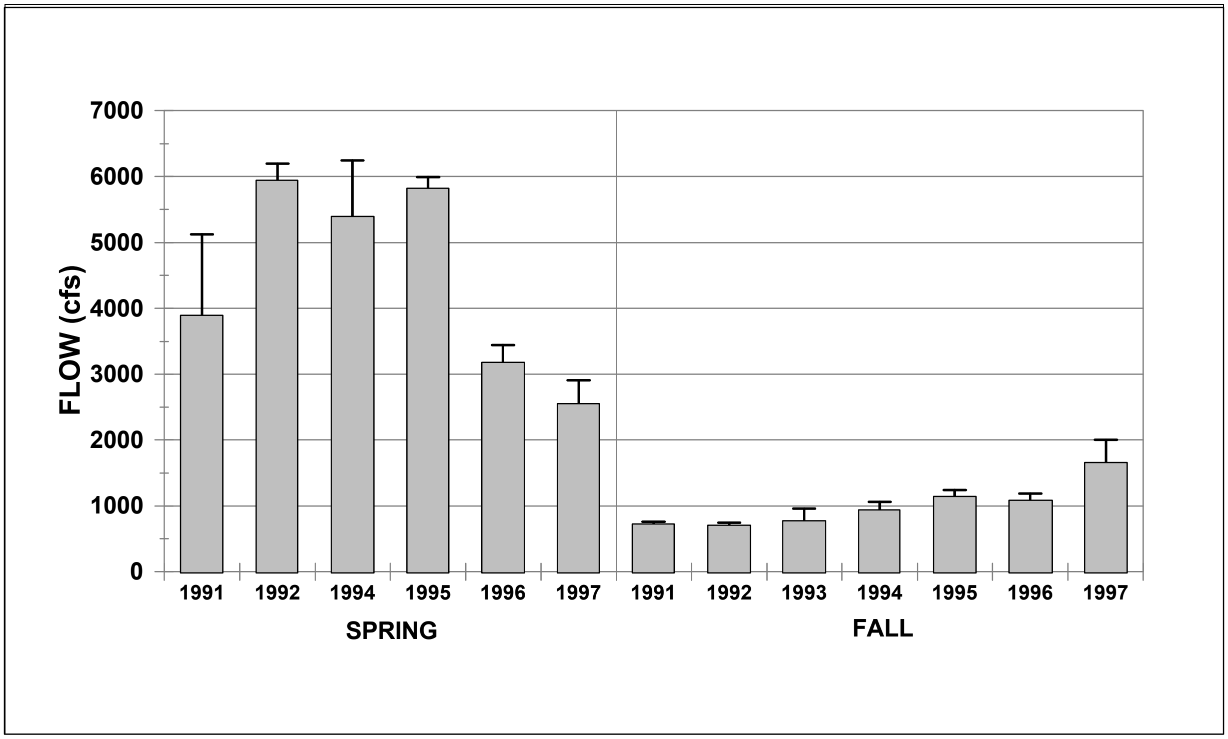


Figure 4.19. Flows during spring and fall USFWS electrofishing trips on the San Juan River.

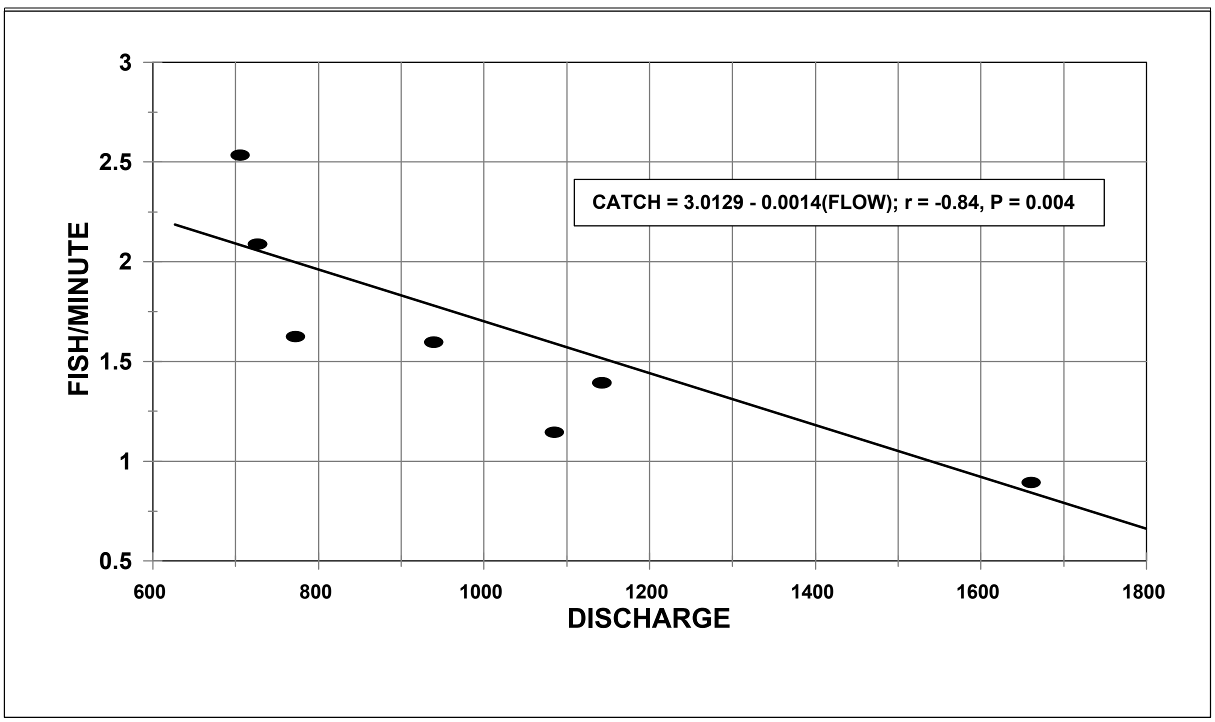


Figure 4.20. Regression line fitted to plot of average catch rates of flannelmouth sucker collected during October (1991 to 1997) USFWS San Juan River electrofishing surveys versus sampling trip discharge (as measured at USGS gage 09371010, Four Corners, New Mexico).

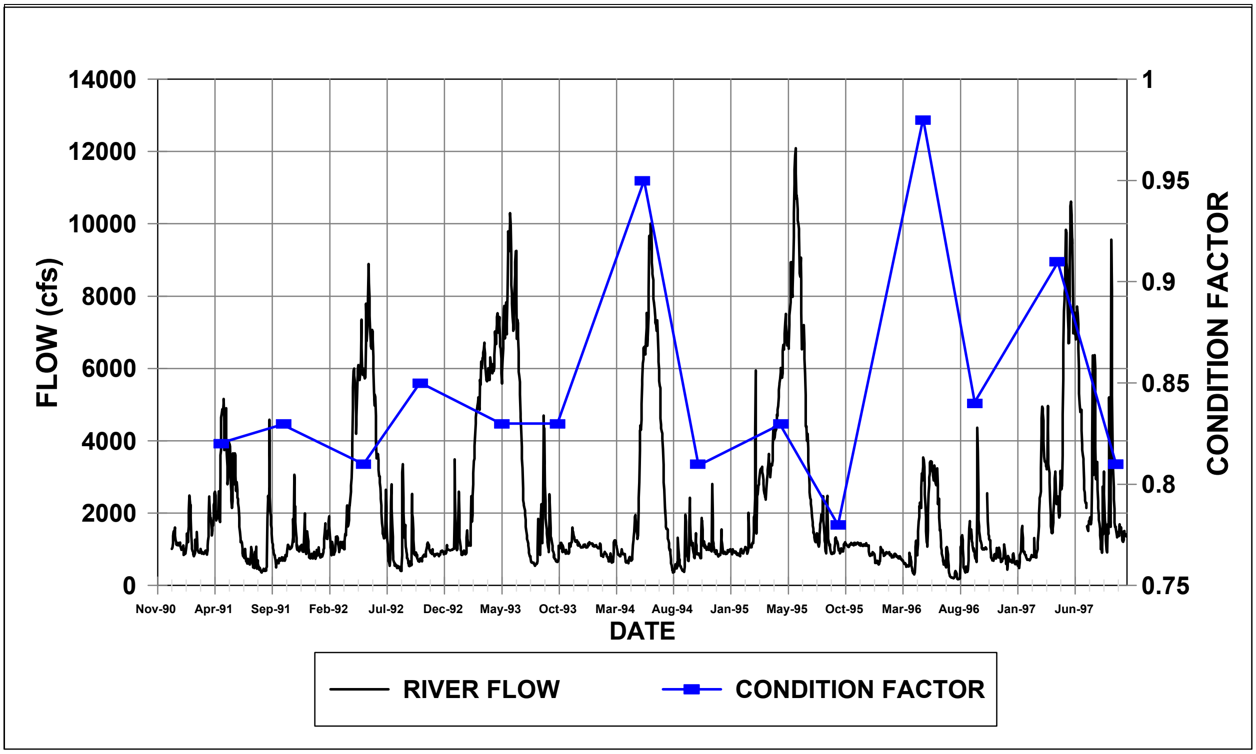


Figure 4.21. **San Juan River discharge (as measured at USGS gage 09371010, Four Corners, New Mexico) versus average juvenile flannelmouth sucker condition. Condition factor was determined using data collected by USFWS electrofishing surveys (RM 52 to 158) within designated reaches.**

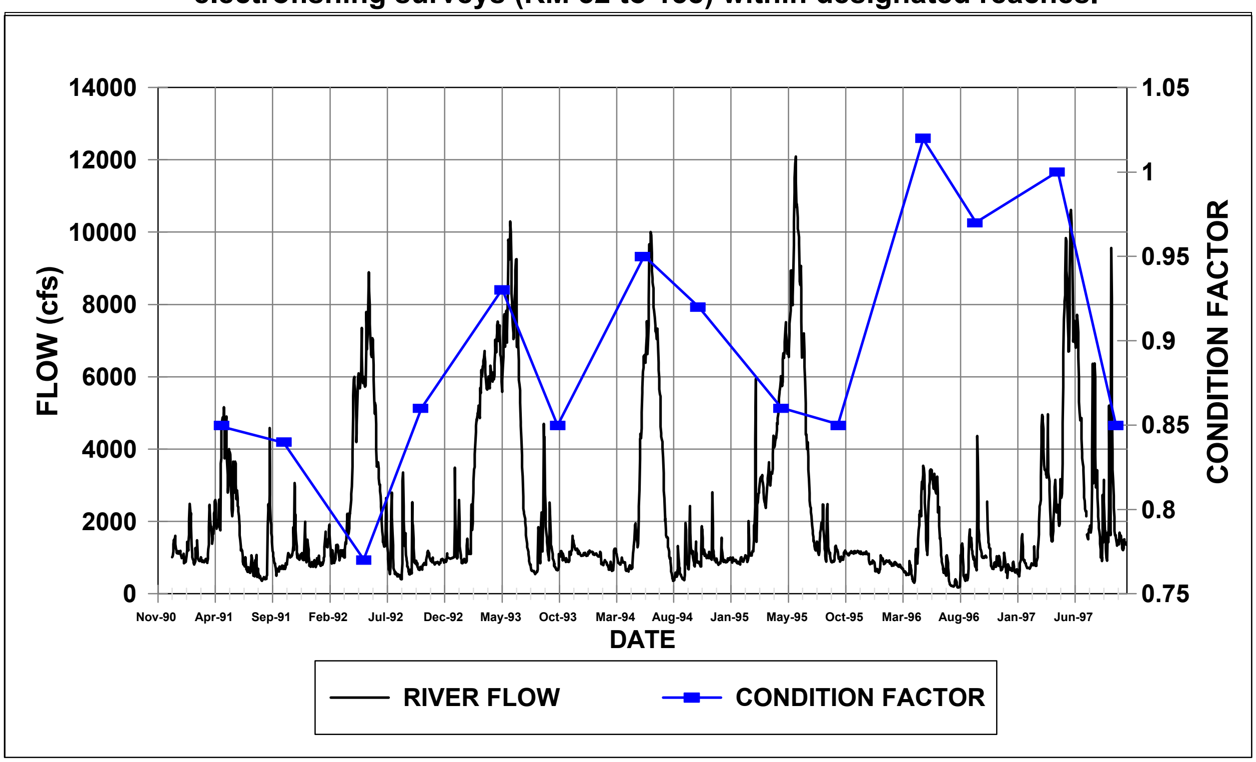


Figure 4.22. **San Juan River discharge (as measured at USGS gage 09371010, Four Corners, New Mexico) versus average adult flannelmouth sucker condition. Condition factor was determined using data collected by USFWS electrofishing surveys (RM 52 to 158) within designated reaches.**

between adult flannelmouth sucker condition in the spring, which may reflect reproductive condition, and YOY abundance the following summer. The timing of the nursery habitat sampling programs may preclude establishing such a relationship; however, although a relationship between length and fecundity was established for flannelmouth sucker (McAda 1977), no such relationship was established for fish condition in the San Juan River.

It is also possible that the overall increase in condition factor noted above is because of an overall increase in biological production in riffles and runs since the initiation of the research flows. No studies have been conducted to assess changes in production over time, but as discussed in Chapter 2, reduced amounts of fine sediments in cobble substrates tend to result in increased biological productivity. As noted earlier in this chapter, one result of the research flows was a general increase in cobble/gravel substrate and a decrease in sand, resulting in both more cobble/gravel substrate now compared with pre-research flow periods, but also a likely increase in biological production because of the cleaner cobble/gravel substrate. The combination of lower and more-stable base flows in most years, and cleaner cobble substrates, may have contributed to both increased production in the river and increased condition factor in flannelmouth sucker.

In conclusion, no clear response to increased spring flows was noted in flannelmouth sucker YOY catch rates, although a decline over the course of the 7-year research period appeared most likely. A decline in adult and juvenile catch rates from 1991 to 1996 was also noted, suggesting that the overall flannelmouth sucker population had declined. Reasons for the decline were not clear, but may be a result of less-favorable conditions for adult flannelmouth sucker since the advent of research flows. Even with the perceived reduction in abundance, flannelmouth sucker remained the most-abundant fish in the San Juan River.

Bluehead Sucker

Young-of-the-Year (YOY)

More than any other species in the San Juan River, native or nonnative, bluehead sucker showed a positive trend in year-class strength with spring runoff hydrologic conditions during the research program. The possibility was examined of whether correlations existed between YOY bluehead sucker catch rates and various hydrologic (Table 4.3) and trip (Table 4.17) parameters using similar data to those described in the preceding flannelmouth sucker section. Although catch data for 1997 were presented, correlations were determined for only the 1991 to 1996 period because of the extreme difference in river discharge experienced during August 1997 relative to previous trips (Figure 4.16). Significant correlations between hydrologic variables and catch rates in both the August and September UDWR data sets and in the NMGF August data were observed (Table 4.19).

Because of autocorrelation between hydrologic variables (Table 4.11), it is not possible to pinpoint the exact aspect of runoff to which bluehead sucker responded. Using the UDWR and NMGF data sets, significant correlations were obtained for every hydrologic parameter (except peak flow) depending on the data set and river reach used (Table 4.19). Correlations with hydrologic data were usually strongest when catch rates were highest, typically in the upper portions of the river (Reaches

Table 4.19. Average catch rates (number/100 m²) with standard errors (in parentheses) and Pearson correlation coefficients (*r* values) of various hydrologic (Table 4.3) and trip (Table 4.17) parameters for bluehead sucker young-of-the-year (YOY) in the San Juan River (only 1991-96 data used in correlations).

CATCH RATES	UTAH DIVISION OF WILDLIFE RESOURCES DATA													NEW MEXICO DEPARTMENT OF GAME AND FISH DATA	
	RM 2 - 158		RM 116 - 158		REACH 1		REACH 2		REACH 3		REACH 4		REACH 5	RM 116 - 158	RM 77 - 158
	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	SEPT.	AUG.	AUG.
1991	35.7 (7.7)	2.7 (1.0)	84.7 (24.0)	10.9 (3.3)	0.7 (0.4)	0.0 (0.0)	0.5 (0.4)	0.0 (0.1)	15.4 (2.7)	0.5 (0.2)	34.5 (8.6)	0.8 (0.2)	3.6 (0.9)	4.2 (3.1)	2.6 (1.9)
1992	14.7 (9.6)	2.7 (1.2)	50.6 (32.0)	6.7 (3.5)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.6 (0.3)	0.3 (0.1)	3.8 (2.1)	2.9 (1.1)	9.1 (2.3)	19.0 (10.9)	16.3 (7.7)
1993	58.2 (16.4)	8.3 (3.0)	152.5 (48.2)	21.8 (10.1)	2.6 (2.1)	1.7 (0.7)	1.0 (0.6)	0.3 (0.5)	13.2 (3.5)	3.6 (1.6)	88.6 (51.3)	7.0 (3.1)	35.8 (21.1)	150.7 (49.6)	103.8 (31.7)
1994	13.4 (5.6)	1.8 (0.7)	27.9 (12.5)	7.9 (3.4)	0.0 (0.0)	0.0 (0.0)	0.6 (0.4)	0.0 (0.0)	8.4 (7.0)	0.3 (0.1)	30.7 (17.8)	5.8 (2.4)	8.4 (4.8)	10.7 (4.4)	7.2 (2.6)
1995	49.2 (50.1)	4.1 (0.9)	207.5 (157.3)	11.9 (3.2)	0.0 (0.0)	0.0 (0.0)	5.0 (1.7)	0.0 (0.0)	1.6 (1.4)	2.6 (1.4)	207.5 (157.3)	2.5 (1.0)	23.6 (7.3)	309.8 (183.2)	168.8 (94.0)
1996	0.0 (1.8)	0.0 (0.0)	0.2 (5.6)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.2 (0.1)	0.2 (0.1)	0.0 (0.0)	0.0 (0.0)	2.4 (1.6)	1.4 (0.9)
1997	1.4	0.1	6.4	0.5	0.0	0.0	0.0	0.0	1.5	0.0	6.4	0.0	0.5	2.4	4.2
CORRELATIONS	**UTAH DIVISION OF WILDLIFE RESOURCES DATA**													**NEW MEXICO DEPARTMENT OF GAME AND FISH DATA**	
	RM 2 - 158		**RM 116 - 158**		**REACH 1**		**REACH 2**		**REACH 3**		**REACH 4**		**REACH 5**	**RM 116 - 158**	**RM 77 - 158**
	AUG.	**SEPT.**	**AUG.**	**SEPT.**	**AUG.**	**SEPT.**	**AUG.**	**SEPT.**	**AUG.**	**SEPT.**	**AUG.**	**SEPT.**	**SEPT.**	**AUG.**	**AUG.**
Peak Flow	0.58	0.60	0.68	0.59	0.17	0.29	0.64	0.29	-0.02	0.62	0.70	0.71	0.75	0.71	0.73
Peak Date	0.47	0.42	0.68	0.39	-0.02	0.13	0.81	0.13	-0.26	0.59	0.81	0.51	0.66	0.83	0.82
Volume	0.77	0.83	0.81	0.78	0.48	0.60	0.62	0.60	0.08	0.87	0.74	0.72	0.94	0.80	0.85
Days > 2,500 cfs	0.80	0.80	0.88	0.74	0.44	0.54	0.72	0.54	0.00	0.89	0.82	0.58	0.93	0.88	0.92
Days > 5,000 cfs	0.68	0.86	0.66	0.79	0.58	0.72	0.40	0.72	0.11	0.83	0.55	0.83	0.94	0.64	0.71
Days > 8,000 cfs	0.65	0.54	0.80	0.54	0.16	0.28	0.86	0.28	-0.06	0.74	0.91	0.52	0.76	0.90	0.90
Trip Flow	0.69	0.81	0.88	0.82	-0.04	0.59	0.93	0.59	0.01	0.53	0.92	0.56	0.64	N/A	N/A
Days After Peak	-0.61	-0.17	-0.74	-0.08	-0.15	-0.10	-0.81	-0.10	0.01	-0.44	-0.85	-0.40	-0.48	N/A	N/A
Trip Date	-0.62	0.52	-0.65	0.62	-0.22	0.08	-0.68	0.08	-0.39	0.37	-0.72	0.27	0.42	N/A	N/A

N/A = not available
Note: Shaded values indicate significant correlations ($P < 0.05$)

3, 4, and 5), and weakest in the lower portions where catch rates were lower (Reaches 1 and 2). Correlations with days > 8,000 cfs were quite strong for UDWR data in Reach 4 (r=0.91) and for both sets of NMGF data (r=0.90). Similar work by Osmundson and Kaeding (1991) in the Colorado River indicated significant positive correlations between peak annual flow and bluehead sucker larval catch rates (r=0.97, p=0.038) and YOY catch rates (r=0.92, p=0.080). Muth and Nesler (1993) found significant correlations between monthly peak discharge and bluehead sucker YOY catch rates (May r=0.83, June r=0.92) in the Yampa River. Autocorrelation among many hydrologic variables confounds strict interpretation of such results; however, it can be stated that bluehead sucker have exhibited a positive trend in year-class strength during relatively wet years in several Upper Basin rivers.

To determine whether the timing of trips relative to peak discharge and trip flows may have influenced catch rates, Pearson correlation coefficients were calculated for catch rates versus trip flow, trip date, and days after peak for the UDWR data sets. Correlations of YOY bluehead sucker catch rates with trip flow were usually positive and often significant (Table 4.19). There was some speculation that higher flows during particular trips might reduce catch rates by reducing the abundance of preferred habitats such as backwaters, or by increasing the depth of these habitats, that could make seining more difficult. August trip flows, however, were fairly positively correlated with other hydrologic factors such as the number of days >8,000 cfs (r=0.78), which likely contributed to the positive correlations between catch rates and trip flow during August trips. Correlations between runoff variables and summer base flows (end of runoff to October 31) for the 7-year research period ranged from r=0.79 to r=0.95, with most being significant ($p<0.05$). Thus, summer base flows tend to be higher during higher runoff years.

Juvenile and Adult

The strong year-classes produced as a result of above average flows in 1993 and 1995 were evident in the October 1997 electrofishing survey by USFWS (Figure 4.23). Like other large-bodied fishes, bluehead sucker was not captured by boat electrofishing in appreciable numbers in the San Juan River until they reached at least 2 years of age. Thus, the October 1997 survey was the first survey during the study in which the two strong year-classes of bluehead sucker produced as a result of research flows were both detectable in the juvenile and adult populations.

As with flannelmouth sucker, bluehead sucker CPUE during October surveys were significantly negatively correlated with trip flows (Figure 4.24). An analysis of covariance was performed to determine whether there were significant differences in CPUE given the negative correlation with flow. Results indicated that total bluehead sucker CPUE (F=9.02, $F_{0.05(1),1,10}$=4.96) and juvenile CPUE (F=6.86) differed between years, but adult CPUE did not (F=4.56). However, to allow for valid comparisons between years, it was necessary to standardize fall catch data by the river reach commonly sampled each year (RM 52 to 158). Many bluehead sucker, however, resided in the river upstream of RM 158 (Ryden and Pfeifer 1996a). In fact, at times at least half of the bluehead sucker sample was found between RM 159 and 180 (Animas River confluence). These factors complicate assessments of changes in the size of the bluehead sucker population.

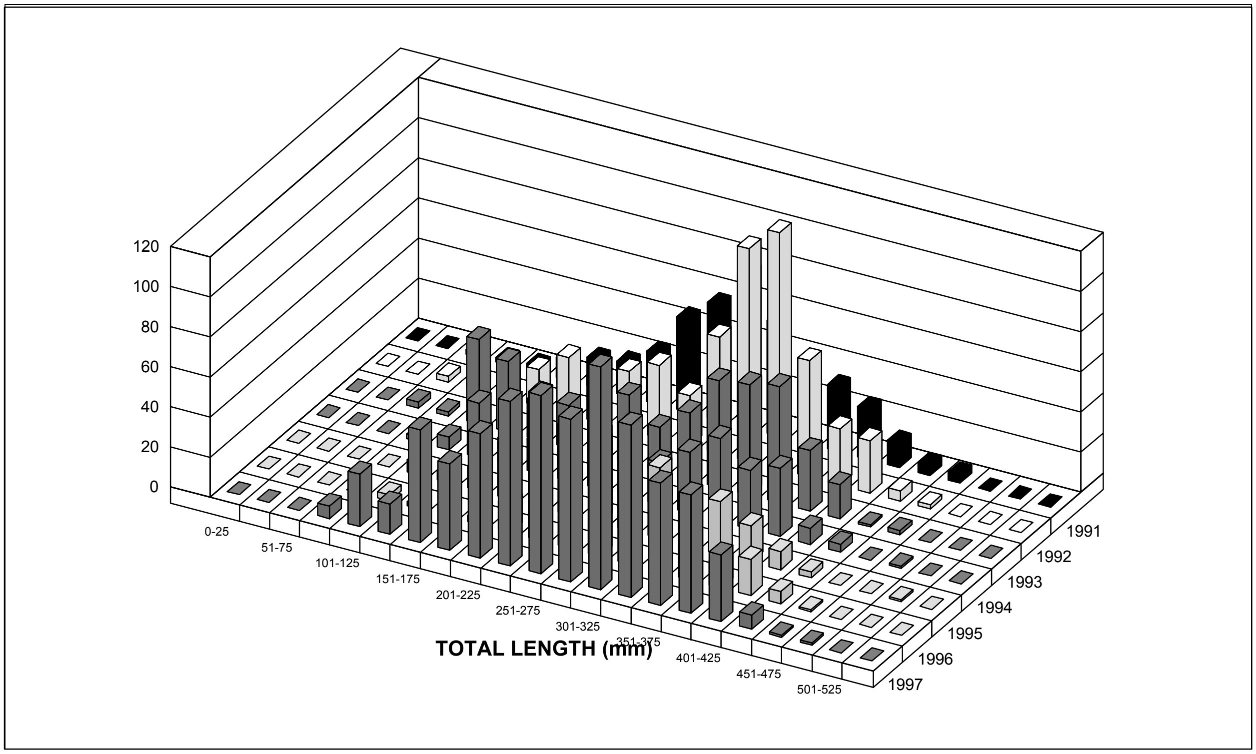


Figure 4.23. Length-frequency histogram for bluehead sucker collected during October USFWS electrofishing surveys on the San Juan River (RM 52 to 158).

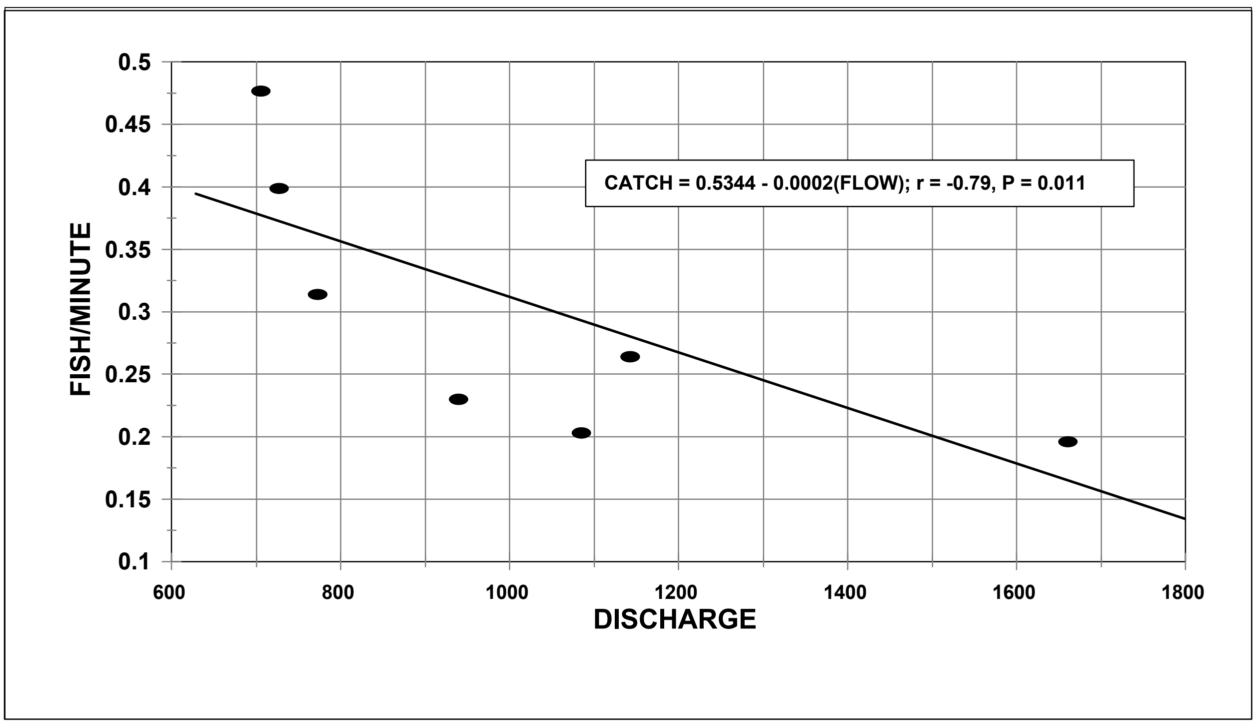


Figure 4.24. Regression line fitted to plot of average catch rates of bluehead sucker collected during October (1991 to 1997) USFWS electrofishing surveys on the San Juan River versus sampling trip discharge (as measured at USGS gage 09371010, Four Corners, New Mexico).

To detect changes in the bluehead sucker population, it was necessary to focus on the upper segment of the survey area (RM 159 to 180) where this species is most abundant. Using the October 1993, 1994, 1996, and 1997 surveys for which catch rates in this upper river segment were available, an increasing population of bluehead sucker (juvenile+adult) through time was indicated (Figure 4.25). A one-way ANOVA was conducted on these data followed by a Student-Newman-Keuls multiple range test to assess differences between years. The results indicated that catch rates in 1994, 1996, and 1997 were all significantly greater than in 1993 ($p<0.001$). Catch rates were also higher in 1997 than 1994 ($p<0.005$). These data suggested that the perceived increases in bluehead sucker reproduction (as indicated by greater numbers of YOY in UDWR and NMGF sampling efforts) that followed higher runoff events were being reflected in the juvenile and adult population in subsequent years in the upper river reach where these fishes were most abundant.

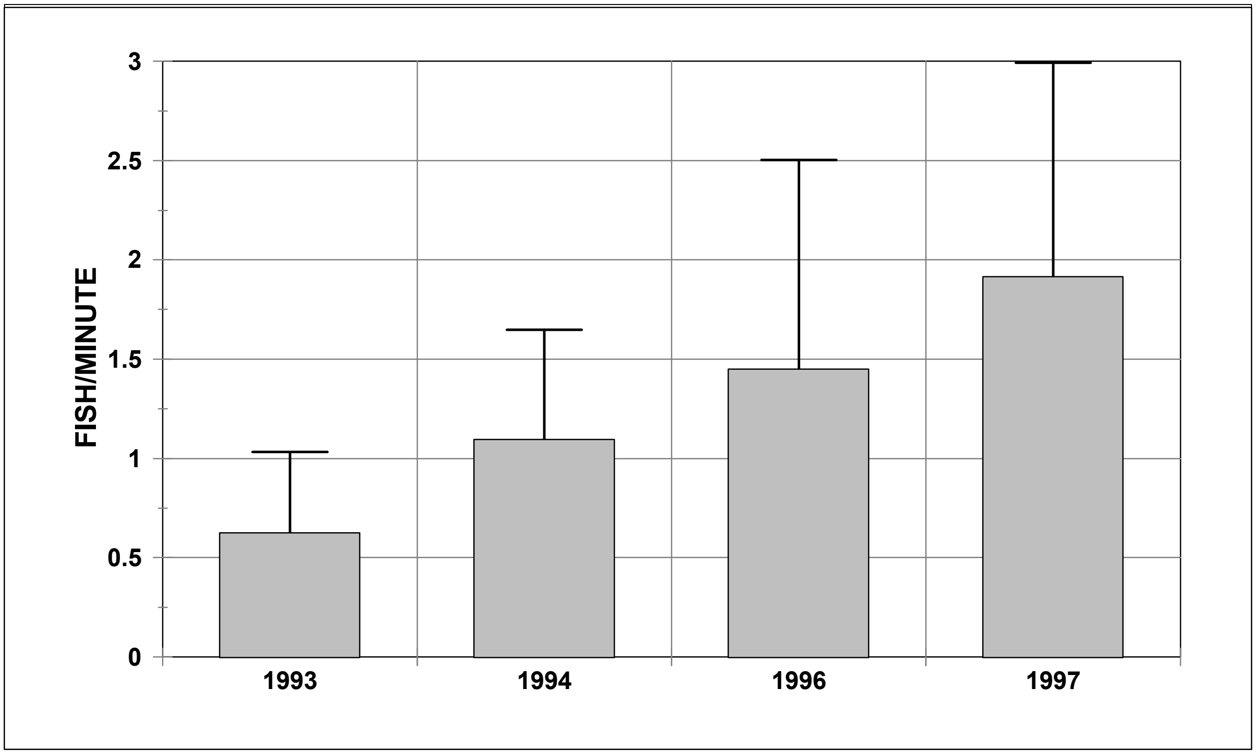


Figure 4.25. Average catch rates (± standard deviation) of bluehead sucker during October USFWS electrofishing surveys on the San Juan River (RM 159 to 180).

It has been suggested that high runoff flows may simply increase the amount of larval drift that occurs, thus displacing larval bluehead sucker from upper reaches of the river (Reach 5) where reproducing adults were concentrated and into lower reaches where sampling takes place. Although this may be occurring, the preliminary evidence that recruitment to the spawning population has been increasing since 1993 would indicate that the net effect on this species is still positive.

Similar to flannelmouth sucker, bluehead sucker also showed an increased condition with more stable fall to spring base flows during 1993-94 and 1995-96, and exhibited increased condition over the same period during 1994-95. This increased condition likewise cannot be attributed to ripening adults prior to the spawn, since a very similar pattern was observed for juveniles (Figures 4.26 and 4.27). The bluehead sucker is a grazer whose mouth is designed for scraping the larger sized substrate characteristic of relatively swift habitats like riffles, whereas flannelmouth sucker possess large, fleshy lips designed for foraging in softer substrates (Woodling 1985). It is conceivable that the swifter habitats in which bluehead sucker forage were less susceptible to potential reductions in productivity as a result of perturbations during the 1994-95 fall to spring period. Also, bluehead sucker are more abundant in the upper reaches of the river that are less exposed to perturbations from storm events. In addition, and as discussed above for flannelmouth sucker, the overall biological productivity of the riffle and run habitats has likely improved since the initiation of the research flows. These factors might explain why bluehead sucker improved in condition during 1994-95 and flannelmouth sucker did not. Both species, however, showed a positive increase in condition with stable post-runoff flows only after the high runoff in 1993. These high flows caused substantial redistribution and cleaning of larger substrates (Bliesner and Lamarra 1994), and likely improved habitat quality and benthic invertebrate production substantially over that which existed following several years of severe drought conditions (1988 to 1991).

In summary, bluehead sucker showed significant positive trends in reproductive success during high spring runoff years, but because of autocorrelation between hydrologic variables, the exact attribute of runoff to which these fishes are responding is not known. It is likely that the August and September seining data used in the above analysis were more accurate for bluehead sucker than flannelmouth sucker because of a slightly later spawning time for bluehead sucker. This results in more bluehead sucker YOY being present in low-velocity habitats in August and September than flannelmouth sucker YOY (see Chapter 3 for more details on life history differences between these two species).

Speckled Dace

The same analysis described for flannelmouth sucker and bluehead sucker was performed for speckled dace using both UDWR and NMGF data. Table 4.20 shows the results of the analyses for the different data sets. Similar to bluehead sucker, speckled dace showed positive correlations with spring runoff volume and days above 2,500 and 8,000 cfs only in the upper river main channel habitats (UDWR data, RM 116 to 158) and in upper river secondary channel habitats (NMFG data) in August. However, UDWR September collections did not show the same correlations. As noted in Chapter 3, speckled dace are generally found in riffles; however, they use low-velocity habitats such as those seined in August and September, primarily as young fish. As they become larger, speckled dace move into habitats with more current. This habitat shift may explain why August data showed relationships with spring flow but September data did not. Young-of-the-year speckled dace may have still occupied low-velocity habitats in August but then moved from those habitats by September. This is similar to what also occurs with both flannelmouth sucker and bluehead sucker, but the timing is slightly different for all three of these species.

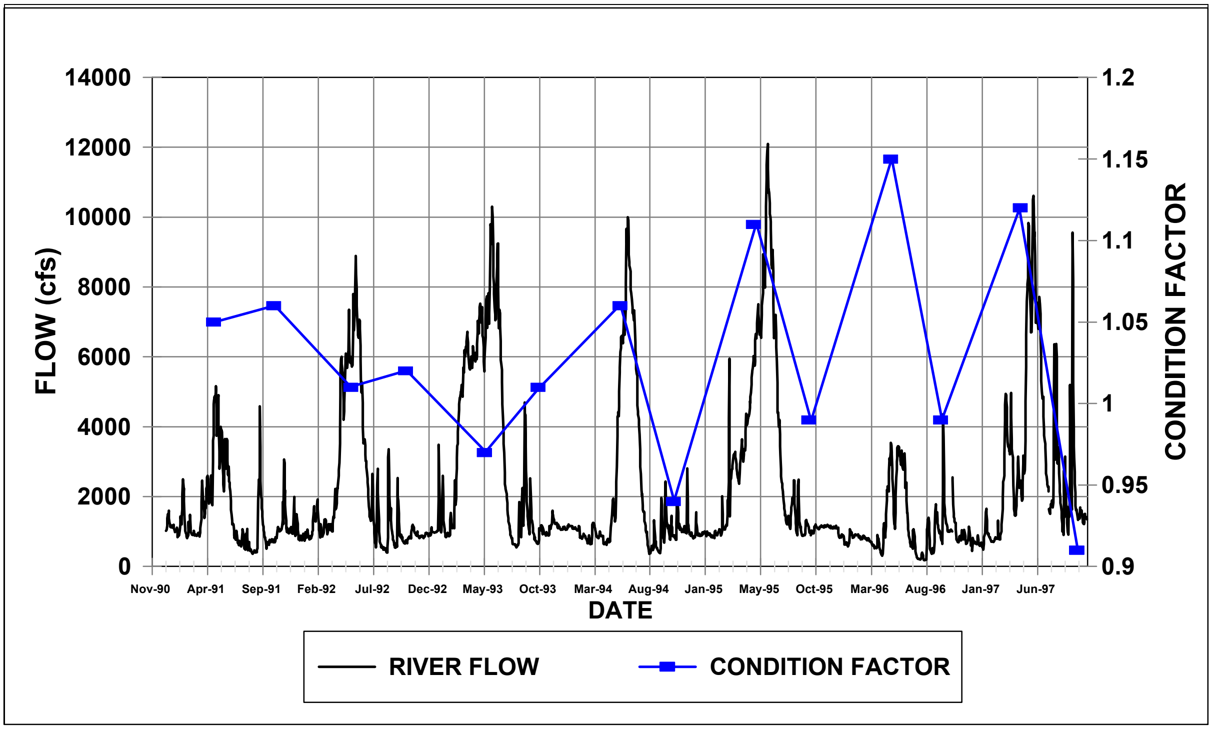


Figure 4.26. San Juan River discharge (as measured at USGS gage 09371010, Four Corners, New Mexico) versus average juvenile bluehead sucker condition. Condition factor was determined using data collected by USFWS electrofishing surveys (RM 52 to 158) within designated reaches.

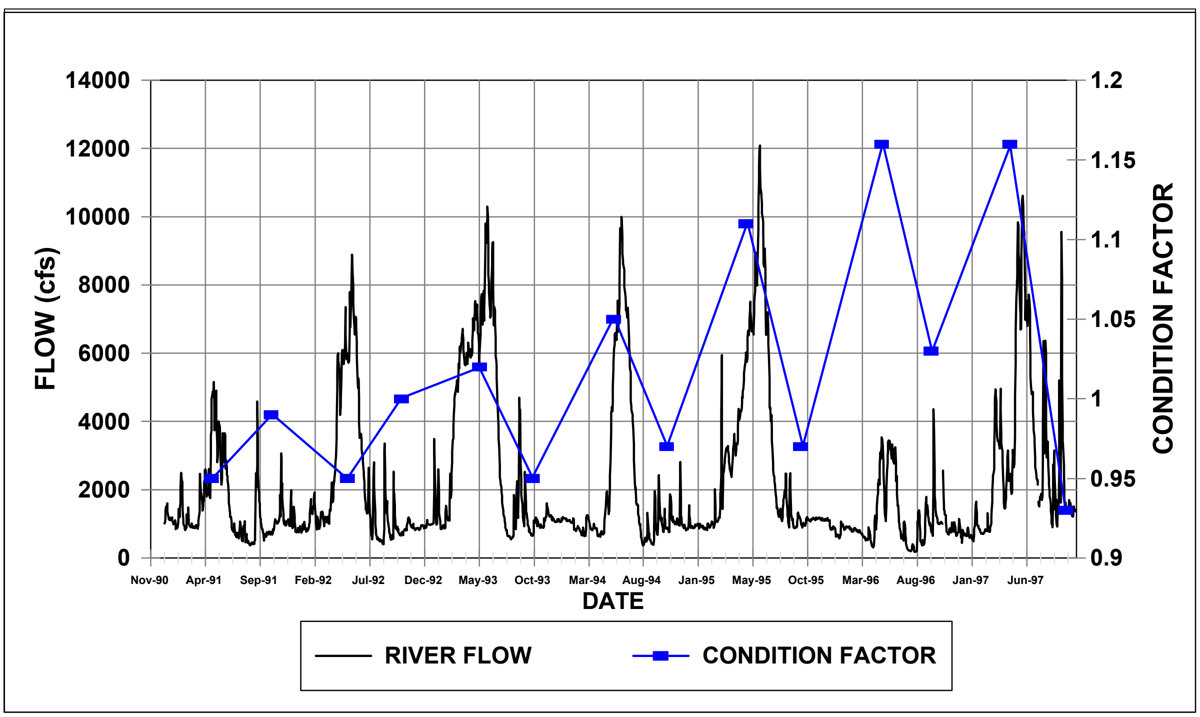


Figure 4.27. San Juan River discharge (as measured at USGS gage 09371010, Four Corners, NM) versus average adult bluehead sucker condition. Condition factor was determined using data collected by USFWS electrofishing surveys (RM 52 to 158) within designated reaches.

Table 4.20. Average catch rates (number/100 m^2) with standard errors (in parentheses) and Pearson correlation coefficients (*r* values) of various hydrologic (Table 4.3) and trip (Table 4.17) parameters for speckled dace in the San Juan River (only 1991-96 data used in correlations).

CATCH RATES	UTAH DIVISION OF WILDLIFE RESOURCES DATA													NEW MEXICO DEPARTMENT OF GAME AND FISH DATA	
	RM 2 - 158		RM 116 - 158		REACH 1		REACH 2		REACH 3		REACH 4		REACH 5	RM 116 - 158	RM 77 - 158
	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	SEPT.	AUG.	AUG.
1991	67.2 (10.0)	12.1 (2.0)	38.3 (11.7)	21.7 (4.9)	17.2 (8.2)	6.6 (2.6)	38.7 (27.1)	2.6 (0.8)	132.0 (18.2)	9.5 (3.6)	56.8 (7.6)	25.8 (4.6)	25.7 (7.1)	22.5 (10.1)	23.3 (6.0)
1992	6.5 (1.2)	10.3 (2.3)	6.8 (3.5)	14.8 (3.5)	5.4 (1.2)	5.2 (5.7)	5.9 (1.3)	13.2 (8.4)	7.8 (2.1)	6.5 (1.1)	8.5 (3.9)	23.3 (5.2)	3.3 (0.9)	30.5 (7.1)	30.1 (6.5)
1993	53.7 (13.0)	95.3 (27.7)	104.2 (28.1)	113.5 (79.9)	4.5 (4.1)	39.9 (13.2)	4.5 (2.1)	32.2 (7.0)	34.1 (10.5)	121.2 (19.8)	115.8 (49.5)	130.1 (75.8)	157.3 (171.6)	334.9 (107.1)	311.9 (76.3)
1994	38.8 (18.2)	42.4 (11.2)	31.9 (10.7)	167.6 (50.1)	20.6 (17.7)	9.4 (11.1)	23.9 (8.7)	9.5 (2.6)	140.1 (107.6)	17.8 (4.9)	27.2 (13.4)	128.7 (57.5)	160.0 (57.2)	297.6 (131.3)	220.4 (77.7)
1995	26.5 (33.8)	16.4 (3.1)	92.2 (104.5)	37.1 (9.4)	0.5 (0.4)	1.3 (0.5)	4.7 (2.1)	1.1 (0.6)	18.0 (7.0)	11.5 (7.7)	92.2 (104.5)	19.1 (5.3)	73.6 (21.1)	216.1 (68.4)	267.4 (62.0)
1996	0.2 (0.3)	0.8 (0.4)	0.5 (0.8)	0.9 (0.2)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.3 (0.1)	0.5 (0.6)	2.0 (1.5)	0.5 (0.3)	0.8 (0.2)	0.6 (0.3)	15.1 (5.5)	11.2 (3.3)
1997	19.5	10.5	65.6	16.0	5.5	15.5	11.4	3.0	20.4	9.7	65.6	15.0	17.0	29.5	23.5

CORRELATIONS	UTAH DIVISION OF WILDLIFE RESOURCES DATA													NEW MEXICO DEPARTMENT OF GAME AND FISH DATA	
	RM 2 - 158		RM 116 - 158		REACH 1		REACH 2		REACH 3		REACH 4		REACH 5	RM 116 - 158	RM 77 - 158
	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	SEPT.	AUG.	AUG.
Peak Flow	0.14	0.49	0.68	0.53	-0.04	0.33	-0.21	0.41	-0.05	0.36	0.58	0.49	0.64	0.76	0.83
Peak Date	-0.06	0.31	0.64	0.40	-0.23	0.11	-0.37	0.15	-0.19	0.19	0.51	0.29	0.53	0.69	0.81
Volume	0.21	0.67	0.85	0.43	-0.27	0.58	-0.36	0.61	-0.23	0.64	0.78	0.49	0.63	0.77	0.88
Days > 2,500 cfs	0.15	0.57	0.86	0.28	-0.39	0.49	-0.42	0.51	-0.34	0.57	0.80	0.33	0.51	0.68	0.83
Days > 5,000 cfs	0.18	0.79	0.77	0.52	-0.24	0.72	-0.41	0.78	-0.25	0.75	0.70	0.62	0.68	0.80	0.85
Days > 8,000 cfs	0.14	0.43	0.81	0.43	-0.22	0.25	-0.29	0.20	-0.11	0.34	0.70	0.35	0.62	0.77	0.90
Trip Flow	0.27	0.59	0.67	0.21	-0.19	0.67	0.04	0.72	-0.06	0.61	0.64	0.40	0.32	N/A	N/A
Days After Peak	-0.18	-0.22	-0.78	-0.36	0.11	-0.03	0.22	-0.07	0.01	-0.13	-0.67	-0.24	-0.46	N/A	N/A
Trip Date	-0.56	0.19	-0.67	0.12	0.00	0.17	-0.25	0.17	-0.25	0.14	-0.68	0.27	0.21	N/A	N/A

N/A = not available
Note: Shaded areas values indicate significant correlations (P < 0.05)

A more-intensive analysis of seasonal sampling data from San Juan River secondary channels between Shiprock and Bluff was conducted to look more closely at speckled dace relationships. Spring sampling involved electrofishing. Summer (August) and autumn (October) samples were obtained with seines (Propst and Hobbes 1993, 1994, 1995, 1996). Linear regression was used to compare density of speckled dace to attributes of flow. ANOVA was used to compare density of speckled dace within reaches among years and within years among reaches.

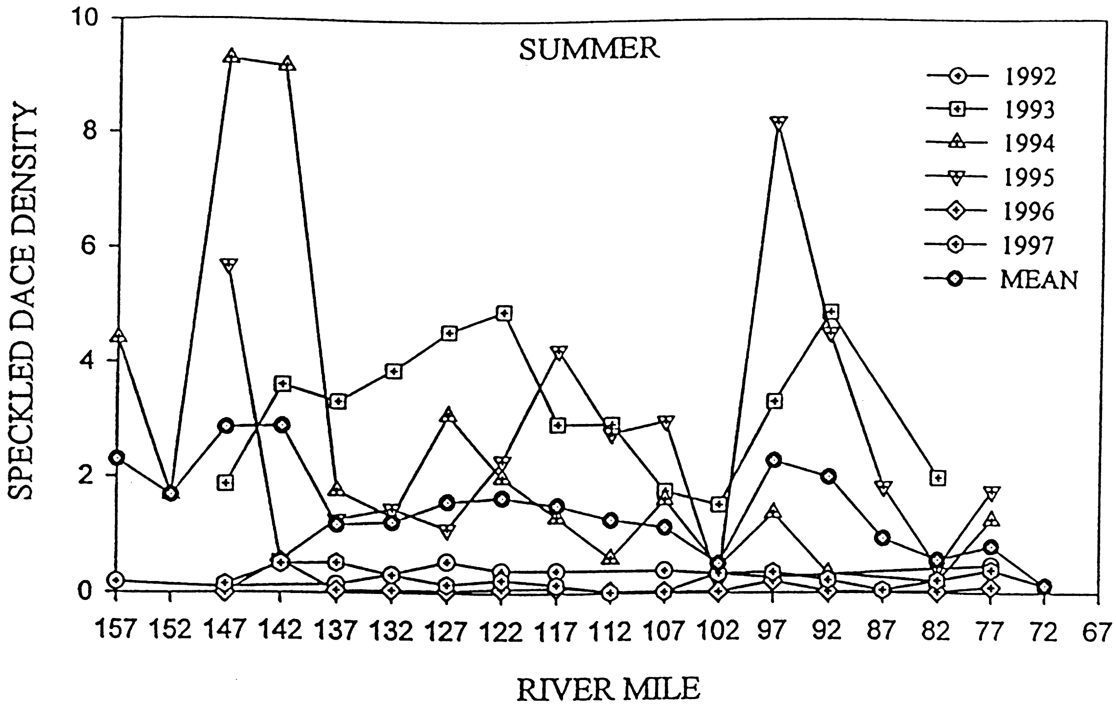
Data obtained during these studies indicate that spring runoff had a strong influence on the speckled dace populations in San Juan River secondary channels (Table 4.21). In most years of average to high runoff (1993, 1994, 1995), speckled dace densities were > 1.5 fish/m^2 during summer, and autumn densities likewise remained comparatively high (Figure 4.28). However, if spring runoff was low (1992, 1996), summer and autumn densities were low (< 0.15 fish/m^2) (Figure 4.28). Data from 1997 (a high spring runoff year) indicated that abundance suppression in a preceding year can strongly affect densities in a subsequent year, although such a suppression was not seen in 1993 following the low to moderate flows of 1988 to 1992. It is not known if speckled dace densities will increase in 1998 to levels similar to those found in secondary channels prior to 1996. The data from samples prior to 1996 suggest that average to high spring runoff is important or perhaps essential to sustaining viable populations of speckled dace in the San Juan River. Speckled dace is a comparatively short-lived fish (< 36 months average) and spawn in their first year (Moyle 1976). Loss of a year-class because of low flows could greatly diminish reproduction and recruitment in subsequent years. The data from San Juan River secondary channels are insufficient to ascertain if the apparent loss of the 1996 year-class will have a long-term effect on the population. Low spring flows from 1988 to 1992 did not have a lasting effect on population levels, so it is likely speckled dace numbers will rebound from the lows of 1996 and 1997.

Table 4.21. Correlation of spring runoff attributes with speckled dace summer density in San Juan River secondary channels.

	Mean Discharge		Discharge Volume		Discharge Peak		Discharge Duration		Days Pre-peak		Days Post-peak		Days $3,000 cfs		Days $5,000 cfs		Days $8,000 cfs	
Reach	*r*	p	*r*	p	*r*	p	*r*	p	*r*	p	*r*	p	*r*	p	*r*	p	*r*	p
5	0.74	#.06	0.37	#.42	0.37	#.42	0.08	#.87	0.15	#.74	0.19	#.68	0.47	#.28	0.72	#.07	0.19	#.68
4	0.84	#.02	0.73	#.06	0.48	#.27	0.49	#.27	0.61	#.15	0.11	#.82	0.83	#.02	0.87	#.01	0.40	#.37
3	0.73	#.06	0.80	#.03	0.55	#.20	0.65	#.11	0.75	#.05	.05	#.91	0.86	#.01	0.76	#.05	.58	#.18

Note: Shaded cells indicate a significant (p# 0.05) relationship.

In contrast to the apparent importance of spring runoff to maintenance of a strong speckled dace population, summer flows seemingly have little effect on the species (Table 4.22). Of the summer flow attributes evaluated, only number of days summer flow was < 500 cfs had a negative effect on speckled dace autumn density, and this relationship was not statistically significant in any geomorphic reach. The broad range of the species and its ubiquitous nature in the West indicate its



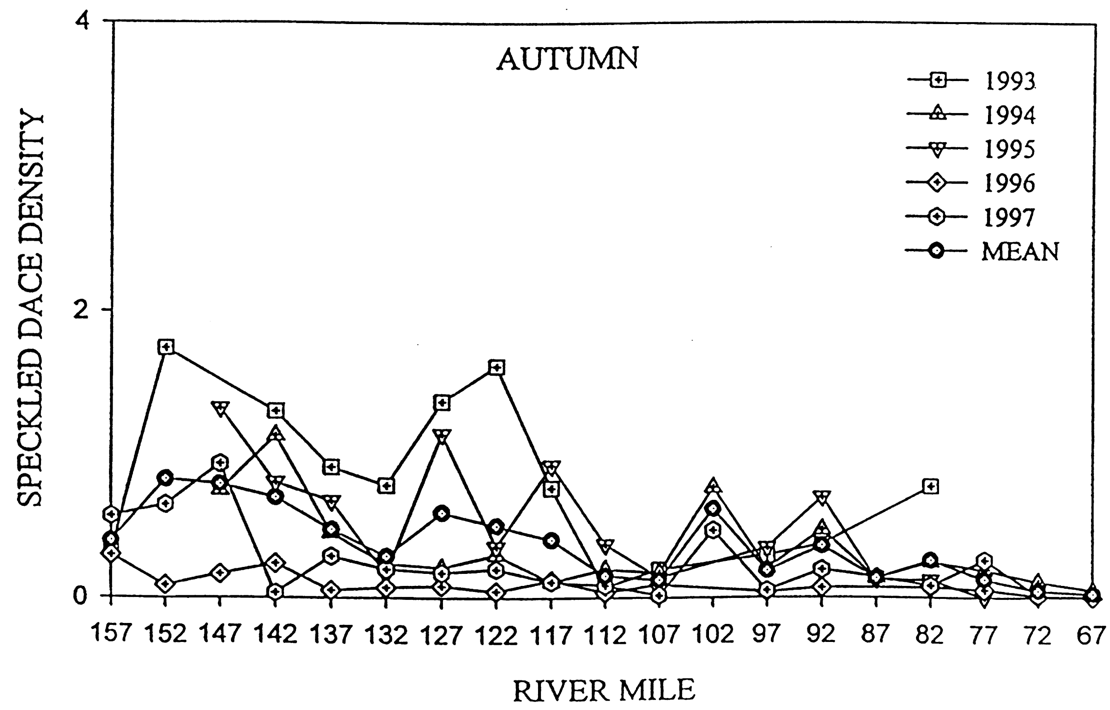


Figure 4.28. Density of speckled dace in San Juan River secondary channels (5-mile increments), 1992 to 1997, New Mexico, Colorado, and Utah.

Table 4.22. Correlation of summer low flow attributes with speckled dace autumn density in San Juan River secondary channels.

	Mean Discharge		Spike Volume		Spike Mean		Days #500 cfs		Days #1,000 cfs		Days $1,000 cfs		Days $2,000 cfs	
Reach	*r*	p	*r*	p	*r*	p	*r*	p	*r*	p	*r*	p	*r*	p
5	0.15	#.81	0.13	#.83	0.03	#.96	-0.64	#.24	-0.26	#.68	0.42	#.48	0.05	#.93
4	0.05	#.94	0.13	#.84	0.08	#.90	-0.50	#.39	-0.08	#.89	0.36	#.55	0.04	#.95
3	0.12	#.84	0.05	#.93	-0.08	#.90	-0.62	#.26	-0.27	#.66	0.36	#.55	0.03	#.96

rather broad environmental tolerances. John (1964) reported speckled dace surviving in intermittent streams with water temperatures of 33E C and diurnal fluctuations of 10 to 15E C. Although water temperature of San Juan River secondary channels rarely, if ever, exceeds 30E C, flow in these habitats is frequently intermittent during summer months.

Larval drift studies also indicated that speckled dace have better reproductive success during high runoff years during the research period than low runoff years. Maximum daily larval catch rates for larval speckled dace during years with runoff flows with more than 25 days greater than 8,000 cfs, and for years with more than 8 days above10,000 cfs, were nearly double those of years with less than 5 days of either flow.

In summary, high spring runoff flows appear to enhance speckled dace abundance, similar to that observed for bluehead sucker. Flows greater than 8,000 cfs are correlated with higher numbers of speckled dace in main channel low-velocity habitats in summer (Table 4.20), and higher numbers of drifting larvae. Flows greater than 5,000 cfs appear to benefit speckled dace in secondary channels (Tables 4.20 and 4.21). Years with relatively long runoff periods (1993) had the highest summer densities in secondary channels, and higher numbers of drifting larvae.

Nonnative Species

Nonnative species are primarily a concern in the San Juan River because of their potential to compete with, and/or prey on, native species. The following sections describe analyses that were performed to determine if flow characteristics were related to increases or declines in nonnative fish abundance.

Channel Catfish and Common Carp

Channel catfish and common carp were the most-abundant and widely distributed nonnative species collected during adult monitoring (electrofishing) surveys since 1991 (Buntjer and Brooks 1996, Ryden and Pfeifer 1996a). Research efforts on the San Juan River from 1991 to 1997 were combined to evaluate the trends in abundance of nonnative channel catfish and common carp collected from main channel (RM 158 to 53) and secondary channel habitats (RM 158 to 77) and their relation to flow. These studies have shown that nonnative fishes have comprised from 14.7% (1994) to 41.8% (1997) of all fishes collected by main channel electrofishing (Figure 4.29).

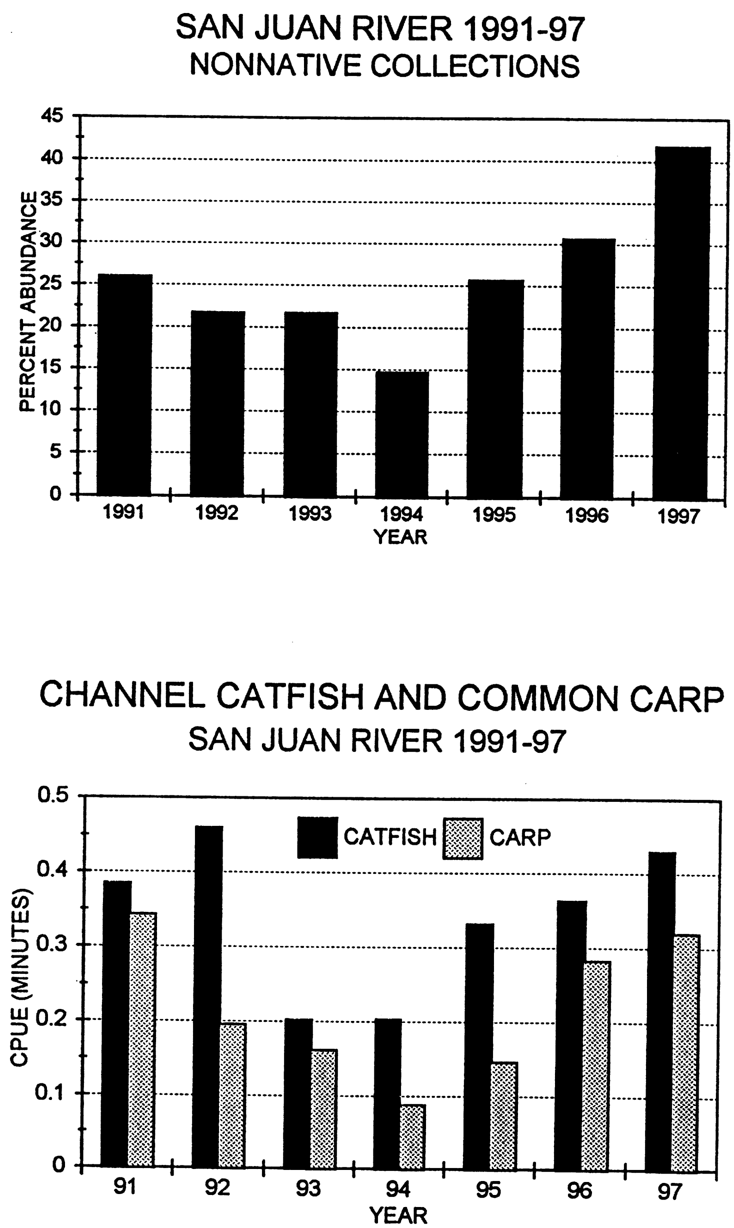


Figure 4.29. Relative abundance of nonnative fishes (top) and catch-per-unit-effort (CPUE) (number of fish/minute) for channel catfish and common carp (bottom) collected during May and October electrofishing surveys of the San Juan River, 1991 to 1997.

Changes in catch rates for both channel catfish and common carp have been observed in the San Juan River since 1991 (Figure 4.29). Channel catfish catch rates in 1997 were higher than observed in 1991 and 1993 to 1996, and only slightly less than those observed in 1992. Common carp catch rates declined each year, from a high in 1991 to a low in 1994, then increased each year through 1997. The changes were reflected in both juveniles and adults of both species (Figures 4.30 and 4.31). Juvenile channel catfish catch rates have typically been highest in Reaches 2 and 3 (RM 105 to 53) and highest for adult channel catfish in Reaches 4 and 5 (RM 166 to 131) (Figure 4.32). Juvenile carp catch rates were generally very low in main channel habitats, but they were highest in Reach 4 (RM 131 to 106) and highest for adult carp in Reaches 5 and 6 (RM 180 to 131) (Figure 4.32). The changes in juvenile and adult catch rates for both channel catfish and carp were attributed to differences in year-class strength, particularly during 1993 through 1995 (Buntjer et al. 1994, Archer et al. 1996). Strong cohorts of channel catfish and common carp observed prior to 1993 were not observed following the high spring runoff in 1993, particularly for channel catfish. In addition, 1992 through 1994 appears to have been a transition period for adult carp because their catch rates declined. However, since 1994, common carp and channel catfish abundance increased.

Catch rates of YOY channel catfish in main channel habitats during fall 1994 (Figure 4.33) were similar to those during 1993, which had a strong year-class (Buntjer et al. 1994). Catch rates of YOY channel catfish in secondary channels were also highest in 1993 and 1994, and much higher than in main channel habitats (Figure 4.33). Although catch rates for YOY channel catfish were much lower in main channel habitats in 1995, catch rates in secondary channels were still relatively high. These results may indicate secondary channels largely contributed to a strong 1995 year-class of channel catfish in a year of high summer flows. Similar trends were observed for YOY common carp in both main channel and secondary channel habitats in 1993 and 1994, although catch rates for YOY carp were much lower than for channel catfish. There did not appear to be a strong year-class of YOY carp during 1995 (a high-flow year) in either main channel or secondary channel habitats.

Common carp and channel catfish catch rates increased in 1997 and were only slightly less than catch rates observed in 1991 and 1992, respectively (Figure 4.30). The increase in catch rates observed during 1997 collections was because of a large increase during spring collections (Figure 4.31). There are two likely reasons for the increase in spring 1997 catch rates. First, YOY catch rates for common carp and channel catfish were highest in 1993 and 1994 in both main channel and secondary channel habitats, indicating strong age-3 and age-4 year-classes in 1997. Second, sampling efficiency may have increased at lower flows: spring flows in 1997 at time of sampling were the lowest during this study. Pearson correlation coefficients (*r* values) were calculated using mean flow at time of sampling and overall catch rate per trip. Carp catch rates showed a significant negative correlation (r=-0.94, p=0.009) with flow during spring sampling. Channel catfish catch rates also showed a negative correlation (r= -0.74, p=0.09) with spring flow. There was no relation between flows and catch rates for either carp or catfish during fall sampling, though flows during fall sampling were generally lower and more consistent among years.

Larval drift sampling in the San Juan River found an inverse relationship between catch of larval channel catfish and runoff volume and duration. Catch rates (number/100m^3) of larval channel

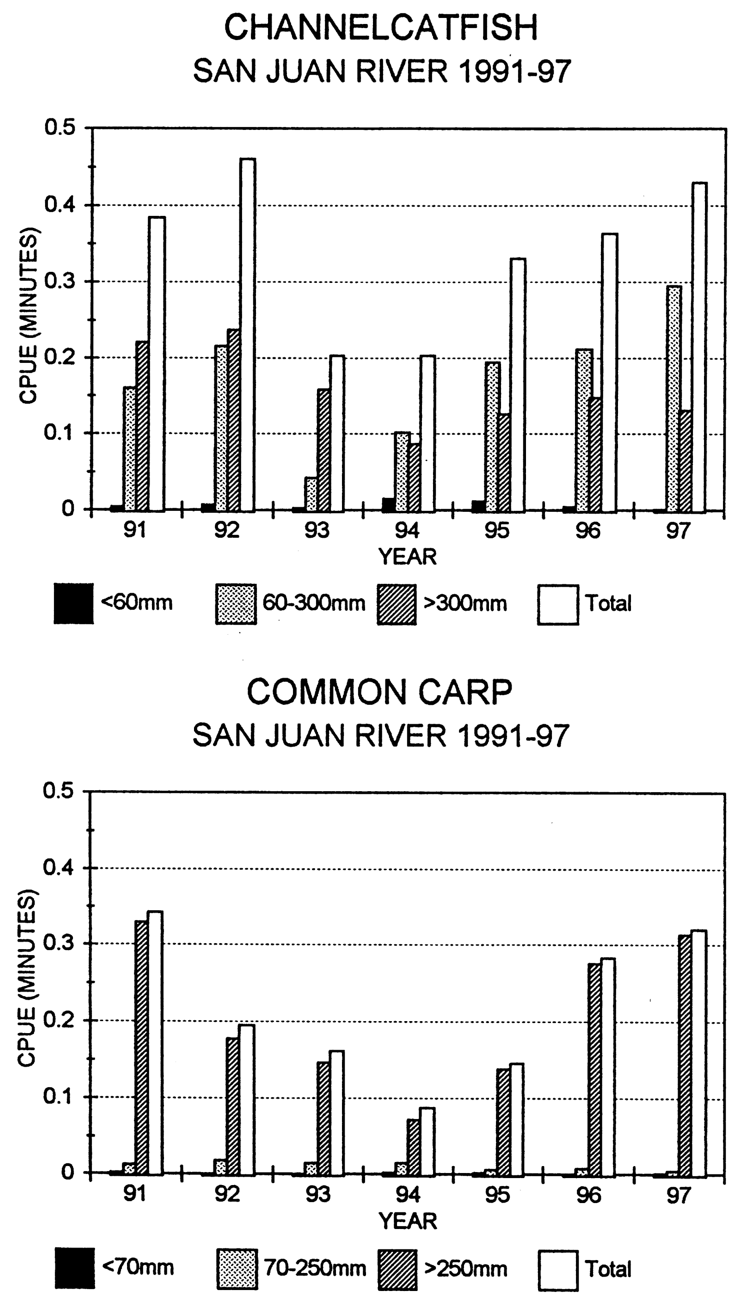
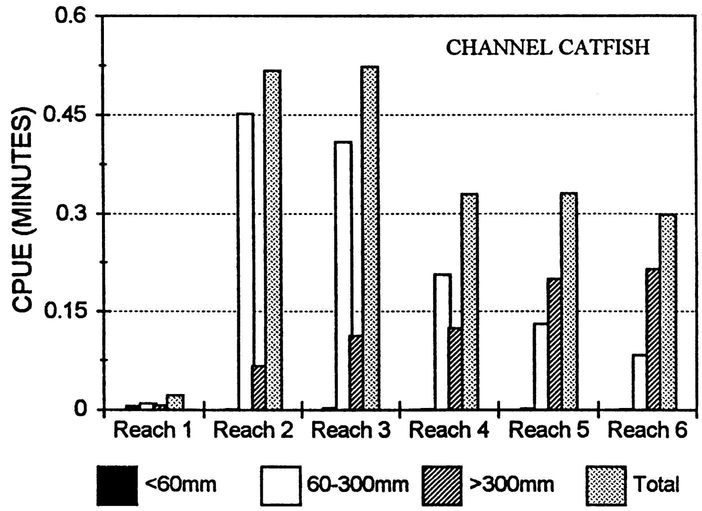


Figure 4.30. Catch-per-unit-effort (CPUE) (number of fish/minute) for channel catfish (top) and common carp (bottom) by size-class and year collected during May and October electrofishing surveys of the San Juan River, 1991 to 1997.

CHANNEL CATFISH
1997 CATCH RATES



COMMON CARP
1997 CATCH RATES

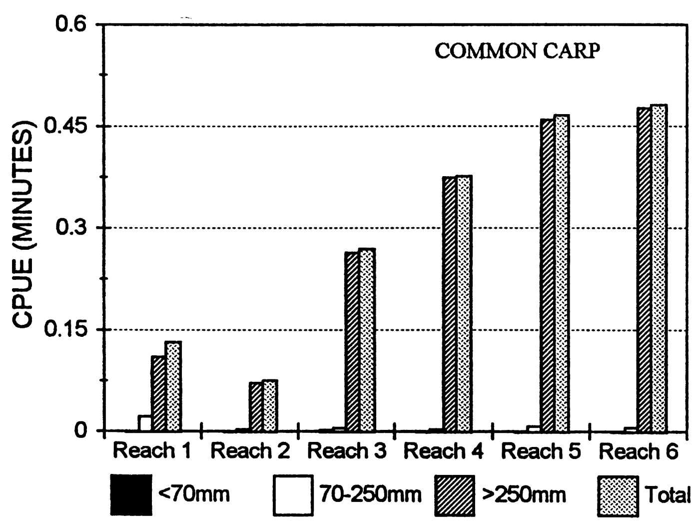
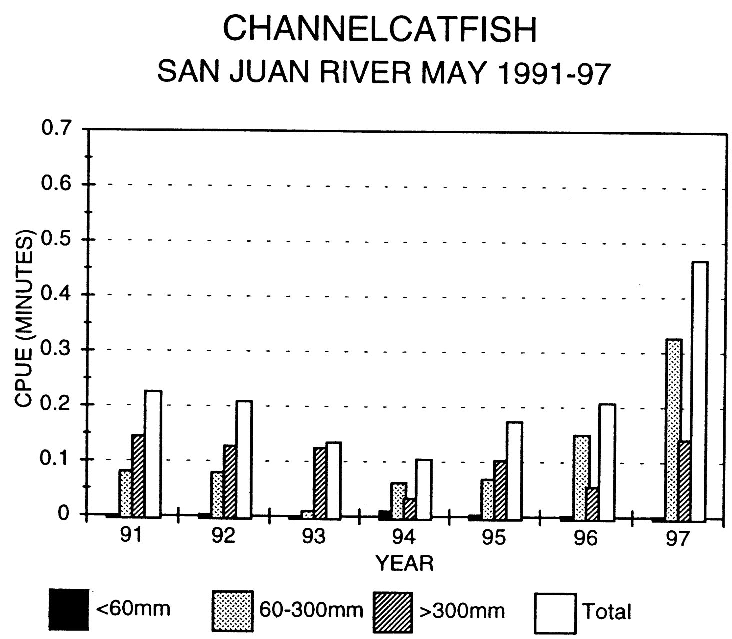


Figure 4.31. Catch-per-unit-effort (CPUE) (number of fish/minute) for channel catfish (top) and common carp (bottom) by size-class and year collected during May and October electrofishing surveys of the San Juan River, 1997.



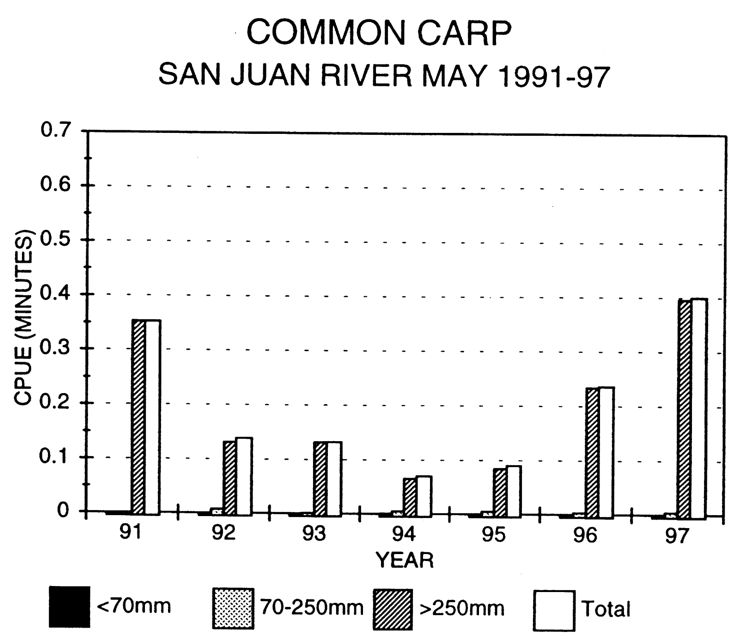
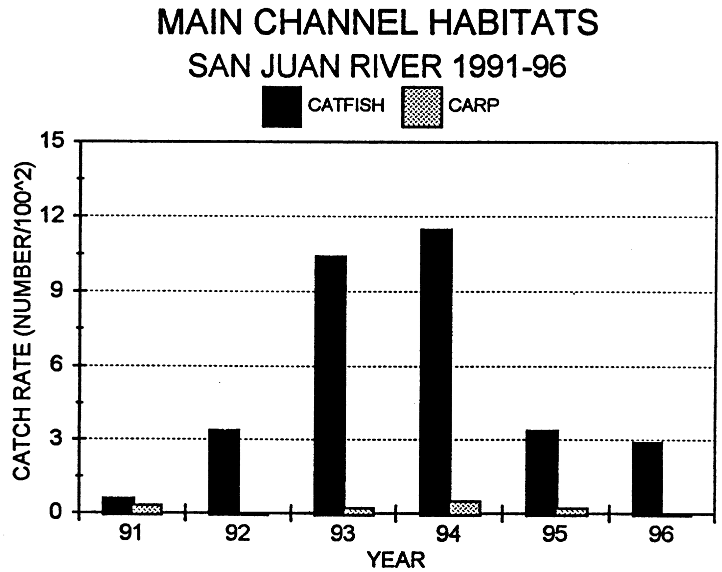


Figure 4.32. Catch-per-unit-effort (CPUE) (number of fish/minute) for channel catfish (top) and common carp (bottom) by size-class and year collected during May electrofishing surveys of the San Juan River, 1991 to 1997.



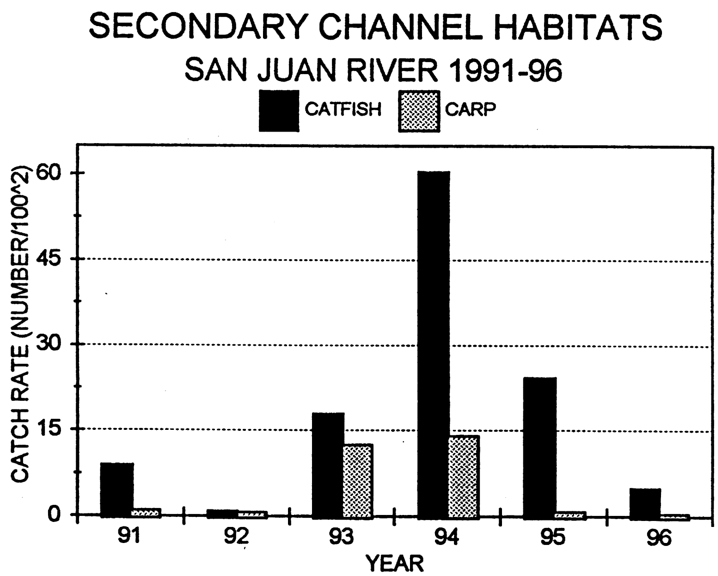


Figure 4.33. Catch rates (number/100m^2) for young-of-the-year (YOY) channel catfish and common carp collected in main channel habitats (top) in autumn and secondary channel habitats in August (bottom) during seining surveys of the San Juan River, 1991 to 1996.

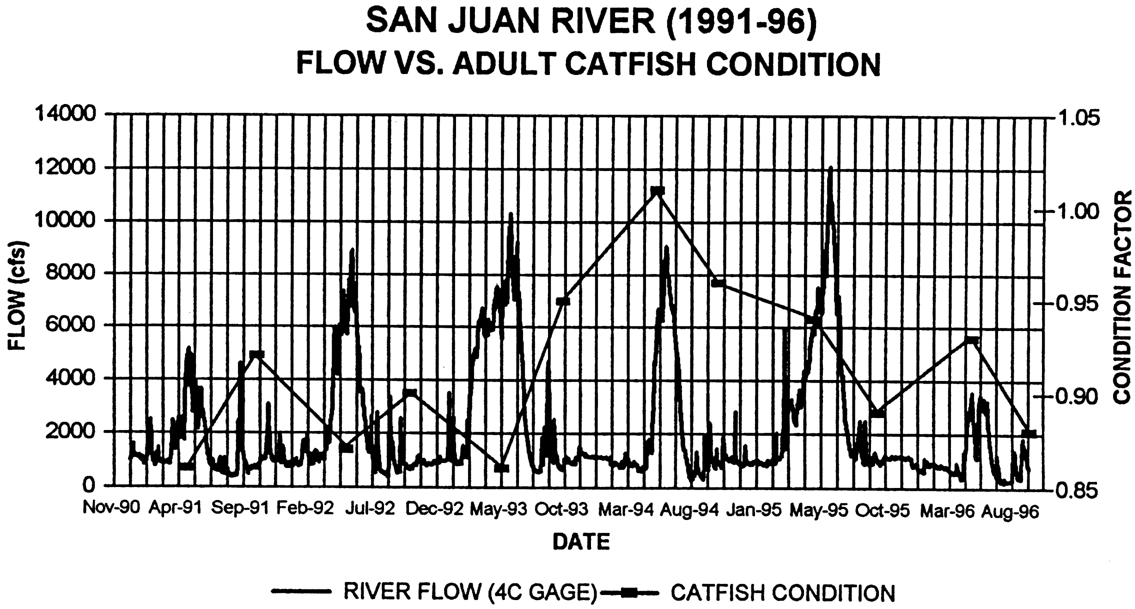
catfish were lowest during years with extended runoff flows greater than 5,000 cfs, and highest during years with extended summer flows less than 500 cfs. Although preliminary, these data suggest a relationship between channel catfish reproductive success as measured by larval drift and flow, with lower flow years being better for reproductive success than higher flow years.

Changes in size-class distributions for channel catfish and common carp have been observed since 1991, particularly for channel catfish (Figure 4.30). Between 1991 and 1993, channel catfish collections were composed predominately of adults. Juvenile and adult catch rates were similar in 1994. During 1995 through 1997, the channel catfish catch was composed predominately of juveniles. Juvenile catch rates have increased each year since 1994, further indicating good reproduction and recruitment of 1993, 1994, and 1995 year-classes. Because juvenile carp catch rates are low, common carp collections have been composed predominately of adults each year. Although there was no direct relationship observed between spring runoff and abundance of YOY channel catfish and common carp, abundance of these fishes has increased since 1993 when high spring releases began.

Temporal changes in fish condition ($c = 100w/l^3$) were observed at various fall to spring base flows. Adult channel catfish and adult common carp both showed improved condition following the fall to spring periods in 1993 to 1994 and 1995 to 1996 when base flows were stable (Figure 4.34).

Primary and secondary productivity increases during prolonged periods of stable flows, particularly in run and riffle type habitats (Bliesner and Lamarra 1996). The improved condition of adult channel catfish and common carp was likely because of the increased food supply. Juvenile channel catfish condition, however, did not respond consistently to any portion of the annual hydrograph, and too few juvenile carp were collected to determine a meaningful relationship.

Although a direct relationship between spring runoff and abundance of YOY channel catfish and common carp in the San Juan River was not detected, there does appear to be a relationship between spring condition of adults and numbers of YOY in the fall. As condition of adult channel catfish and common carp increases in the spring, abundance of YOY catfish and carp increases in the summer and fall in both main channel and secondary channel habitats. Condition of channel catfish in spring was positively correlated (r=0.88, p=0.05) with abundance of YOY catfish in main channel habitats in September and positively correlated (r=0.81, p=0.048) with abundance of YOY catfish in secondary channel habitats in August (NMGF data, RM 158 to 77). Condition of adult carp in spring and YOY abundance in main channel habitats in September also showed a positive correlation (r =0.70, p=0.19). In secondary channel habitats the correlation was slightly better between adult carp condition in spring and YOY carp in August (r=0.80, p=0.10). Overall, the relation between adult carp condition and YOY abundance was not as strong as with channel catfish. Because carp begin spawning near the time of spring sampling, it is likely that in some years earlier spawning resulted in different condition and, therefore, weaker correlations. The reason for increased spring condition in some years and not others is not known, but spring flow parameters do not appear to be a deciding factor.



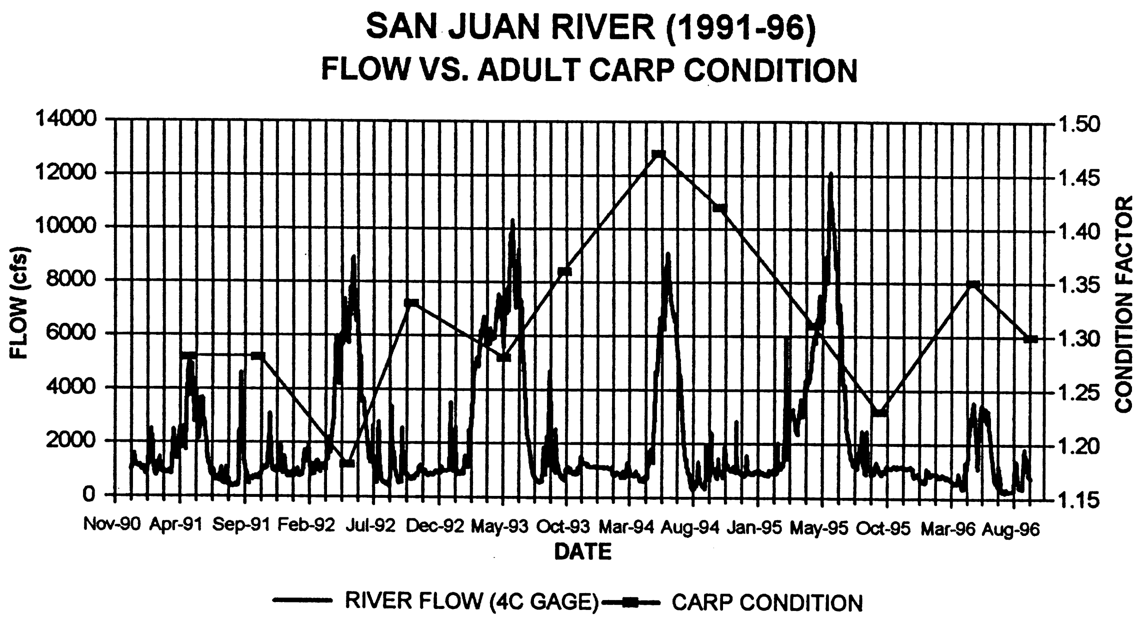


Figure 4.34. Flow (as measured at Four Corners gage 09371010) vs. average condition (*K* = 100*w*/*l*3) for adult channel catfish (top) and adult common carp (bottom) collected during May and October electrofishing surveys of the San Juan River, 1991 to 1997.

In September 1996, adult channel catfish were collected by electrofishing and implanted with radio transmitters. These fish were monitored monthly from October 1996 through September 1997 to evaluate habitat use relative to availability. Adult channel catfish occupied only six habitat types throughout the year, including (in order of most-frequent use) runs, eddies, slackwaters, run/riffles, pools, and flooded vegetation. Run habitat was the most-frequently occupied habitat year round. However, habitat "selection" (see Colorado pikeminnow section above for a discussion of how selection was determined) of radio-tagged channel catfish varied among months (Table 4.23). During winter base flows, adult channel catfish selected the greatest number of habitats, including eddies, slackwaters, and pools. In spring, slackwaters and eddies were still selected habitats. However, habitat complexity values were highest in spring as different individuals were found in areas with a variety of habitat types (i.e., riffles, run/riffles, and sand shoals) associated with runs.

Table 4.23. Habitat selection for radio-tagged channel catfish in the San Juan River, October 1996 through September 1997.

Habitat Type	Dec	Jan	Feb	Apr	May	Jun	Jul	Aug	Sep	Oct
Eddy	50		47	27						74
Pool	50									
Slackwater		95	50	66						
Run					100	100	100	100	91	26
Run/Riffle				8					9	
Mean Habitat Complexity	5	2	4	5	4	3	4	3	3	4

Note: Monthly selection was calculated by the aggregate percent method (Swanson et al. 1974). Mean habitat complexity is the number of habitat types found in the area of river being used by the fish each month.

During peak flows in June, two of eight individuals moved into sidechannel run habitats where water velocities were lower than main channel run habitat. Others remained in runs near the stream margins, including one individual that moved into flooded vegetation. During peak flows, run habitat was the only selected habitat type. In summer, runs were also the only selected habitat and the runs were most often in areas with slackwaters, eddies, and riffles nearby. Habitat use in fall was similar to summer, though runs and eddies were both selected habitats.

In general, most of the areas occupied by adult channel catfish were relatively simple habitats with low habitat-complexity values (see Figure 4.15). They appeared to respond seasonally to changes in temperature and flow, preferring areas near slackwaters, eddies, and pools in winter and moving near the stream margins or into sidechannels, presumably seeking refuge from high water velocities, during spring runoff. There did not appear to be any large-scale movement patterns associated with changes in flow. Because radiotelemetry data were collected only for 1 year, it was not possible to state how habitat use would change under different flow regimes. However, because there were only minor differences in seasonal patterns of habitat use and localized movement during high flows, changes in habitat use under different flow conditions were not expected.

During electrofishing surveys since 1991, adult channel catfish were collected in all habitat types, but were most-frequently collected in shoreline areas adjacent to moderate velocity runs (about 1.6 fps) over sand and cobble substrates, and often in association with flannelmouth sucker and bluehead sucker. Juvenile channel catfish were commonly collected in aggregations over sand and silt substrates near cobble bars and associated riffles in low-velocity run habitats. Common carp were most abundant in low-velocity shoreline habitats over sand and silt substrates. Shallow and exposed shorelines areas downstream of riffles and adjacent to low-velocity run habitats were commonly occupied only by adult common carp.

In summary, there does not appear to be a significant relation between the spring hydrograph and abundance of YOY channel catfish and common carp, although there may be a negative relationship between larval drift abundance and flow. However, there were positive correlations with condition of adult channel catfish and common carp in spring and YOY abundance during summer and fall. In addition, adult catfish and common carp condition in spring was higher in years when the preceding winter base flows were stable. Common carp and channel catfish do not appear to be responding negatively to natural hydrograph mimicry. The decrease in catch rates observed for adult channel catfish in fall 1997 may be because of mechanical removal efforts that began intensively in spring 1996.

Red Shiner

The same analysis described above for flannelmouth sucker and bluehead sucker was performed for red shiner (Table 4.24). This analysis used UDWR seining data from main channel habitats and NMFG seining data from secondary channels during summer (generally August) and autumn (generally October). The August NMFG data between RM 77 and RM 158 had significant correlations with some spring runoff variables, including volume, days above 2,500 cfs, and days above 8,000 cfs (Table 4.24). The September UDWR data had a significant correlation only in Reach 2. No other correlations were significant, suggesting that riverwide, red shiner densities are not consistently high or low following high spring flow years.

A more-intensive analysis of the secondary channel data was conducted. Sampling methodologies for these data are found in Propst and Hobbes (1993, 1994, 1995) and Gido and Propst (1994). Density of red shiner in secondary channels was highest in August (summer) when YOY specimens typically comprised a large proportion of most samples (Figure 4.35). Greatest red shiner summer densities in secondary channels generally occurred in 1993 and 1995, years with high spring runoff (Figure 4.35). Low spring runoff in 1996 (Figure 2.5) did not appear to have a suppressive effect on red shiner summer density in secondary channels. Summer density in 1996 was as high or higher than in years with average spring runoff. Based upon these data, it appears that red shiner often show increased reproductive success with high spring flows and that very low spring flows do not appear to diminish reproductive success.

Table 4.24. Average catch rates (number/100 m²) with standard errors (in parentheses) and Pearson correlation coefficients (*r* values) of various hydrologic (Table 4.3) and trip (Table 4.17) parameters for red shiner in the San Juan River (only 1991-96 data used in correlations).

CATCH RATES	UTAH DIVISION OF WILDLIFE RESOURCES DATA													NEW MEXICO DEPARTMENT OF GAME AND FISH DATA	
	RM 2 - 158		RM 116 - 158		REACH 1		REACH 2		REACH 3		REACH 4		REACH 5	RM 116 - 158	RM 77 - 158
	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	SEPT.	AUG.	AUG.
1991	357.6 (108.8)	174.4 (21.6)	448.3 (215.8)	176.8 (43.5)	219.3 (104.7)	149.5 (123.5)	165.4 (113.6)	92.3 (29.2)	311.9 (300.8)	202.8 (29.4)	498.7 (91.7)	308.4 (83.9)	146.1 (34.2)	159.1 (151.0)	125.6 (90.9)
1992	41.4 (13.6)	153.0 (26.1)	27.8 (6.3)	148.1 (32.4)	25.0 (4.3)	16.7 (85.0)	17.6 (11.9)	113.1 (51.2)	80.6 (48.9)	189.8 (60.0)	30.0 (7.9)	155.2 (55.0)	203.5 (47.6)	105.3 (31.4)	95.7 (22.1)
1993	553.9 (104.5)	502.3 (83.3)	543.4 (187.3)	332.3 (125.8)	269.9 (175.3)	199.8 (51.8)	300.1 (60.5)	340.8 (60.2)	621.6 (240.6)	1036.8 (255.0)	1094.5 (405.2)	348.6 (131.7)	331.1 (191.6)	1044.0 (447.4)	877.7 (290.3)
1994	172.6 (75.8)	401.3 (106.7)	95.7 (33.3)	921.5 (481.3)	176.7 (67.2)	194.4 (139.5)	321.0 (414.8)	252.5 (45.7)	332.6 (302.6)	382.3 (66.7)	121.9 (52.0)	1473.1 (734.0)	429.8 (152.3)	311.1 (259.2)	259.3 (149.0)
1995	93.5 (38.3)	188.9 (36.2)	55.2 (73.4)	150.2 (41.2)	72.6 (73.6)	85.0 (17.7)	31.8 (11.1)	182.8 (40.7)	222.0 (103.5)	285.3 (80.1)	55.2 (73.4)	253.3 (146.6)	136.2 (62.5)	543.1 (193.3)	1063.2 (286.2)
1996	60.0 (9.6)	277.2 (37.4)	87.2 (20.2)	307.5 (54.7)	51.3 (6.3)	325.8 (103.0)	13.1 (7.5)	117.5 (27.0)	81.9 (34.4)	345.8 (93.2)	87.2 (26.9)	319.3 (131.6)	294.7 (61.9)	339.5 (123.0)	251.4 (78.1)
1997	86.6	114.6	75.1	21.0	119.3	206.0	42.1	43.3	38.7	238.9	75.1	103.4	21.6	44.0	42.8
CORRELATIONS	UTAH DIVISION OF WILDLIFE RESOURCES DATA													NEW MEXICO DEPARTMENT OF GAME AND FISH DATA	
	RM 2 - 158		RM 116 - 158		REACH 1		REACH 2		REACH 3		REACH 4		REACH 5	RM 116 - 158	RM 77 - 158
	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	AUG.	SEPT.	SEPT.	AUG.	AUG.
Peak Flow	0.10	0.25	-0.10	0.16	0.10	-0.57	0.28	0.62	0.39	0.30	0.08	0.21	-0.06	0.45	0.67
Peak Date	-0.11	0.17	-0.30	0.14	-0.10	-0.41	0.08	0.52	0.20	0.19	-0.12	0.18	0.02	0.43	0.77
Volume	0.35	0.38	0.17	-0.04	0.25	-0.43	0.29	0.73	0.57	0.57	0.39	-0.05	0.01	0.72	0.83
Days > 2,500 cfs	0.28	0.26	0.13	-0.19	0.15	-0.44	0.13	0.62	0.48	0.51	0.34	-0.19	-0.14	0.71	0.89
Days > 5,000 cfs	0.42	0.49	0.23	0.05	0.30	-0.34	0.39	0.82	0.63	0.70	0.48	0.01	0.20	0.76	0.72
Days > 8,000 cfs	0.11	0.28	-0.07	-0.11	0.12	-0.26	0.20	0.61	0.39	0.34	0.09	0.15	0.00	0.60	0.90
Trip Flow	0.01	0.15	-0.01	-0.27	-0..02	-0.63	-0.19	0.38	0.10	0.42	-0.05	-0.25	-0.20	N/A	N/A
Days After Peak	-0.12	-0.31	0.07	-0.29	-0.17	0.00	-0.30	-0.51	-0.43	-0.24	-0.09	-0.26	-0.29	N/A	N/A
Trip Date	-0.37	-0.25	-0.38	-0.25	-0.43	-0.80	-0.17	0.09	-0.40	-0.07	-0.28	-0.12	-0.50	N/A	N/A

N/A = not available
Note: Shaded areas values indicate significant correlations ($P < 0.05$)

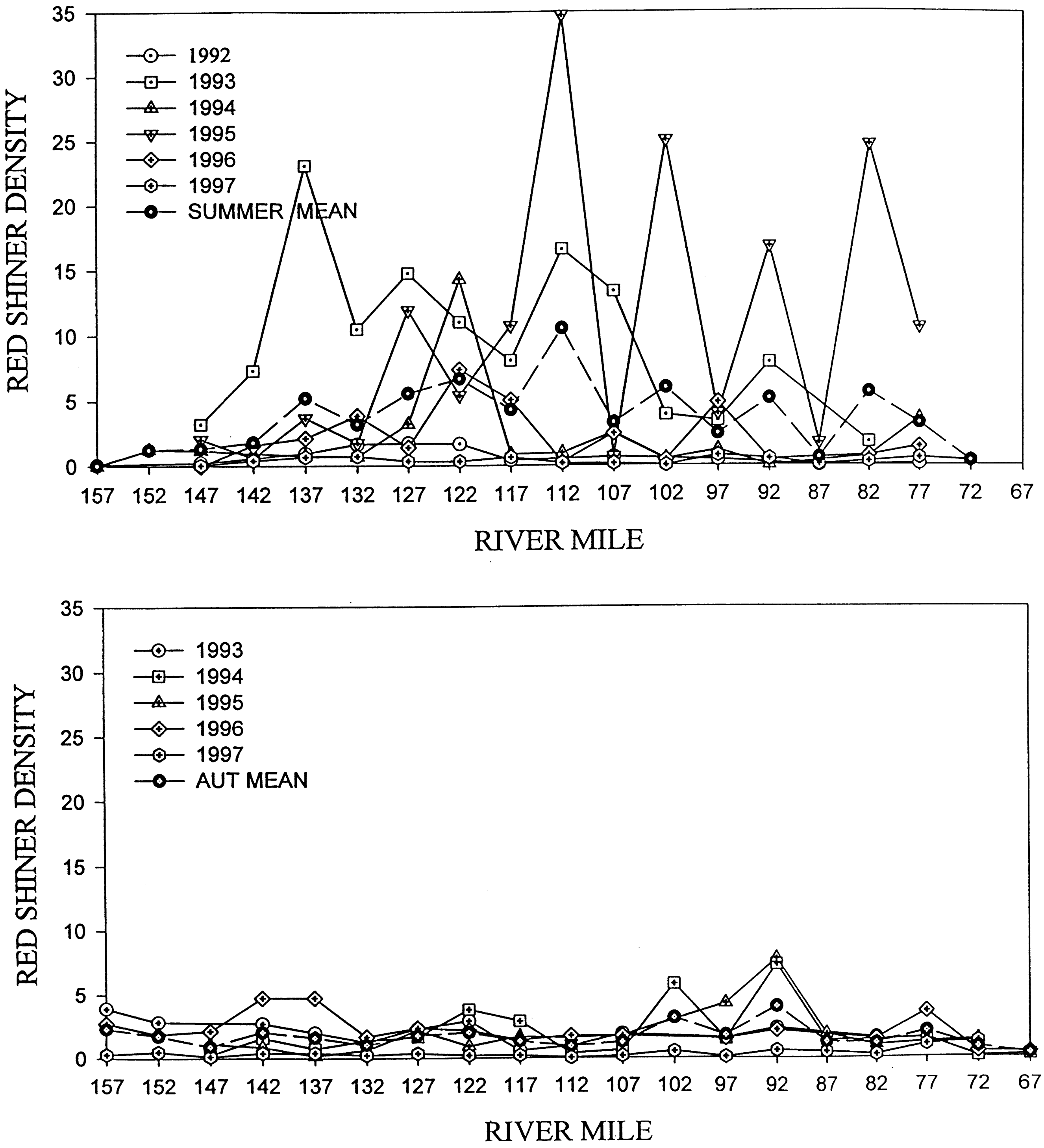


Figure 4.35. Density of red shiner in the San Juan River (5-mile increments), 1992 to 1997, New Mexico, Colorado, and Utah.

At least one reason for the positive response of red shiner in secondary channels to high spring flows (despite displacement of a portion of adults) may be the cleansing of interstitial spaces among cobble in riffle habitats by elevated flows. Red shiner is a crevice spawner (Gale 1986) (see Chapter 3 for more detail), and mobilization of fine sediments from cobble areas likely enhances these areas for spawning; transport of fine sediments from cobble areas reduces the likelihood that the demersal, adhesive eggs (Robison and Buchanan 1988) will be smothered by silt. Thus, in years with high spring runoff, red shiner egg survival was relatively high, and this was reflected in the high abundance of YOY red shiners during summer inventories.

The low spring runoff of 1996 was coupled with low summer discharge. Water temperature increased to the spawning threshold temperature (about 20E C) (Gale 1986) earlier in 1996, and water temperature remained in the optimal spawning range (23 to 30E C) longer with low summer discharge. Gale (1986) documented that under optimal water temperature conditions, an individual female will produce several egg clutches, and total production may exceed 8,000 eggs per female over a 10-week reproductive season. Thus, in 1996, elevated water temperatures and an extended spawning season may have partially compensated for the absence of sediment-mobilizing spring flows.

Gido et al. (1997) provided data indicating that spring runoff diminished the abundance of nonnative fishes, including red shiner, in San Juan River secondary channels. Data from a permanent study site at RM 136.7 provided confirmation of their study (Table 4.25). Pre-runoff data were the average density for all samples from February to peak runoff (typically June). Post-runoff densities were estimated from samples taken after peak runoff and prior to appearance of YOY red shiner. Despite the apparent reduction in adult red shiner density pre- and post-runoff, the reproductive success (measured as summer density of YOY fish) was not appreciably impaired.

Table 4.25. Pre- and post-peak spring runoff density of red shiner at the Channel from Hell permanent study site.

Year	Density	Months Sampled
1993 Post-peak	0.1985	July
1994 Pre-peak	2.9115	February & April
1994 Post-peak	0.8160	June & July
1995 Pre-peak	1.1131	February, March, April, May
1995 Post-peak	0.7834	June & July
1996 Pre-peak	2.8398	February, March, May
1996 Post-peak	0.5630	June & July

Autumn densities of red shiner (typically ≤ 2.5 fish/m^2) were lower than summer densities (typically ≥ 2.5 fish/m^2) (Figure 4.35). Among years within each geomorphic reach and among reaches within each year, red shiner densities were fairly similar. However, autumn 1997 densities in all geomorphic reaches were substantially lower than in other years of study (Figure 4.35). High flows throughout the 1997 spawning season likely depressed water temperatures, thereby reducing reproductive success. In addition, high mean summer flows and flow spikes in excess of 5,000 cfs (Figure 2.5) may have displaced larval red shiner.

Among the discharge variables and relationships examined, elevated summer flows appeared to have the most-substantial negative impacts on red shiner density (Table 4.26). At least two attributes of red shiner biology provide possible reasons for apparent (autumn) density suppression. Red shiner spawns when water temperatures exceed about 20E C, but spawning success is apparently greatest between 23 and 30E C. Elevated summer flows keep water temperature at or below the optimal spawning temperature for red shiner. Red shiner is a fractional spawner, in that a given female may spawn several times during the reproductive season if environmental conditions are suitable. Elevated summer flows may, by suppressing water temperature, diminish the length of the spawning season. Data (length/frequency) from secondary channel permanent sites indicate that the spawning season of red shiner, even in low-flow years, is relatively brief (about 3 weeks). Thus, high summer flows may act to suppress red shiner density by maintaining water temperatures below optimal spawning levels and by temporally reducing the spawning season. Conversely, autumn density of red shiner was higher in years with low summer flows. During years of low summer flows, water temperatures were higher and were likely above the threshold temperature (about 20E C) for a longer period of time, thus enabling greater reproductive success. These data suggest that a low temperature flow spike of 3,000 cfs or greater in August may suppress red shiner numbers.

Table 4.26. Correlation of summer flow attributes versus autumn density of red shiner in San Juan River secondary channels by geomorphic reach.

Variable								
Reach	**Mean Discharge**	**Spike Volume**	**Spike Mean**	**<500**	**<1000**	**>1000**	**>2000**	**Low Flow Duration**
Cyplut 5	-0.77	-0.62	-0.50	0.68	0.86	-0.63	-0.63	0.50
Cyplut 4	-0.81	-0.80	-0.78	0,47	0.77	0.62	-0.84	-0.00
Cyplut 3	0.01	-0.38	-0.57	-0.15	-0.13	0.01	-0.47	-0.25

Although elevated summer flows may suppress red shiner spawning success, it is unlikely that such a flow regime would eliminate spawning by the species. Flow spikes, if timed to coincide with emergence of larvae, may have additional negative impacts on red shiner by displacing recently hatched larvae into unsuitable habitats.

In summary, red shiner densities appear to vary within years between main channel and secondary channel habitats. Flows that may reduce numbers of red shiner in secondary channels may not have the same effect on main channel habitats. It is possible that during some years red shiner move into secondary channel from the main channel, and in other years the reverse movement occurs. Consistent collections from similar main channel and secondary channel habitats were not made so this potential cannot be tested. The data from the 7-year research effort suggest that red shiner density in all habitats in the San Juan River fluctuates over time but is not well correlated with flow events.

Fathead Minnow

An analysis of fish density and hydrologic variables similar to that described above for flannelmouth sucker and bluehead sucker was performed for fathead minnow. This analysis used UDWR seining data from main channel habitats and NMFG seining data from secondary channels from August and September broken into various portions of the river. No significant correlations were found for any of the analyses. These data suggest that fathead minnow densities are not related to spring flow variables in either main channel or secondary channel habitats.

A more-intensive analysis was made of the secondary channel fathead minnow data. The methods used to obtain data on fathead minnow distribution, abundance, habitat use, and response to different flow regimes were the same as those reported above for speckled dace and red shiner (Propst and Hobbes 1996).

Fathead minnow was typically the second most-common fish species inhabiting San Juan River secondary channels during summer and autumn. In some instances, it was the most-common species in a sampled secondary channel. During the 7-years of study (1991 to 1997), there was considerable variation in the summer density of fathead minnow in secondary channels. No attribute of spring runoff was significantly related to summer density of fathead minnow (Table 4.27). Summer flow levels, however, appeared to have at least a moderate effect on autumn densities in Reaches 5 and 4, but not in Reach 3 (Table 4.28). The data indicate that fathead minnow abundance is enhanced by low summer flows and suppressed by elevated summer flows. Summer flow spikes may depress autumn abundance, although no relationship of fathead minnow density to summer flow attributes was consistent among geomorphic reaches (Table 4.28). The lack of consistent patterns among geomorphic reaches suggests that density may be less dependent upon attributes of flow than on factors such as habitat availability. Although habitat features are at least partially mediated by flow regimes, the low-velocity shoreline habitats with cover typically occupied by fathead minnow are present at all flow regimes. Other factors, such as timing of spawning and spawning season duration, also influence seasonal and annual density of fathead minnow. These factors, however, were not examined for this report.

In summary, fathead minnow densities in San Juan River secondary channels and main channel habitats were not strongly influenced by flow. Low summer flow evidently enhanced and high summer flow seemed to depress autumn fathead minnow density in secondary channels, but not consistently among all reaches. These data suggest that suppression of fathead minnow numbers in the San Juan River secondary channels could be achieved with summer flows exceeding 1,000 cfs and by maintaining flows above 500 cfs. Summer flow spikes greater than 3,000 cfs may also suppress this species similar to the potential suppression of red shiner.

Table 4.27. Correlation of spring runoff attributes with fathead minnow summer density in San Juan River secondary channels.

	Mean Discharge		Discharge Volume		Discharge Peak		Discharge Duration		Days Pre-peak		Days Post-peak		Days $3,000 cfs		Days $5,000 cfs		Days $8,000 cfs	
Reach	*r*	p	*r*	p	*r*	p	*r*	p	*r*	p	*r*	p	*r*	p	*r*	p	*r*	p
5	0.53	#.23	0.13	#.78	0.02	#.97	0.21	#.65	0.12	#.79	0.41	#.36	0.27	#.56	0.55	#.20	0.12	#.79
4	0.04	#.93	0.26	#.57	0.44	#.33	0.51	#.24	0.43	#.33	0.51	#.24	-0.14	#.77	0.03	#.95	0.32	#.48
3	0.10	#.83	0.29	#.53	0.12	#.79	0.26	#.57	0.33	#.47	0.07	#.89	0.32	#.48	0.16	#.74	0.35	#.45

Table 4.28. Correlation of summer low-flow attributes with fathead minnow autumn density in San Juan River secondary channels.

	Mean Discharge		Spike Volume		Spike Mean		Days #500 cfs		Days #1,000 cfs		Days $1,000 cfs		Days $2,000 cfs	
Reach	*r*	p	*r*	p	*r*	p	*r*	p	*r*	p	*r*	p	*r*	p
5	-0.81	#.10	-0.67	#.21	0.53	#.36	0.86	#.06	0.91	#.03*	-0.76	#.14	-0.65	#.23
4	-0.80	#.10	-0.90	#.03*	-0.85	#.07	0.91	#.03*	0.78	#.12	-0.94	#.02*	-0.86	#.06
3	0.41	#.50	-0.01	#.99	-0.20	#.75	-0.34	#.57	0.45	#.45	0.36	#.56	0.10	#.88

CHAPTER 5: CONTAMINANT CONSIDERATIONS IN THE FLOW RECOMMENDATION PROCESS

Contaminants were identified as a potential issue of concern for the native fishes in the San Juan River when the SJRIP was initiated. Both natural (selenium) and manmade (polycyclic aromatic hydrocarbons (PAHs)) contaminants were identified for study during the 7-year research period. Several studies were conducted that investigated contaminant levels in the river, as well as potential sources and effects of contaminants on the native fishes (Abell and Wilson 1994; Wilson et al. 1995; Hamilton and Buhl 1995, 1996; Odell 1995, 1997). This chapter reviews the results of these contaminant studies and discusses how those results were used in the flow recommendation process.

HISTORICAL CONDITIONS

The available data on concentrations of selected dissolved trace elements such as arsenic (As), copper (Cu), selenium (Se), and zinc (Zn) in the reaches of the San Juan, Animas, La Plata, and Mancos rivers were compiled from the Environmental Protection Agency's (EPA's) STORET database. The database was searched for samples collected at any gaging station on the San Juan River between the Archuleta, New Mexico, and Bluff, Utah, gaging stations. The data sources consisted of the STORET database compiled by the EPA and the USGS through 1994 and data collected by the Farmington New Mexico BIA during the San Juan Study from 1991 to 1997.

The data sources contain analyses performed using various methods; hence, there are many different detection limits for each element. For example, the detection limits ranged from 0.5 parts per billion (ppb) to 100 ppb for As, 1 to 10 ppb for Cu, and 2 to 50 ppb for Zn. In order to include these measurements below their detection limit, the detection limit for As, Cu, and Zn was multiplied by 0.5, and for Se it was multiplied by 0.6. The corrected detection limit values were then treated as measured concentrations in the statistical analysis for each element.

For each reach of the San Juan River, there was no statistically significant difference in the mean concentrations of these trace elements. The variances in the measurements are so large that no trends in the mean concentrations could be determined (i.e., by least squares the coefficient of determination was less than 10%). The only way to observe a trend was to calculate the mean values at various sites along the river. After this calculation, there was still no trend in the means for As and Zn. From Archuleta to Bluff, Se showed an increase from 0.7 to 1.3 ppb (the detection limit is 1 ppb). The mean Cu concentration went from 4 to 5 ppb (the detection limit for Cu is 2 to 5 ppb). For the dissolved trace elements in water (As, Cu, Se, and Zn) there was not a statistically significant change in concentrations as the flow decreased. Allowable samples were constrained to those collected only within the lower reaches of the river (Shiprock, New Mexico, to Mexican Hat, Utah). At flows below 500 cfs, no changes were detected. Linear regression of concentrations versus flows has $r^2 < 0.05$ for each element. If a trend between these contaminants and flow existed, it was small and masked by variation in measured levels of the elements.

Using the same analysis of looking for trends in the mean values provided additional information (Table 5.1). The analysis was initially carried out using all measurements along the mainstem. It was then restricted step by step, going only to stations from Shiprock to Bluff. Analysis was then carried out for flow conditions of less 1,500 cfs and, finally, for flows less than 500 cfs. The extreme concentration was also used to show the highest concentration observed under the low flow condition (Table 5.1). This was an attempt to include a seasonal high concentration not reflected in the mean value. No trends were seen in these data to suggest a relationship between contaminant concentration and flow.

Table 5-1. Mean concentrations of selected trace elements under various constraints.

CONSTRAINTS	MEAN CONCENTRATION AS PPB (NO. OF SAMPLES) [STD. DEV.]			
	Arsenic (As)	Copper (Cu)	Selenium (Se)	Zinc (Zn)
Archuleta-Bluff	2 (1298)[3]	4 (435)[3]	0.9 (1175)[0.6]	19 (1300)[60]
Shiprock-Bluff	2 (683)[3]	5 (293)[3]	1.0 (619)[0.7]	21 (681)[41]
Shiprock-Bluff < 1,500 cfs	2 (377)[4]	5 (128)[3]	1.0 (311)[0.8]	18 (372)[32]
Shiprock-Bluff < 500 cfs	2 (45)[1]	5 (10)[2]	1.1 (41)[0.6]	14 (46)[40]
CONSTRAINTS	**EXTREME CONCENTRATION AS PPB (YEAR OF OCCURRENCE)**			
	As	**Cu**	**Se**	**Zn**
Shiprock-Bluff < 500 cfs	3 31 scattered days	10 (7-6-72)	2 (4-7-81,7-18-89 8-30-93,4-24-96)	270 (8-21-92)

During the 7-year study, various biological samples (fishes, macroinvertebrates, and periphyton) were collected from the San Juan River. These samples were analyzed for up to 32 trace elements including As, Cu, Se, and Zn. Fish bile samples and semi-permeable membrane device (SPMD) samples have also been collected for analysis of PAHs at various sites along the San Juan River and its tributaries.

The trace element concentrations in organisms are highly variable depending on species and environmental conditions. In any single species, there are some differences in trace element or PAH concentrations that depend on location. Most trace elements showed no concentration differences in organisms as a function of location. The variation was large, and too few samples were collected to detect any systematic differences. The concentration differences in PAHs were usually abrupt, indicating some local cause for the difference. For Se, the highest concentrations occurred in organisms collected near Blanco, New Mexico (RM 205), and concentrations gradually decreased downstream and did not change below Shiprock (RM 150), as shown in Figure 5.1.

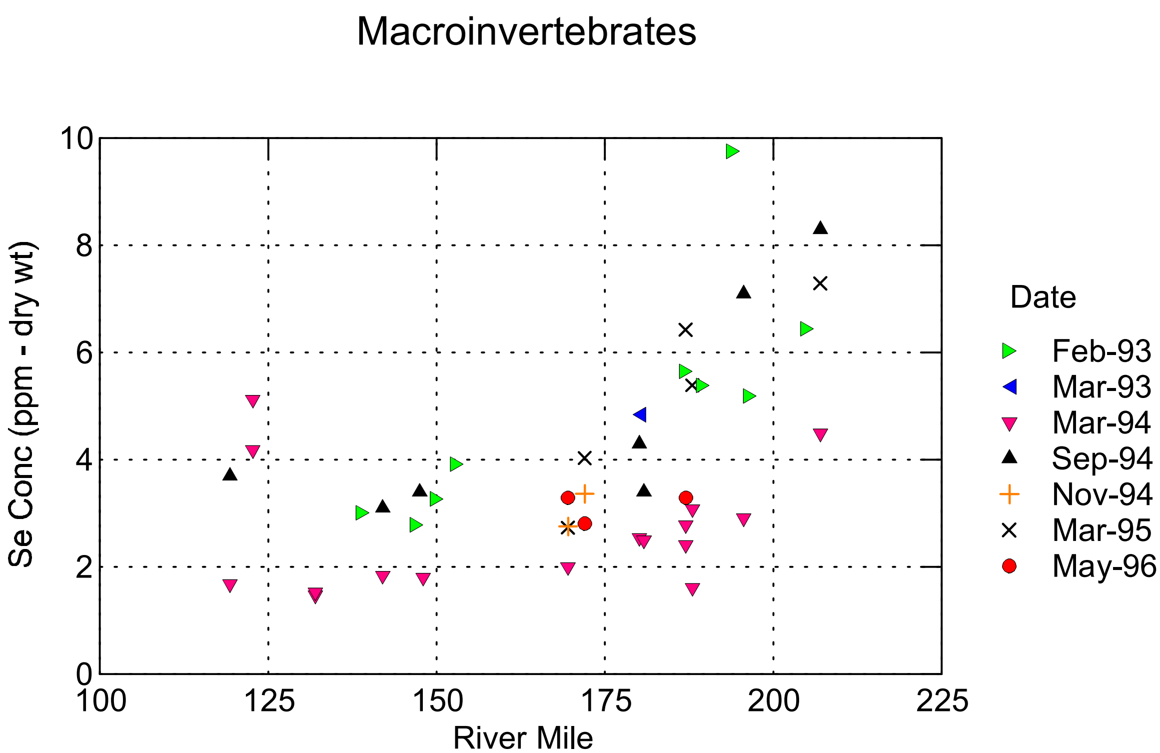


Figure 5.1. Selenium (Se) concentration in macroinvertebrates vs. distance downstream in the San Juan River.

Elevated PAH levels in channel catfish and common carp bile have been found in some locations of the San Juan River, but no clear pattern with flow has been established (Wilson et al. 1995). SPMD samples also did not indicate any significantly elevated levels, except in the Animas River sample at Farmington.

TOXICITY STUDIES

Hazards of As, Cu, Se, and Zn were assessed for Colorado pikeminnow and razorback sucker by Hamilton and Buhl (1996). Acute toxicity tests (96 hours) were completed on the larvae of the two species in water made up of experimental mixtures simulating various tributary waters along the San Juan River. Both the single salts, including arsenate, Cu, selenate, selenite, and Zn, and mixtures of all salts were tested. In general, razorback sucker is more sensitive to arsenate and the Se forms than Colorado pikeminnow (Table 5.2). For both species, the Gallegos Canyon mixture had synergistic toxicity and the Ojo Amarillo Canyon mixture had antagonistic toxicity. Applying a standard ratio of biological effect concentrations to environmental water concentrations of 100 to 1, only Cu had ratios less than the standard ratio. In addition to these experimental mixtures, Cu alone could adversely affect larval Colorado pikeminnow and razorback sucker in these reaches of the San Juan River, assuming the standard ratio is correct for Cu. Based on these results, some elements could be a concern for the native fishes in the San Juan River, but no relationship to flow could be determined.

Table 5.2. Acute toxicity (LC_{50}-96 hr) concentrations for several contaminants in the San Juan River.

	ACUTE TOXICITY (LC_{50}, 96H) IN PPB			
	Arsenic (As)	Copper (Cu)	Selenium (Se)	Zinc (Zn)
Colorado pikeminnow larvae	105,000	305	88,000	8,400
razorback sucker larvae	17,800	269	15,900	9,800

Chronic toxicity effects of Se on reproduction and survival of larval Colorado pikeminnow were studied by Hamilton in 1997 using dietary concentrations of 0, 5, and 10 ppm and water borne concentration of 0 and 5 ppb, but the results are not yet available. Preliminary results indicate that at the Se levels tested, which were above most values found in the San Juan River (Table 5.1, Figure 5.1), no difference in reproductive success could be found between the treatment and control groups.

FLOW/WATER QUALITY IMPLICATIONS

Based on the available water quality data from past sampling, there does not appear to be a significant change in trace element concentrations under low-flow conditions, as indicated in the individual columns of Table 5.1. Therefore, increased days with low flows should not cause a significant change in the trace element concentration.

The possible biological implication of a minimum flow recommendation at 500 cfs was analyzed in the following way:

> First, based on past observations, the effect of 500 cfs flows should not measurably change the overall trace element content of the water. Therefore, the organisms are not going to be exposed to different conditions.
>
> Second, for the area between Shiprock and Bluff where most of the endangered fishes have been found, the values found in Table 5.1 for As, Cu, Se, and Zn were examined under a 500-cfs flow condition. The extreme concentrations for these elements were 2, 10, 2, and 270 ppb, respectively. The toxicity of these elements at these concentrations was calculated as the ratios of the biological effect concentration to environmental water concentration. For Colorado pikeminnow the ratios were As = 52,500, Cu = 31, Se = 44,000, and Zn = 31. For razorback sucker the ratios were As = 8,900, Cu = 27, Se = 5,700, and Zn = 36. Assuming the ratios should exceed 100, then Cu and Zn are of concern for the larval stages. However, it seems unrealistic for the projected Cu concentrations to exceed the ratio > 100 criterion, because the Cu concentrations would have to be < 3 ppb, which is at or below the detection limit of commonly used analytical methods. The above ratios are unchanged over past flow conditions, so the concern is also expected to be unchanged for these four elements under the low-flow recommendation. It should be noted that only one value for Zn is of concern, and it may be the result of a sampling or analytical error, since this level is more than an order of magnitude higher than the mean and is a single incident.

Polycyclic aromatic hydrocarbon contamination is likely to be minimally affected by maintaining base flows at 500 cfs. To the extent that these flows are below historical levels, the low solubility of PAHs, the localized nature of potential effects, and the lack of indicated problems in the San Juan River would suggest that there will not be an increased risk at 500 cfs. A possible impact could occur if oil were spilled during low-flow conditions, which might provide less dilution. Given the modest change in base flows from historical conditions and the increase in summer base flows, the overall risk is minimal.

In summary, the available data do not suggest that contaminant levels and river discharge levels are related. Hence, contaminant issues were not used to develop flow recommendations. However, the contaminant load of future development projects should be carefully examined to determine the impact to contaminant concentrations in the river, especially those constituents that indicate a potential problem at present levels.

CHAPTER 6: SUMMARY OF FISH FLOW/HABITAT RELATIONSHIPS

This chapter summarizes the information presented in Chapters 2, 3, and 4, and highlights the information on which the flow recommendations were based. Because habitat is one of the main ecological factors directly affected by flows, habitat-use information gathered on the San Juan River, as well as from other Upper Basin areas, was fundamental to developing flow recommendations. The most basic breakdown of this relationship was to determine what flows are needed to create and maintain important habitats on a seasonal basis for different life stages.

A few direct biological responses to the research flows were noted during the 7-year research period, and they are summarized below. A general description of important habitats for each of the native species is given, followed by a short discussion of possible strategies of reducing nonnative species with flow management. Finally, a concise list of important habitat conditions and flow criteria needed to meet these habitat needs is presented.

It is important to note that these relationships are based on conclusions from the SJRIP 7-year research studies, as well as on existing information from throughout the Upper Basin. This information is the best available to date; however, further studies could provide new or contrary information that should be duly considered and incorporated into the flow recommendations when that information becomes available.

RESPONSES TO RESEARCH FLOWS

During the 7-year research period, it was expected that some increases in reproductive success would be seen in Colorado pikeminnow and perhaps razorback sucker. But as discussed in Chapter 4, responses were apparently too small to measure clearly, apparently because of a lack of adults in the system and thus an insufficient number of young to measure a response. The number of young Colorado pikeminnow collected in the river from 1987 through 1997 appeared to show some response to different types of spring runoff conditions. The number of young Colorado pikeminnow collected was very low during years with very low and short spring runoff (1988 through 1991 especially). Number of young also appeared to increase during high-flow years with fairly natural hydrographs, but the relationship is not clear because of differences in the area sampled and the amount of effort expended each year. These relationships do fit the general pattern for Colorado pikeminnow reproductive success seen in other rivers in the Upper Basin (Holden and Wick 1982, McAda and Kaeding 1989, Osmundson and Kaeding 1991, Bestgen et al. 1998).

Since the advent of research flows, another pattern seen in San Juan River catch statistics was a decline in flannelmouth sucker numbers and an increase in bluehead sucker numbers. In addition, condition factor, a ratio of body weight to length, increased for both species. These changes in the two sucker populations suggest that cobble habitats have improved in productivity (which was not studied) and overall abundance (which was confirmed by the physical studies), making conditions better for bluehead sucker than pre-research, post-dam periods. These same conditions have apparently suppressed flannelmouth sucker density. This change is likely a natural process in response to a more-natural river situation in terms of flow, sediment transport, food availability, and habitat condition.

Bluehead sucker reproductive success, as measured by capture of YOY, was positively correlated with most spring runoff variables, including flow volume and days over 5,000 and 8,000 cfs. This information indicates that the research period flows that mimicked a natural hydrograph have improved reproductive success, as measured by capture of YOY in late summer which has resulted in increased abundance of adults.

In addition, speckled dace abundance in upstream reaches improved since the advent of the research flows, showing significant positive correlations with spring runoff factors of flow volume and days with flows over 5,000 and 8,000 cfs. Speckled dace larval drift also was highest during high runoff years.

The relationships discussed above were generally a result of natural hydrograph mimicry, providing more natural peaks and volumes to the spring runoff by making releases from Navajo Dam match the natural peak of the Animas River. In addition, late summer base flows from the dam were reduced and may also have had a positive effect on survival of YOY native fishes.

The other "response" that was documented during the 7-year research flow period, but was not necessarily related to research flows, was the survival of stocked juvenile/subadult razorback sucker and YOY Colorado pikeminnow. Although both of these species have been stocked in other parts of the Colorado River system, very few of these fish survived (Minckley et al. 1991, Masslich and Holden 1996), making their survival in the San Juan River fairly remarkable. This information strongly suggests that the available San Juan River habitat during the research period was adequate for the size-classes stocked. The subsequent recapture of both species, and the growth and continued survival that has been seen in both species (Holden and Masslich 1997), continues to suggest that the San Juan River can support these species. These stocked fish have allowed the gathering of habitat selection information showing that important habitats include edge pools, eddies, and pools for larger razorback sucker, and backwaters and other low-velocity habitats for YOY Colorado pikeminnow.

Additional habitat selection information was gathered from radio-tagged wild Colorado pikeminnow adults during the 7-year research period. Although not a biological response to the research flows directly, this information provided direct habitat-use data for the San Juan River, including the location of a spawning area.

The biological information gathered during the 7-year research period was used in several ways to develop flow recommendations. Direct responses that could be correlated to specific flow levels were used to support those flow levels. For example, the improved abundance of YOY bluehead sucker and speckled dace supported a flow recommendation for runoff flows above 5,000 and 8,000 cfs. Other responses were more qualitative, such as the apparent decreased Colorado pikeminnow reproductive success during years with low spring flow or increased success during high, more natural spring runoff flows. The habitat-use information was used to determine which habitats were most important, and then flow/habitat relationships were developed through the physical studies conducted relating development and maintenance of these habitats to flow. The following sections highlight the habitat-use information and the physical relationships that were determined to provide and maintain those important habitats.

GENERAL SUMMARY OF NATIVE SPECIES HABITAT NEEDS

Seasonal habitat use and life history information for the native fishes are shown in Figure 6.1, which is overlain on a typical natural hydrograph so that the relationship between the natural flow pattern and magnitude can be related to important habitat and life history needs. Adults of the two endangered species, Colorado pikeminnow and razorback sucker, prefer eddies, pools, and other relatively low-velocity habitats year-round. These habitats comprise a relatively small portion of the total available habitat in the San Juan River (see Figures 2.7 and 2.8) compared to the Green or Colorado rivers. Adults also use these habitats in more complex portions of the river (areas associated with several different habitat types). Spawning for both species requires relatively clean cobble bars (cobble with adequate interstitial space). Colorado pikeminnow spawning areas appear to have cleaner cobble and are generally less common than the cobble bars used by razorback sucker.

Post-larval Colorado pikeminnow typically prefer backwaters, which comprise a small portion of available habitat in the San Juan River. However, studies during the 7-year research period have demonstrated that YOY Colorado pikeminnow use a variety of other low-velocity San Juan River habitats as well, and the success of stocked YOY Colorado pikeminnow has been better in the San Juan River than anywhere else it has been attempted (Masslich and Holden 1996). These low-velocity habitats must be available year-round, but seem particularly important in the late summer and fall period when post-larval Colorado pikeminnow are in the river. Based on information from the Upper Basin, young razorback sucker life stages seem to prefer flooded areas of low or no velocity that are rich in food. These areas are generally large, inundated portions of the floodplain that may remain flooded much of the year or year-round. Within the current flow regime, such flooded bottomland habitats are not available in the San Juan River, and may never have been available, because of the steepness of the river floodplain. Young razorback sucker have been found in backwaters in the Green River, but individuals in these habitats appear to have lower survival than those in flooded bottomlands. It will not be known if habitat for young razorback sucker currently exists in the San Juan River until a spawning population is established and sufficient larvae are produced for habitat-use studies. Two razorback sucker larvae collected in 1998 in the San Juan

River were found in backwaters. Hopefully, additional larvae and YOY will be found in future years to clarify their habitat use.

Flannelmouth sucker and bluehead sucker also require cobble bars for spawning (Figure 6.1), but these species seem to be much less selective about cobble bar quality than the two endangered species; they tend to spawn throughout the river rather than in selected areas. During nonspawning periods, adult flannelmouth sucker and bluehead sucker use a variety of habitats but commonly use riffles to a greater extent than do the other large-bodied species. Flannelmouth sucker and razorback sucker are known to use backwaters in their early life stages, but young suckers move out of these low-velocity habitats and into mainstream habitats rather quickly as they grow. Speckled dace use smaller substrate (gravel) for spawning and spawn throughout the river. Overall, this species prefers riffle areas or cobble/gravel substrates.

Temperature is also an important habitat consideration, especially related to spawning. Temperature is an important cue for spawning for all of the native species, and flow/temperature combinations are needed for successful spawning. Temperature monitoring in the San Juan River has shown that relatively natural temperature patterns did occur in the river below Farmington during the research period, as well as during pre- and post-dam periods, although Navajo Dam does have a small negative effect on summer temperatures. The increased spring flow releases of the research period, along with colder Animas River temperatures, decreased spring and early summer temperature during peak flows (May, June, and July) compared to the pre- and post-dam periods below Farmington. Mid- and late-summer temperatures were actually slightly higher than the post-dam period likely because of lower base-flow releases. Therefore, mimicry of a natural hydrograph has not necessarily improved the temperature pattern for the native fishes.

In addition to the physical habitat needs of the fishes, habitat quality is also an important factor to consider in flow recommendations. Clean cobble bars for spawning are important for all the native fishes, but especially for Colorado pikeminnow. As discussed in Chapter 4, fine sediments embed larger substrates during low-flow periods. Building cobble bars and keeping them clean (by removing smaller sand and silt particles) are important considerations. Complex river areas are important for both Colorado pikeminnow and razorback sucker adults, especially during the spring and summer. Flows to maintain complexity are important to these fish species. Backwaters need to be relatively clean, and depth of backwaters appears to be important for young Colorado pikeminnow. Backwaters also likely need to be productive to provide the young fish an abundant food supply. As discussed in Chapters 2 and 4, summer and fall storm events can fill backwaters and other habitats with fine sediment, reducing their quality and quantity for native fishes. Higher flows are needed to clean the backwaters and restore their abundance and productivity. Therefore, building backwaters and cobble bars, and keeping them clean, are important habitat quality factors. Flows from 1962 through 1991 did not provide the dynamic natural hydrograph required to provide the habitat quality for a healthy native fish community.

SPECIES LIFE STAGE	WINTER	PRE-RUNOFF	RUNOFF	SUMMER/FALL BASE FLOW
Colorado Pikeminnow				
Adult	Eddies and other low-velocity habitats such as pools in complex river sections.	Eddies and mouths of tributaries, complex areas with warmer water temperature.	Migrate to spawning areas, eddies, slackwaters, and pools.	Spawn in July, cobble bars with clean cobble and adjacent eddies and slackwaters. In fall, eddies, pools, and slackwaters in complex areas for resting and adjacent riffles and
Juvenile (YOY)	Backwaters and other low-velocity habitats.	Backwaters and other low-velocity habitats.	Backwaters, and as the fish become larger, eddies and other habitats with more current.	Larvae drift downstream from spawning areas and use backwaters and other low-velocity habitats.
Razorback Sucker				
Adult	Edge pools and pools in complex river sections.	Spawning migrations, pools, eddies, edge pools in complex areas.	Spawn on ascending limb and near peak on cobble bars. Eddies, flooded vegetation, and pools in complex areas.	Main channel runs in less-complex portions of the river.
Juvenile (YOY)	Poorly understood but likely backwaters and flooded bottomlands.	Poorly understood.	Larvae drift downstream to flooded bottomlands, backwaters, and similar low-velocity, rich habitats.	Poorly understood but likely use flooded bottomlands, backwaters, and other low-velocity habitats.
Flannelmouth Sucker				
Adult	Poorly understood, runs, pools, and riffles in main channel.	Poorly understood, but use runs, pools, and riffles in main channel.	Spawn just after razorback sucker near peak of runoff on cobble bars. Less selective than razorback sucker.	Runs, riffles, and pools.
Juvenile (YOY)	Use habitats with current rather than backwaters and other low-velocity habitats.	Similar to winter.	Larvae drift to backwaters and other low-velocity habitats, juveniles common in secondary channels.	YOY found in backwaters until late summer when they apparently start using habitats with more current such as runs and riffles.
Bluehead Sucker				
Adult	Riffles and other habitats with cobble substrates.	Same as winter.	Same as winter.	Spawn in late June, early July on cobble bars, move back to riffle areas after spawning.
Juvenile (YOY)	Riffles, runs in main channel areas.	Same as winter.	Juveniles common in secondary channels.	Larvae drift downstream to backwaters and other low-velocity habitats, move to habitats with current by early fall.
Speckled Dace				
Adult	Riffles, runs, and other habitats with cobble or gravel substrate.	Same as winter.	Spawn over gravel habitats from late spring to summer.	Larvae found in drift, YOY use backwaters and other low-velocity habitats for a short period before moving to swifter habitats.

Figure 6.1. The relationship between habitat needs and flow for the native fishes of the San Juan River.

Biological productivity appeared to increase during the 7-year research period, and the condition factor of flannelmouth sucker and bluehead sucker responded to these improved conditions. This suggests that mimicry of the natural hydrograph aided in providing better habitat quality.

RELATIONSHIPS BETWEEN FLOW AND NONNATIVE SPECIES

Flow manipulation, especially the creation of high spring peaks, has been suggested as a way to control some nonnative species. However, this thesis is not supported by the results of the 7-year research period in the San Juan River. It appears that reregulated flows do not have the same impacts on reducing nonnative species abundance as do flood events in unregulated rivers (Minckley and Meffe 1987), or perhaps the San Juan River behaves differently than other southwestern streams. Nonnative species were either not reduced by high spring flows in the San Juan River, or they were reduced for only a short period of time and their numbers appeared to remain relatively consistent during most years. Channel catfish larval drift did show a reduction in catch rate during higher-flow years compared to low-flow years, but this difference was not seen in YOY or juvenile channel catfish. Red shiner abundance in secondary channels in RM 77 to 158 were actually positively correlated to the number of days with flows greater than 8,000 cfs.

Summer flow spikes that perturbated red shiner habitats with flow increase and increased sediment, especially those in secondary channels, appeared to cause some reduction in red shiner and fathead minnow numbers, but the overall effect was temporary. Similar patterns in main channel habitats were not identified. Therefore, although the creation of summer flow spikes may have a short-term effect on secondary channel habitats inhabited by these two nonnative species, there is little evidence that such a flow recommendation would result in significant riverwide reductions in their populations. In addition, a summer flow spike could negatively impact the young of the native species, and may have other negative impacts on productivity and other factors important to the native fish community.

FLOW/HABITAT RELATIONSHIPS

As discussed in Chapter 4, a number of studies were conducted during the 7-year research period that documented changes because of mimicry of a natural hydrograph and addressed the flow levels needed to build and maintain important habitats, especially cobble bars for spawning and backwaters for fish nursery areas. One change measured was a decrease in bed elevation, primarily because of a reduction in the amount of sand in the substrate. This change was likely linked to the increase in biological productivity, the increase in bluehead sucker abundance, and the increase in sucker condition factor as discussed above.

Habitat complexity is also important to Colorado pikeminnow and razorback sucker, but habitat complexity as measured by the number of habitats available in a given river reach was not studied directly. Channel complexity as measured by island count is likely related to habitat complexity since many of the complex river sections have high island count (see Figure 4.15). Channel complexity did increase during 1995, a high-flow year with a peak over 10,000 cfs. In addition, more low-velocity habitats and backwaters were available at base flows of 1,000 cfs or lower than at higher base flows. Base flows during the 7-year research period were generally reduced from the pre-study period years, more closely mimicking natural conditions and resulting in more low-velocity habitats and likely increasing habitat complexity.

Cobble bar construction was studied in detail, and it was concluded that flow of 8,000 cfs for 8 days or more are required for cobble bar construction. Maintenance of cobble bars, primarily scouring of fine sediments from interstitial spaces, occurs at a flow of 2,500 cfs or more. The longer the duration of this flow, the more cobble would be cleaned, but a minimum of 10 days prior to spawning would be needed. Since the various native species spawn from late April or May (razorback sucker) to mid-July (Colorado pikeminnow), a long duration for flows at 2,500 cfs would provide clean cobble for all native species.

Backwaters are important low-velocity habitats, especially for YOY Colorado pikeminnow. Backwater quantity and quality are related to fine sediment amounts. Adequate flushing of backwaters is needed to maximize both quantity and quality. Flows of 5,000 cfs for 3 weeks or more are needed for complete flushing of study backwaters after heavy perturbation by fine sediments.

SUMMARY

Studies during the 7-year research period, as well as information from studies in other portions of the Colorado River system, provided considerable biological and physical information that can be used to develop flow recommendations. Table 6.1 summarizes this information by relating the physical flow parameters to the biological response or habitat needs of the fish community as established by research on the San Juan and other Colorado Basin rivers.

Table 6.1. Flow requirements needed to produce important biological responses and habitats in the San Juan River.

BIOLOGICAL RESPONSE/HABITAT REQUIREMENT	FLOW CHARACTERISTIC
Reproductive success of Colorado pikeminnow lower in years with low spring runoff peaks, and higher in years with high and broad runoff peaks.	Mimicry of a natural hydrograph, especially during relatively high runoff years.
Decline in flannelmouth sucker abundance, increase in bluehead sucker abundance, and increased condition factor in both species.	Mimicry of natural hydrograph with higher spring flows and lower base flows.
Bluehead sucker reproductive success.	Increased number of days of spring runoff >5,000 and 8,000 cfs correlated with increased success.
Speckled dace reproductive success.	Increased number of days of spring runoff >5,000 and 8,000 cfs correlated with increased success.
Success of stocking YOY Colorado pikeminnow and subadult razorback sucker.	Mimicry of natural hydrograph has provided suitable habitat for these size-classes.
Eddies, pools, edge pools, other low-velocity habitats year-round for adult Colorado pikeminnow and razorback sucker.	Mimicry of natural hydrograph has lowered base flows to provide more low-velocity habitats. Flows >10,000 cfs provide more channel complexity which provides for more habitat complexity.
Flows to cue razorback sucker and Colorado pikeminnow for migration and/or spawning.	Mimicry of natural hydrograph with higher spring flows.
Adult Colorado pikeminnow and razorback sucker use complex river areas.	Flows >10,000 cfs provide more channel complexity which provides for more habitat complexity, lower base flows add to amount of low-velocity habitats.
Clean cobble bars for spawning of all native species, especially Colorado pikeminnow.	Flows >8,000 cfs for 8 days to construct cobble bars, and >2,500 cfs for 10 days to clean cobble bars, during spring runoff.
Backwaters and other low-velocity habitats are important nursery habitats for Colorado pikeminnow and other native fishes.	High spring flows create conditions for backwater formation, low base flows allow them to appear in late summer and fall, flows >5,000 cfs for 3 weeks create and clean backwaters.
Flooded bottomlands appear to be important nursery areas for razorback sucker, but other habitats may be used in the San Juan River.	Overbank flows (> 8,000 cfs) increase flooded vegetation, and backwaters formed in association with edge features maximize on receding flows of 8,000 to 4,000 cfs.
Temperatures of 10 to 14 EC at peak runoff for razorback sucker spawning and near 18 to 20 EC at bottom of descending limb for Colorado pikeminnow spawning.	Proposed releases from Navajo Dam are too cool to replicate pre-dam temperature timing, but temperatures are above spawning threshold for Colorado pikeminnow during the correct period.
Reduction of nonnative fish abundance.	Most nonnative fishes did not decrease during research period, summer flow spikes reduce numbers of red shiner in secondary channels in the short term.

CHAPTER 7: FLOW RECOMMENDATION DEVELOPMENT PROCESS

Chapter 6 summarized the various biological and physical factors that were important to the native fish community and were related to flow. The next step in the flow recommendation process was to determine how best to structure a flow recommendation that incorporated those various factors. Some flow recommendation processes have used fixed seasonal flow levels, such as 8,000 cfs, as a minimum spring runoff flow. The process envisioned for the SJRIP, a more dynamic recommendation, uses a modeling process that combines physical and biological information with a flow model of the basin. To be useful in this regard, the model needed to (1) include a range of flows, since natural hydrographs are not static; (2) provide information for the reoperation of Navajo Dam, since this is the single controllable feature affecting flow; (3) be useful in evaluating present and future water development effects; and (4) be easily altered as new information becomes available through monitoring and research and the adaptive management process. To meet these needs of the flow recommendation process, a modeling process was developed that mimicked a natural hydrograph as a base and fine tuned the model using important biological and physical factors. This chapter describes the process undertaken to develop the model used to evaluate various development scenarios and their effect on flow requirements for the endangered and other native fishes.

BASIS FOR FLOW RECOMMENDATION

A biological-response driven model for determination of flow recommendations begins with development of habitat selection by species, life stage, and time of year as reported in Chapters 3, 4, and 6. This matrix of habitat selections with time is compared to basic hydrograph components of summer base flow, winter/spring base flow, and ascending and descending limbs of the spring runoff to determine the periods to examine for specific flow/habitat relationships. An assessment of the habitats that will control for each of the habitat segments is made to select those flow/habitat relationships that will be most intensively modeled. The habitat components that are controlling in the flow recommendation process are shown in Table 7.1. Controlling habitats are either backwaters or cobble bars. Other habitats may be more heavily used by the fishes, but the habitat/flow relationships indicate that their abundance is not as directly affected by flow as those listed in Table 7.1 or, if affected, their abundance is adequate at all flows considered. Other habitats preferred during a given time of year (e.g., eddies during summer and fall) may maximize at high flow and therefore could not be maximized without compromising another preferred habitat more abundant at low flow or using an impractical amount of water. In cases of conflict between competing habitat availability, habitat/flow relationships that follow naturally shaped hydrographs would control over those that do not.

Table 7.1. Controlling habitat conditions by hydrograph season.

Period	Habitat Condition Used in Flow Requirement Determination
Summer/Fall Base Flow	Backwaters and, to a lesser degree, other low-velocity habitat (pools, slackwaters, etc.) for YOY Colorado pikeminnow, razorback sucker
Winter/Spring Base Flow	Backwaters and other low-velocity habitats for all life stages
Ascending Limb	Clean cobble for spawning razorback sucker at intermediate to high flow
Descending Limb	Backwater habitat at all flows for YOY razorback sucker and clean cobble for spawning of Colorado pikeminnow at intermediate to low flow

Habitat availability is dependent upon two relationships: (1) habitat formation and maintenance as a result of flow/geomorphology relationships and (2) availability of habitat vs. flow following creation or maintenance of the habitat. Each of these relationships is controlled by the response of channel morphology to flows. Because the habitat-forming flows usually occur during spring runoff, the flow/geomorphology relationship becomes critical in defining the shape of the runoff curve and the frequency of occurrence of specific flows.

In addition to the habitat selection/habitat availability/geomorphology/flow relationship, there are direct biological responses to flow conditions that are considered in completing flow recommendations (see Chapter 4). In cases where two conditions compete, the one that controls is the condition that would most directly positively affect the endangered species.

FLOW/HABITAT MODEL

Two types of flow/habitat relationships were considered. The first type consisted of those relationships between the specific habitats and the hydrologic conditions. These relationships deal with flow/geomorphology relationships such as cobble and fine sediment transport and are discussed separately. The second type includes those relationships between habitat availability and flow and were based on data reported in Chapters 3 and 4. Another type of relationship exists that relates habitat quality to flow. While these direct relationships for habitat quality could not be adequately quantified to model, the relationships tended to follow the conditions necessary to maximize area. Therefore, they are implicitly addressed in the flow/habitat availability relationships. For example, backwater quality is dependent largely on backwaters being relatively clean of sand or silt that may fill the backwater. Summer and fall storm events often fill backwaters with sediment, reducing their productivity and usefulness to native fishes as well as reducing the number and size of backwaters available at a particular flow. Therefore, flows designed to clean backwaters of sediment are the same flows that maximize backwater area so the quantity and quality of backwaters are directly related to the same flow events.

While a range of low-velocity habitats are used by YOY Colorado pikeminnow in particular, backwaters (sum of backwaters, embayments, and backwater pools) were used most heavily in relation to availability (see Chapter 6). For example, 60% of the stocked YOY Colorado pikeminnow captured were in backwaters (see Chapter 4), yet backwaters account for only about 20% of all low- velocity habitats in the San Juan River at low flow (see Chapter 3). Pools accounted for another 15% of the captures and slackwaters 13%. Further, conditions that maximize backwaters also maximize pools and shoals, two low-velocity habitats (Figure 7.1), but not eddies or slackwaters. Slackwater area is relatively independent of flow, while eddies increase with increasing flow in the San Juan River (Figure 7.1). Since backwaters are most limiting and most used, they were used in the flow habitat modeling process.

Flow/habitat relationships for backwaters were developed for each of Reaches 1 to 6. Because Reaches 3 and 4 were easily filled with sediment by summer/fall storm events, two relationships were developed. The first relationship was developed using data for which no perturbating storms occurred between the end of runoff and mapping. The second relationship was developed from a perturbation model relating the number of storm-event days to the amount of habitat area lost.

A storm-event day was defined as a day when the daily gain in flow between Farmington, New Mexico, and Bluff, Utah, and the daily flow at Bluff, Utah, were each more than 150 cfs greater than the preceding 5-day average. A storm-event day was given a weight of 2 if the gain in flow was 3,000 cfs or more. These two parameters were selected based on calibration against known storm events in the last 3 years, optimizing for the number of storm events accurately predicted. There were 19 storm events with sediment concentration measurements during the 7-year research period of which 16, or 84%, were predicted with the model. The three storm events that were not predicted had elevated sediment concentrations with a very small change in flow. There was no statistically significant relationship between sediment concentration and flow for these 19 storm events.

Based on this model, the perturbating storm events were predicted for each month for the period August through December, measured by the weighted storm event days. For each habitat mapping, the number of storm-event days was computed between the end of runoff and the time of mapping. Habitat-mapping data were grouped into three categories: (1) nonperturbated and flushed (runoff adequate to clean backwaters), (2) nonperturbated and not flushed, and (3) perturbated. A flow/habitat relationship was developed for each reach utilizing the nonperturbated measurements. A second curve was developed for Reaches 3 and 4 for nonflushed conditions. The average perturbation (loss of habitat area) per weighted event day was computed for Reaches 3 and 4 by comparing the measured habitat area with the prediction of the flow/habitat model for nonperturbated conditions and dividing the average loss by the average number of weighted event days for that reach. By this process, it was found that Reach 3 lost 6% of the habitat area for every weighted event day, and Reach 4 lost 5%. The other reaches did not show a consistent trend, indicating that the variability of data from the model is random rather than associated with perturbation. Figure 7.2 shows the individual data points and model curves for Reach 3. Figure 7.3 presents the combined model curves for Reaches 1 to 4 (flushed and nonflushed) and Reaches 1 to 5 (flushed and nonflushed).

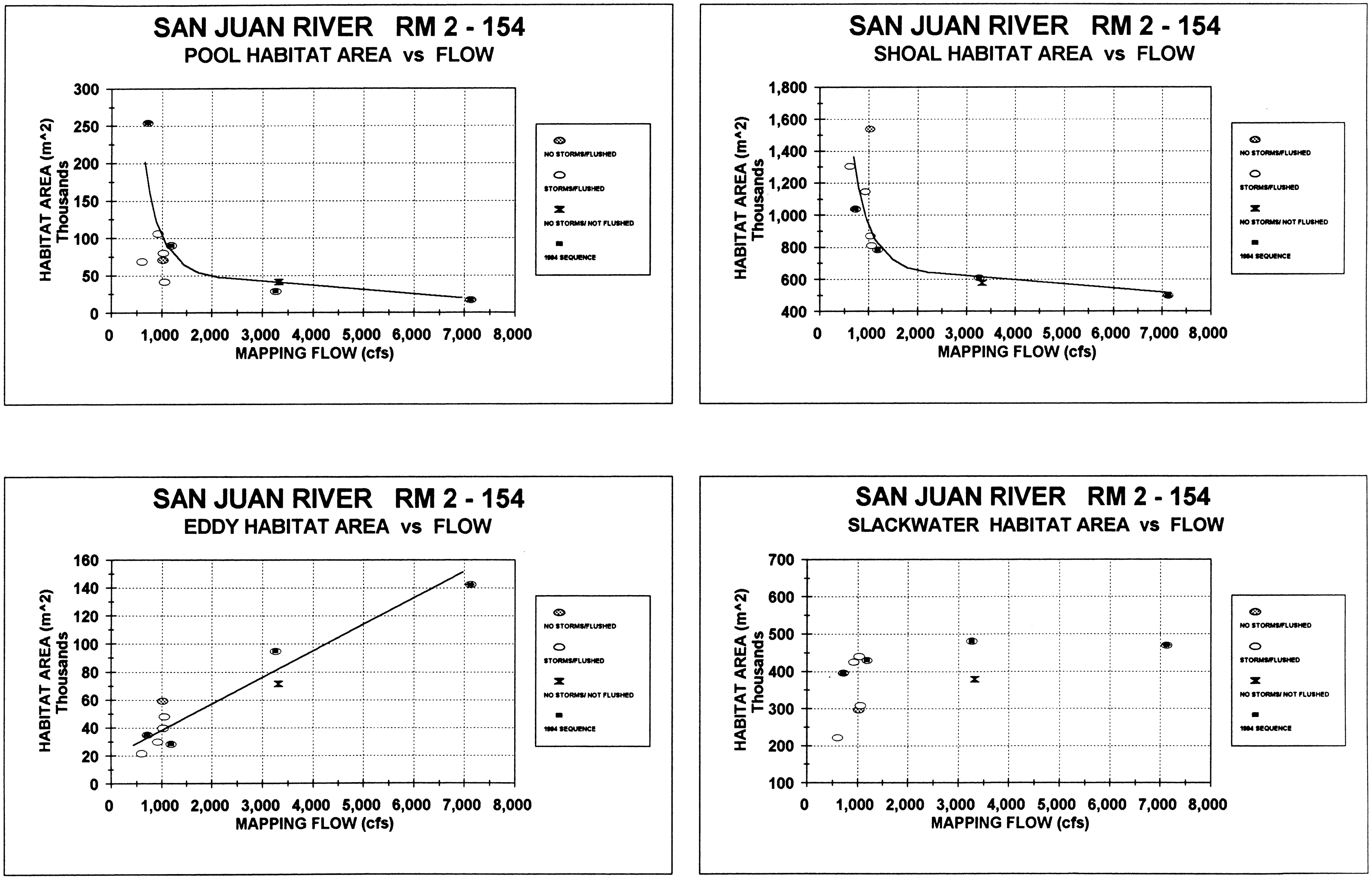


Figure 7.1. Flow/habitat relationships for four low-velocity habitats used by rare fishes in the San Juan River.

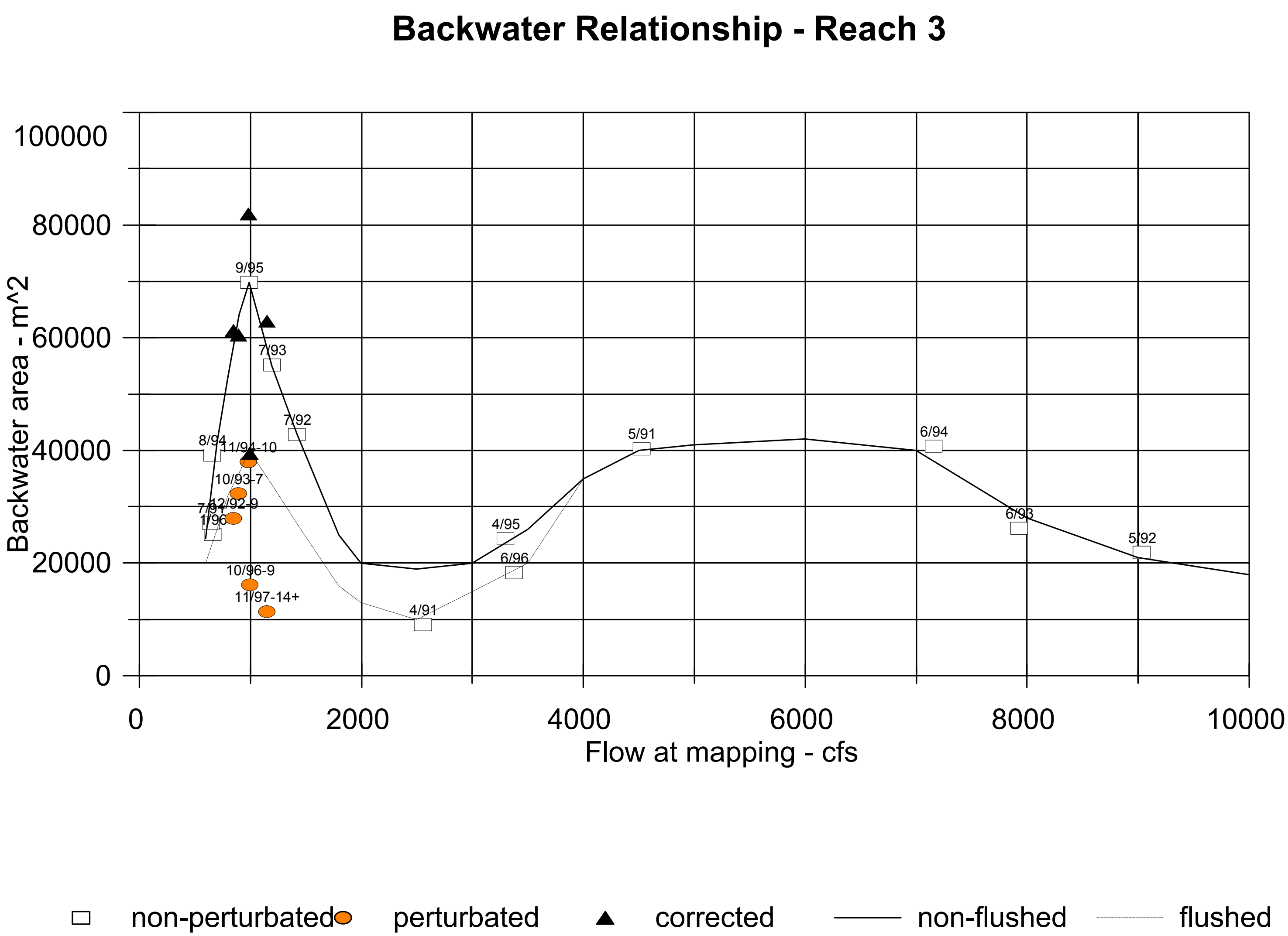


Figure 7.2. Flow/backwater habitat area relationships for Reach 3.

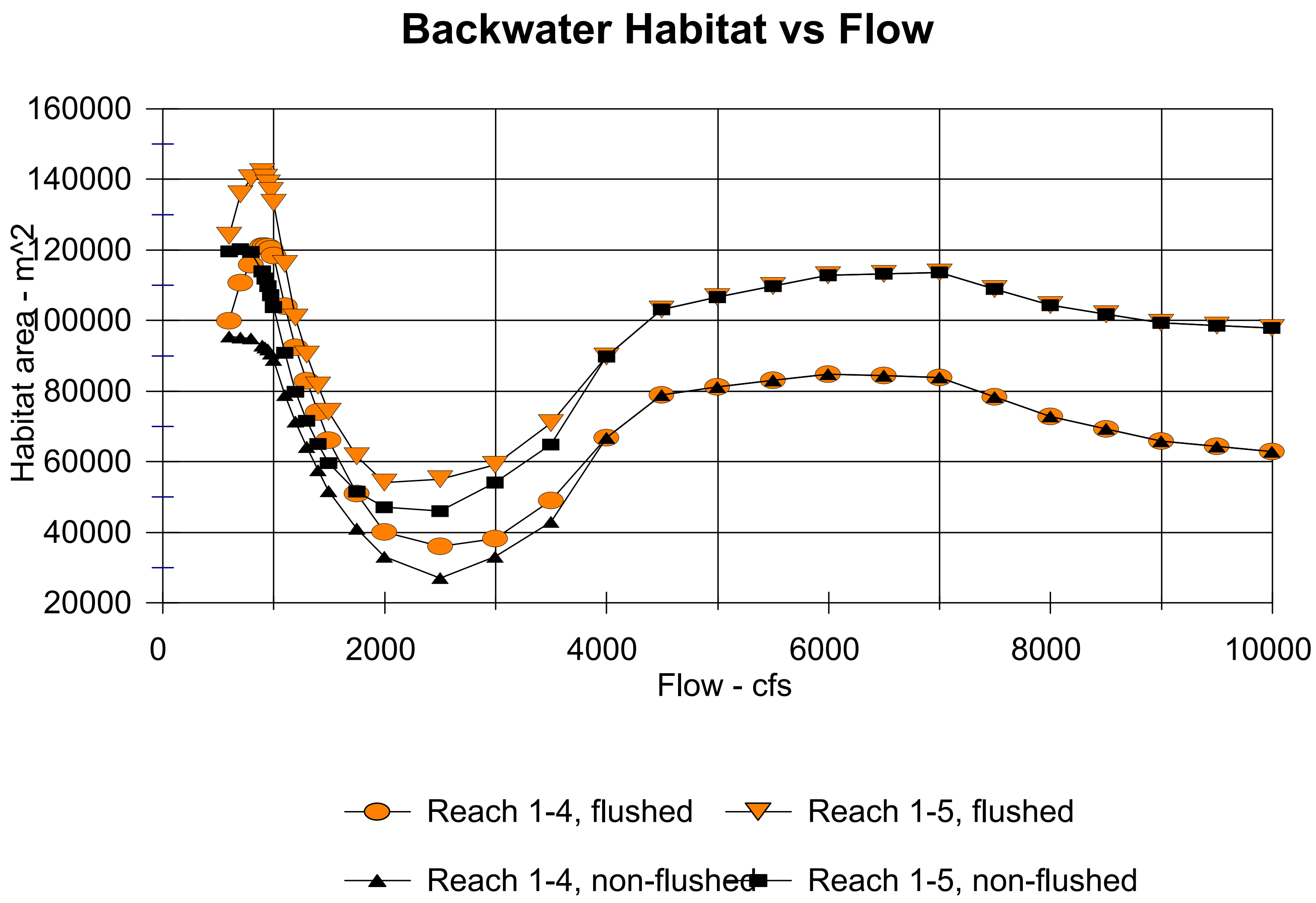


Figure 7.3. **Flow/backwater habitat model for Reaches 1 to 4 and 1 to 5 based on flushed and nonflushed conditions.**

In application, if runoff flows exceeded 5,000 cfs for 21 days or more, then the flushed model was used, and the average habitat available for the month was predicted to be that available at the mean monthly flow, less the perturbations to date. If the runoff flows were over 5,000 cfs for 1 day but less than 21 days, the post-runoff maximum was linearly interpolated between the nonflushed and flushed curves and then perturbated as above. If runoff flows did not exceed 5,000 cfs, then the previous December value was used as the new base from which to perturbate. In all cases, the minimum habitat area computed was 322,800 ft^2 for Reaches 1 to 4 and 430,400 ft^2 for Reaches 1 through 5. A linear regression of the modeled backwater area against the actual area for the available data utilizing this model yielded an r^2 of 0.89 ($p<.01$, $n=78$) for the combination of Reaches 1 through 5. This model was applied to each year of the historical hydrograph and each year of each modeled condition to determine the impact to backwater habitat area for each level of development analyzed.

SEDIMENT TRANSPORT MODELING

Two levels of sediment transport modeling were completed (see Chapter 4). Cobble transport related to spawning habitat and fine sediment transport related to backwater maintenance.

Cobble Transport Modeling for Spawning Bar Preparation

Spawning habitat for Colorado pikeminnow and razorback sucker depends upon clean cobble. It is assumed that cobble bars with open interstitial space exceeding 1.5 times the median cobble diameter in the bar meet the necessary conditions (Bliesner and Lamarra 1995). This information was based on actual measurements taken at spawning areas on the San Juan, Colorado, and Yampa rivers. Cobble movement and cobble bar characterization studies discussed in Chapter 4 established that clean cobble exists when flows exceed 2,500 cfs prior to characterization. It was deduced from the data collected that 10 days of flows exceeding 2,500 cfs would be minimally adequate to prepare cobble for spawning in the short term. A conservative assumption is that spawning would not be successful in years that these conditions are not met. Observation of the river during low flow suggests that some spawning habitat would exist, even at very low flows, but no studies have been conducted to quantify such a possibility.

For Colorado pikeminnow in the San Juan River, clean cobble must exist at flows near base flow in July. These cobble locations are the most difficult to keep clean because of fine sediment inflow and penetration of the bar. Criteria were established to protect spawning conditions under these limiting constraints. Razorback sucker spawn at higher flows on the ascending limb or at the peak. At the higher stages associated with larger flows, more clean, loose cobble is available. It is therefore assumed that if adequate spawning habitat is available for Colorado pikeminnow, it will be available for razorback sucker.

This cobble bar maintenance flow threshold assumes that flows are periodically of sufficient magnitude to transport adequate quantities of cobble to re-form old bars and/or form new ones that may subsequently erode and develop clean locations. Based on the modeling results reported in Chapter 4, it was determined that bankfull flows of 8,000 cfs for 8 days or more are required for bar construction. While the test period did not include enough low-flow years to assess the minimum frequency of occurrence of these bar building flows, assessment of historical spawning data (Table 4.14) indicates some spawning success occurred during 5 years of flows that did not meet these conditions (1988 to 1992), although spawning was not documented during all of these years. However, 5 years is an inadequate frequency to maintain channel capacity. During the period 1962 to 1991, the average frequency of meeting the criteria of 8,000 cfs for 8 days was 26%, when the channel below Farmington exhibited a slight narrowing and deepening based on cross-channel surveys measured in 1961 and 1994 (Bliesner and Lamarra 1995). At the same time, the bankfull channel surface area, as interpreted from aerial photography, was reduced by about one-third, mainly because of vegetation of secondary channels. The cross-sectional area was not lost, but some channel capacity was lost because of increased roughness in these channels. Given these conditions, an average frequency of 1 year in 3 for a 8,000-cfs spring peak (8 days minimum) is recommended for channel maintenance purposes.

Fine Sediment Transport

The U.S. Army Corps of Engineers (Corps) HEC-6 model was used to model fine sediment transport conditions in two secondary channel/backwater associations (see Chapter 4). From this modeling activity, flows of 5,000 cfs for at least 21 days were determined necessary for backwater cleaning. The frequency required depends on the perturbating conditions from summer/fall storm events. An operational rule was added to the river operation simulation model to provide at least a minimum flushing release in years following a perturbating post-runoff period, defined as having more than 13 weighted storm event days.

The shape of the release hydrograph was also determined based on modeling a range of typical hydrographs (see Chapter 4). The primary release hydrograph would have a 4-week ramp up, a 3-week peak, and a 2-week descending limb to optimize the sediment transport conditions for both fine and course sediment. Secondarily, this hydrograph would be reduced to a 1-week ramp up, a 1-week peak, and 1-week ramp down as a minimum, with the priority of first reducing the descending limb, then the ascending limb, then the peak.

RIVER OPERATION SIMULATION MODEL

Basin-scale models exist that take hydrologic input data and simulate the behavior of various processes under different sets of water allocation and infrastructure management. A distinguishing feature of these simulation models is their ability to assess water resources system responses over the long term.

There are several best-science river basin simulation models available, any one of which would be appropriate for developing and analyzing San Juan River flow recommendations. RiverWare was selected primarily because of its flexibility and capability to simulate all key features within the San Juan River Basin. Also, the Bureau, principle collaborator in developing RiverWare, was willing to support its application in the San Juan River Basin.

Selection of RiverWare allows attention to focus on the data and analyses of deriving flow recommendations, rather than on the generic hydrologic modeling tool employed. Its present configuration, associated post-processing requirements, and tools are being documented and packaged for availability through the Bureau.

RIVERWARE

RiverWare is a generic hydrologic modeling tool using an object-oriented design and a graphical user interface (GUI) to allow users to develop data-driven and variable time-step models for both planning and operational uses. Because of its flexible and extensible design, it can be readily customized to fit specialized modeling needs for any river system. One of the features of RiverWare is its ability to solve a river basin network (developed by the user with the GUI) with different controllers or solution techniques. Currently, there are three different controllers: simulation, rule-based simulation, and optimization. A fourth controller for water ownership and accounting is currently being developed. RiverWare has been in development since 1993 and is the result of a continuing collaborative effort between the Center for Advanced Decision Support for Water and Environmental Systems at the University of Colorado, the Bureau, and the Tennessee Valley Authority (TVA).

A model of a river system network is constructed by placing objects from a palette onto a workspace using the GUI. Objects in RiverWare represent the features of a river basin. The objects supported by RiverWare are storage reservoirs, power reservoirs, pumped storage reservoirs, river reaches, aggregate river reaches, confluences, aggregate diversions for municipal and industrial (M&I) and agricultural demands, canals, groundwater, and data objects. Each object has many slots. Slots are essentially place holders for information associated with that object. For example, a storage reservoir has slots such as inflow, outflow, storage, evaporation, elevation, and volume tables. The slots that are visible depend on the methods that the user selects. Almost all of the objects have several different methods available, thus allowing the user to easily customize the physical behavior of an object. For example, to change how a reservoir computes its evaporation, the user simply selects an appropriate evaporation method from the list of methods on the reservoir object. RiverWare adds the appropriate slots to the object and the user provides the necessary data. The selected method and data control how the reservoir will compute its evaporation. After the objects are put into the workspace and the appropriate methods are selected, they can be linked together so information from one object is propagated to another. For example, the outflow of a reservoir could be linked to the inflow of a downstream river reach. By selecting appropriate objects, methods, and linking the objects together, a river basin network is formed.

After the river basin network is complete, the user can take advantage of many features and utilities that make it easy to input, output, view, manipulate, and analyze data in a model. These utilities include the Simulation Control Table, Data Management Interfaces, plotting, snapshot, expression slots on data objects, and the ability to write binary Microsoft Excel spreadsheet files. Simulation Control Tables allow the user to customize views of information in the model and also to run the model and view the updated model run results. Data Management Interfaces provide a way to transport data between a model and external data sources, such as a database or an ASCII file. With the plotting utilities, virtually any information in the model can be easily plotted for analysis and report generation. The snapshot utility provides the user a way to save information from a model run so it can be used to compare with subsequent model runs. Expression slots on data objects provide a powerful way to algebraically manipulate data within the model. Additionally, RiverWare has a robust diagnostics utility for checking for and helping to pinpoint problems.

Current RiverWare applications where the models are operational include: (1) long-term policy planning model on the Colorado River (rules model with monthly time-step); (2) midterm planning and operations model on Colorado River (24-month simulation model with monthly time-step); (3) daily operational model for Hoover Dam (BHOPS, simulation model); (4) operational model for the TVA (TVA, optimization model with 6-hour time-step); (5) Upalco Planning Model (rules model with daily time-step); and (6) San Juan River Model for SJRIP (rules models with monthly and pseudo daily time-step). RiverWare models currently under development include: (1) Upper Rio Grande River Basin Model (accounting and rules model with daily time-step); (2) Gunnison River Basin Model (rules model with monthly time-step); and (3) Yakima River Basin Models (rules models with both monthly and daily time-steps).

RIVERWARE MODEL OF THE SAN JUAN RIVER

Hydrologic simulation models, such as RiverWare, are essentially mass balance models operating within a rule-based framework to simulate hydrologic interactions among water sources and their uses. Maintaining a water balance assures that the sum of inflows less the sum of outflows equals the change of storage within the basin. Water inflows consist of natural stream flows, transbasin inflows (Dolores Project return flows), and precipitation. Outflows consist of water flowing across the downstream basin boundary (San Juan River at Bluff), consumptive use (crops, M&I, natural vegetation, free water surface evaporation, etc.), and transbasin diversions (San Juan-Chama). Water storage consists of the water within basin lakes and reservoirs, soils, and groundwater aquifers.

In the San Juan River model, only unnatural (man-induced) hydrologic effects are explicitly modeled. The model begins with the natural inflows and natural, ungauged, gains and losses to river reaches. Starting from this basis eliminates the need to model natural hydrologic processes such as rainfall/runoff. Thus, precipitation falling upon natural vegetation, consumptive use by natural vegetation, runoff of excess precipitation, evaporation from the free water surfaces of rivers, etc. are assumed to be reflected in the natural inflows and reach gains and losses and are therefore not modeled. Likewise, it is assumed that precipitation runoff from man-affected areas (agricultural lands, cities, etc.) is not significantly different from natural conditions to warrant explicit modeling treatment.

Thus, the inflows for the simulated water balance of the San Juan River Basin consist of the estimated natural inflows, stream reach gains, and the Dolores Project return flow to the San Juan River Basin. The outflows consist of the man-affected (gaged) flow of the San Juan River at Bluff, consumptive irrigation (irrigated crop evapotranspiration less effective precipitation), M&I depletions, net (in excess of natural) evaporation from manmade reservoirs and stock ponds, and the San Juan-Chama Transbasin Diversion. The change in storage is reflected in the difference between beginning and ending reservoir content and groundwater volume. Groundwater storage in the current model includes the underlying NIIP and the irrigation in McElmo and Montezuma creeks. The effects of soil water storage for irrigated lands are assumed to be reflected in the effective rainfall and consumptive irrigation calculations and are not explicitly modeled.

The 1970 to 1993 monthly natural flows expected at 23 gauging stations along the San Juan River and its tributaries above Mexican Hat, Utah, were calculated by the Bureau. The monthly natural flows were estimated by adjusting gaged flows to account for upstream irrigated crop depletions, reservoir influences (operational and evaporative), transbasin diversions, M&I uses, and flows directly bypassing the gage. Natural reach gains and losses were calculated as the difference in the natural flow estimates between gauging stations. No lagging of return flows (diversions less depletions) was incorporated except for the three areas underlain by the simulated groundwater storage.

Irrigated crop depletions were calculated using the SCS TR21 modified Blaney-Criddle consumptive use less effective precipitation. When water supplies are insufficient to meet diversion requirements for full crop demand, shortages are simulated following the Type I study approach. The Bureau's XCON program was used to compute both nonshorted and shorted irrigation depletions.

Previous modeling of the San Juan River in support of project authorization and Consultation relied on Colorado River Simulation System (CRSS) estimates of the 1929 to 1974 monthly natural flow at Archuleta, New Mexico, and Bluff. As part of the current exercise, an analysis of the 1929 to 1974 streamflow record was conducted to determine whether there were differences in the statistical properties of the San Juan River Basin hydrology pre- and post-1974. Statistics were calculated using a 20-year moving window to assess changes in the mean flow and the variability and seasonality of the flows. An investigation of the impacts on reservoir storage needed to meet various target yields and yield failure was also performed. The 1974 to 1993 record was found to exhibit significant differences from the prior record in terms of these criteria. It was a relatively wet period. It was therefore determined that inclusion of the 1929-1973 data would likely lead to more reasonable and more stringent estimates of low flows and drought conditions.

Therefore, the monthly 1970 to 1993 natural flows recalculated by the Bureau as explained above were extended from 1969 back to 1929 using a spatial disaggregation model. The particular disaggregation model used preserves the mean, standard deviation, and one-month lag statistics of the hydrologic series. The model relies on key stations with full periods of record (in this case 1929 to 1993) as drivers for the record extension. The natural flows at Archuleta and Bluff were forced, by adjusting stream reach gains and losses to exactly match the CRSS natural flows at Archuleta and Bluff for the period 1929 to 1969.

The 1935 to 1993 monthly gaged record for the San Juan River at Pagosa Springs, Colorado, served as the key station for stations, including all tributaries, above Navajo Reservoir. The gaged record at Pagosa Springs was extended back to 1929 using the spacial disaggregation method with the 1929 to 1934 CRSS natural flow for the San Juan River near Archuleta as its key station. For stations in the Animas drainage, the Animas River at Durango, Colorado, was the key station for 1929 to 1993. The tributaries entering the San Juan River below Farmington (La Plata, Mancos, and McElmo) were disaggregated using the La Plata River at Hesperus, Colorado, as the key station.

From the full set of natural flows (the 1929 to 1969 extension and the 1970 to 1993 Bureau natural flows) the gains and losses were calculated for each reach by subtracting the upstream stations from the downstream station. However, for stations along the San Juan River (Farmington, Shiprock, and Four Corners, New Mexico), another method was used to find the gain and loss files. The reasons for this change were: (1) for this study monthly natural flows at these stations needed to be further disaggregated into daily values; and (2) the daily gage error at these stations could be suppressed by using a different method to find gains and losses.

For these stations along the mainstem of the San Juan River, the monthly natural flows for 1929 to 1969 were estimated by distributing gains and losses between Archuleta and Bluff (Mexican Hat). The method consisted of subtracting the monthly natural flows of the La Plata River, the Mancos River, McElmo Creek, and the CRSS San Juan River near Bluff from the CRSS natural flow at Archuleta. The net gains and losses in this reach were then distributed among the intermediate stations along the mainstem of the San Juan River. The distribution for each reach was calculated as the mean annual gain or loss using the 1970 to 1993 natural flows for the appropriate station set. The distributions, expressed as a percentage of the total gain or loss by reach, were 0.0% from Archuleta to Farmington, 7.0% from Farmington to Shiprock, 58.7% from Shiprock to Four Corners, and 34.3% from Four Corners to Mexican Hat. Using these percentages, the monthly gain or loss was computed for each intermediate station for years 1929 to 1969. For 1970 to 1993 the gain or loss was found by the difference of the Bureau natural flows.

The RiverWare model of the San Juan River Basin operates on a monthly time-step, simulating the flow at every gauging station for various depletion scenarios (current, depletion base, and various potential future projects). The model determines daily flows for the simulated Navajo Dam releases only. Monthly flows provided insufficient information to adequately describe the runoff hydrograph (magnitude, duration, timing, and shape) or to link with the other models (sediment transport and habitat) integrated within this study. Thus, it was necessary to temporally disaggregate monthly flows to daily flows for the San Juan River mainstem below Navajo Dam. This was achieved by a daily mass balance on the mainstem computed in a spreadsheet after each RiverWare run. The daily distribution of natural stream reach gains and losses were estimated using the difference between daily gage records. Likewise, the gaged flow records for the Animas, La Plata, and Mancos rivers at their mouths were used to disaggregate the RiverWare simulated monthly flow of each river to daily flow. Simulated monthly diversions and return flows along the mainstem were disaggregated to daily values by distributing the monthly flows into quarter month values. The distributed quarter month flows were then uniformly converted to daily flows.

Irrigation diversions, depletions, return flows, transbasin diversions, and M&I uses were explicitly represented and modeled in RiverWare for all major San Juan tributaries (San Juan River above Navajo Dam, Piedra, Los Pinos, Animas, La Plata, and Mancos rivers and McElmo Creek). All other tributaries were aggregated into the gains and losses to the reach of the San Juan River into which they flow. The unnatural depletions from these minor tributaries were treated as direct diversions from the San Juan River. Navajo, Vallecito, and Florida reservoirs and Jackson Gulch were explicit nodes within the model and their operations were simulated according to rules. Operations of Electra Lake and all other water impoundments, including stock ponds, were ignored. However, the evaporation losses from these facilities were included as depletions from their associated streams.

Several refinements were developed to compensate for peculiarities in the way the natural flow study handled some depletions and the resulting RiverWare configuration. In the natural flow study offstream depletions, remote from the mainstem and major tributaries, were treated as direct diversions from the mainstem. As a result these offstream depletions, both irrigation and nonirrigation, could call on Navajo Reservoir in the model and overdraw the reservoir during simulations. By limiting these offstream depletions to the natural gains occurring within their associated river reach, this problem was avoided. Other refinements included compensation for phreatophyte depletions along the mainstem and adjustments to lag return flows.

The San Juan-Chama project was simulated following the rules of the Authorization Act. Daily bypass flow requirements in the Rio Blanco, Little Navajo, and Navajo rivers were maintained. The maximum single year diversion (270,000 af), maximum total 10-year diversion (1,350,000 af), and capacity of the diversion tunnels were also respected. The diverted water was stored and released from Heron Reservoir, which was also simulated in the San Juan RiverWare model. The release pattern from Heron Reservoir followed the mean call pattern of the current San Juan-Chama contracts.

The proposed Animas La Plata Project (ALP) was simulated in RiverWare by entering the flow impacts the project would have at various points along the San Juan, Animas, and La Plata rivers. These impacts were determined by the Bureau’s daily simulation model of the ALP for two project configurations. The configuration included in the depletion base model simulation was for Phase 1, Stage A. The long-term average depletion for this configuration as described in the February 1996 Biological Opinion is 57,100 acre feet (af) per year. The modeling results provided by the Bureau and included as a demand in the RiverWare model show an average depletion of 55,610 af per year. The second configuration, included in one of the future development simulations, is for full project development resulting in an average annual depletion of 149,200 af. The Bureau modeling results that were used in the RiverWare run presented an average depletion of 143,514 af per year. Due to the discrepancy, the depletions for these two configurations are under-represented in the RiverWare model.

Figure 7.4 shows a hydrologic schematic of the San Juan River Basin as modeled. Figure 7.5 shows the model as it appears on the computer screen, showing the nodes and the links (lines) among them, described above, along the San Juan River mainstem from Navajo Dam towards Farmington.

Before using the San Juan RiverWare model for analysis and derivation of flow recommendations, it had to be validated, verified, and calibrated like any model. The configuration of the model was validated by having the model simulate gaged flows from the natural flows and the historical depletions, reservoir releases, and flow routing used to compute the natural flows. This was essentially a back-calculation of the gaged flows from the natural flows. The model configuration was determined to be valid once the simulated flows at all gage points exactly matched the gaged flows.

Once the model configuration was validated, reservoir operation rules were substituted for the historic releases, and the model was rerun. The reservoir operating rules were calibrated so that the end of month reservoir contents closely matched the historical observed contents. Once this match was obtained, rules designed to simulate the Type I shortage were implemented and the full irrigation demands substituted for the historical shorted demands. Again the rules were adjusted until the simulated flows at all gauging stations closely matched the observed gaged flows. Once this was achieved the model was assumed calibrated and verified.

Simulation of reservoir operations, particularly reoperation to “mimic” natural flows, requires forecasts of reservoir inflows. For forecasting inflows to Vallecito and Lemon reservoirs, the fraction of the deviation of the actual inflow from the mean inflow is added to the mean inflow. The deviation fraction starts small early in the year and approaches 100% when close to the peak runoff month. For the Navajo Reservoir operation simulation, a forecast error approach is used, whereby the mean historical forecast error for each month is predetermined and applied. Reoperation of Navajo Dam also requires forecasting the time of peak runoff for the Animas River. At this time, the median Animas River peak flow date (June 1) is set as a constant, since no significant relationship could be developed for predicting timing of the peak. The required timing of the peak release from Navajo Dam was adjusted to optimize the hydrograph statistics to mimic the 1929 to 1993 period of analysis.

PARAMETER SELECTION AND OPTIMIZATION PROCESS

Once the basic model was complete and ready to use, the parameters of interest in judging whether flow recommendations were being met were developed. The parameters presented in Table 7.2 are those used to evaluate reservoir operating criteria and flow recommendations. These parameters include species and habitat response attributes that were developed from the summary in Chapter

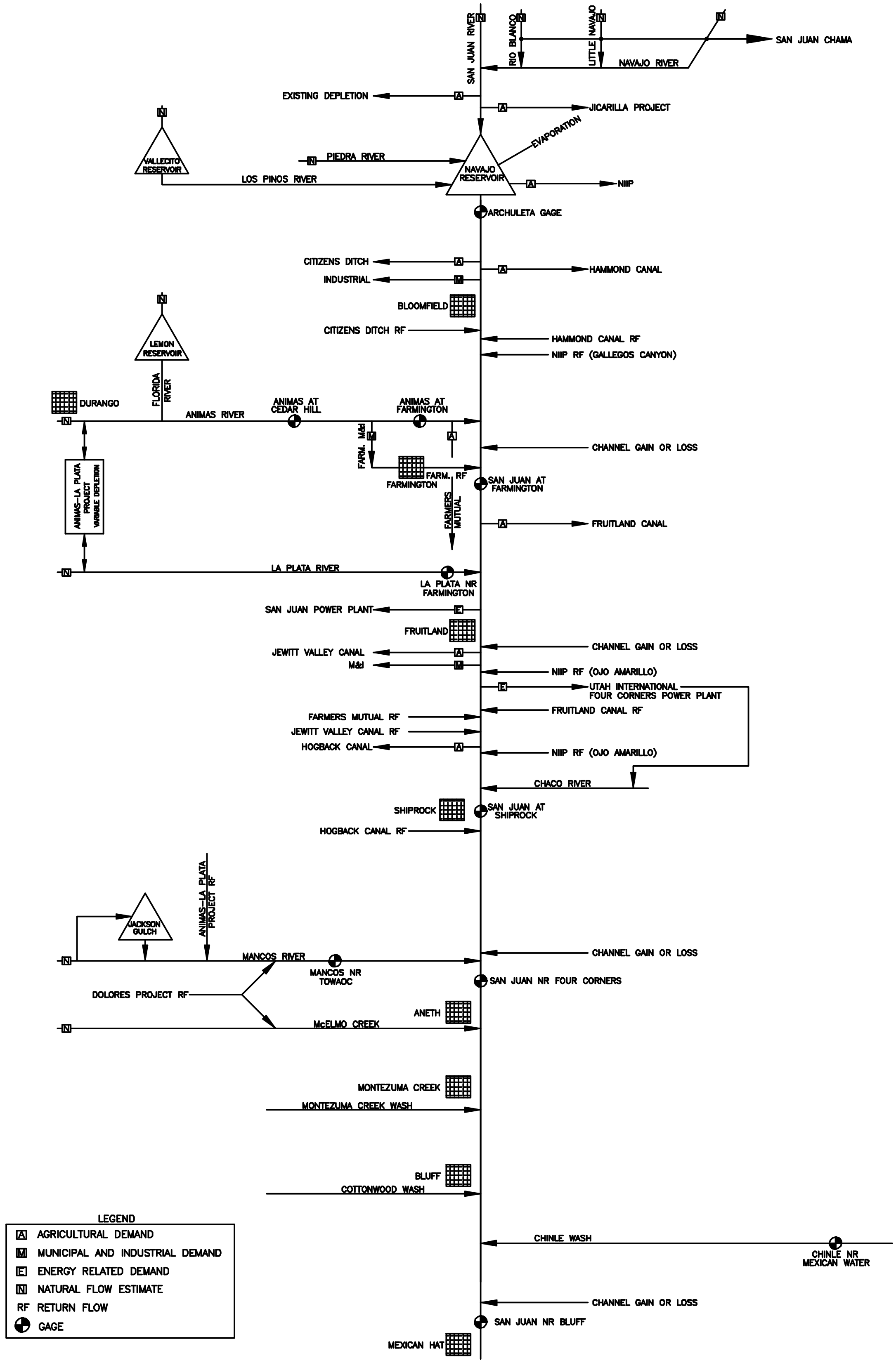


Figure 7.4. Schematic of the San Juan River Basin as modeled, excluding gains and losses associated with the Animas-La Plata Project (ALP) without modeled details of the tributaries.

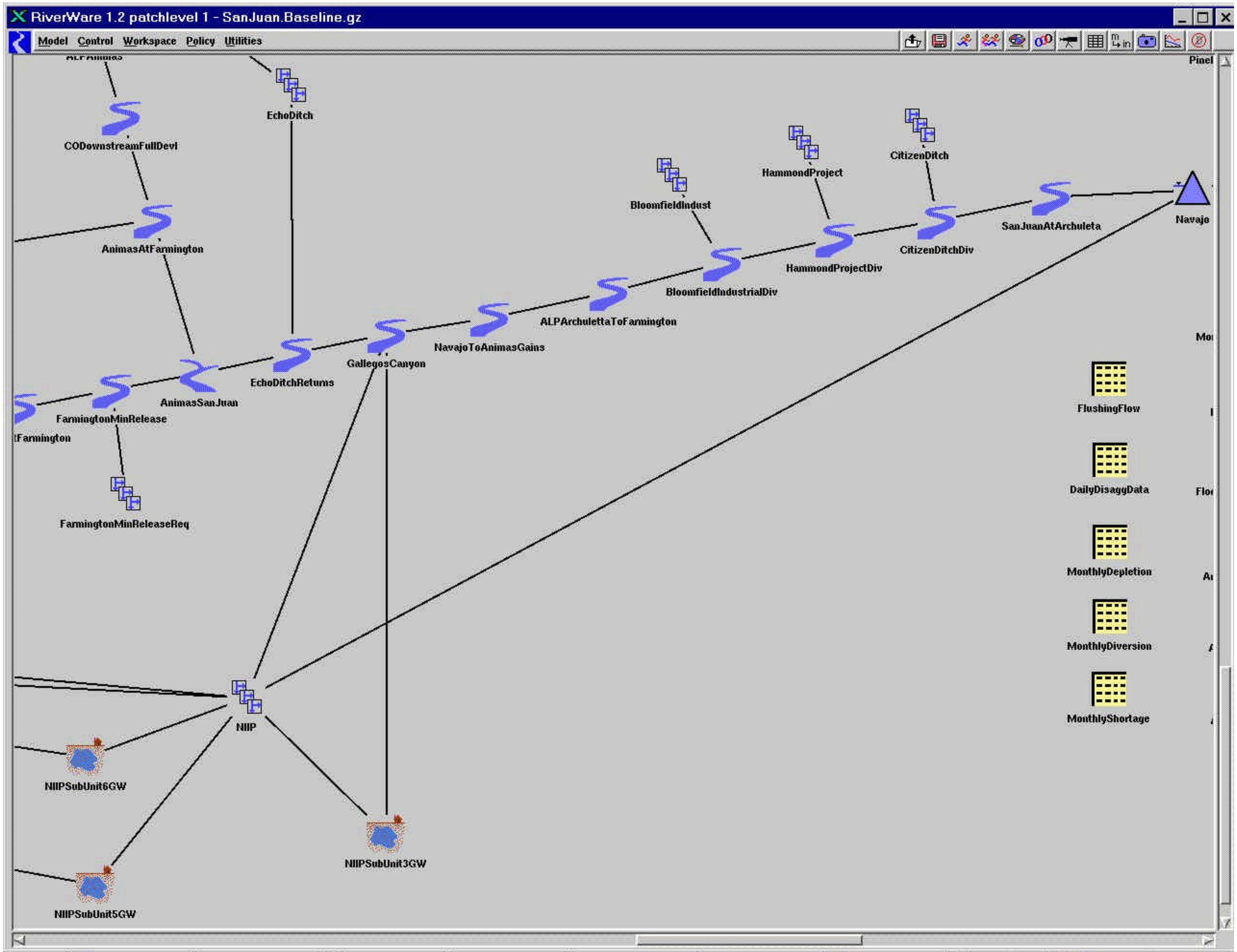


Figure 7.5 **The San Juan RiverWare Model as it appears on the computer screen showing the mainstem reach from Navajo Dam downstream towards Farmington, New Mexico.**

Table 7.2. Parameters used for comparison and optimization in the operation modeling process.

Peak runoff magnitude - cfs	Average and minimum frequency 5,000 cfs for 21 days or more
Runoff volume (Mar to July) - af	Average and minimum frequency 2,500 cfs for 10 days or more
Duration of flow above 10,000 cfs	Average date of peak
Duration of flow above 8,000 cfs	Standard deviation of peak
Duration of flow above 5,000 cfs	Backwater habitat availability during base flow for Colorado pikeminnow
Duration of flow above 2,500 cfs	
Average and minimum frequency 10,000 cfs for 5 days or more	Backwater availability during high flow for razorback sucker
Average and minimum frequency 8,000 cfs for 10 days or more	

6. For example, 8,000 cfs for 8 days is the habitat criteria for building cobble bars, but it was modified to 8,000 cfs for 10 days to consider biological response of native species, primarily bluehead sucker and speckled dace.

These parameters were computed for pre-dam, post-dam, and research period conditions and comparable projected conditions under various scenarios of hypothetical future development. The results of future development runs were then compared to the standards set and historic conditions to arrive at optimal operating criteria for various levels of development.

The reservoir operating rules associated with the operation model were tested and optimized to generate the best set of conditions from the list in Table 7.2 for every development option considered. The operating rules presented in Chapter 8 resulted from this operation sensitivity analysis.

The final step was to select several hypothetical operation scenarios with which to run the model to determine if and when the flow recommendations could be met. These scenarios included "current conditions" based on 1993 acreages for all projects taken from a recent Bureau natural flow study. This scenario most closely reflects the conditions that have been observed during the 7-year research period and provides a basis for comparing the results of the other scenarios that represent future development potential. Tables 7.3 and 7.4 present depletion levels for each scenario with 5,000-cfs and 6,000-cfs peak reservoir releases respectively. These release levels span the range of practicable maximum reservoir releases.

All additional scenarios were developed based on hypothetical, or proposed, water use. The "depletion base condition" was based on the depletion levels used in recent Consultations for ALP and NIIP adjusted to reflect "corrections" by the states of Colorado and New Mexico. For example, ALP was included at 55,610 af (Tables 7.3 and 7.4) to reflect the results of that Consultation. This

Table 7.3. Summary of average annual depletions[a] for each model scenario with a peak release of 5,000 cfs.

	CURRENT[b] (AF)	DEPLETION BASE[c] (AF)	DB+59,000 (AF)	DB+122,000 (AF)	DB+210,000 (AF)	DB+280,000 (AF)
NEW MEXICO DEPLETIONS[d]						
NAVAJO LANDS IRRIGATION DEPLETIONS						
Navajo Indian Irrigation Project	135,330	149,403	209,402	272,642	272,642	272,642
Hogback	9,535	12,100	12,100	12,100	12,074	12,025
Fruitland	6,147	7,898	7,898	7,898	7,874	7,849
Cudei	715	900	900	900	900	895
Subtotal - Indian Lands	**151,727**	**170,302**	**230,301**	**293,541**	**293,488**	**293,411**
NON-NAVAJO LANDS IRRIGATION DEPLETIONS						
Above Navajo Dam	925	1,189	1,189	1,189	1,189	1,187
Animas River	24,873	36,725	36,725	36,725	36,725	36,725
La Plata River	8,276	9,639	9,639	9,639	9,639	9,639
Upper San Juan	6,680	9,137	9,137	9,137	9,107	9,079
Hammond Area	7,507	10,268	10,268	10,268	10,233	10,202
Farmers Mutual Ditch	7,462	9,559	9,559	9,559	9,447	9,433
Jewett Valley	2,379	3,088	3,088	3,088	3,081	3,068
Westwater	110	110	110	110	110	110
Subtotal - Non-Navajo Lands	**58,212**	**79,715**	**79,715**	**79,715**	**79,531**	**79,442**
Total New Mexico Irrigation Depletions	**209,939**	**250,017**	**310,016**	**373,256**	**373,018**	**372,853**
NON-IRRIGATION DEPLETIONS						
Navajo Reservoir Evaporation	29,139	28,274	27,165	26,962	27,305	26,671
Utah International	31,388	39,000	39,000	39,000	38,906	38,850
San Juan Power Plant	16,200	16,200	16,200	16,200	16,168	16,138
Industrial Diversions near Bloomfield	2,500	2,500	2,500	2,500	2,500	2,500
Municipal and Industrial Uses	6,945	8,963	8,963	8,963	8,958	8,954
Scattered Rural Domestic Uses[e]	1,400	1,400	1,400	1,400	1,400	1,400
Scattered Stockponds & Livestock Uses[e]	2,200	2,200	2,200	2,200	2,200	2,200
Fish and Wildlife[d]	1,400	1,400	1,400	1,400	1,400	1,400
Total New Mexico Non-Irrigation Depletions	**91,172**	**99,937**	**98,828**	**98,625**	**98,837**	**98,113**
San Juan Project Exportation	107,514	107,514	107,514	107,514	107,514	107,514
Unspecified Minor Depletions[e]	1,500	1,500	1,500	1,500	1,500	1,500
Navajo-Gallup						32,000
Jicarilla Apache[f]						25,000
Total New Mexico Depletions (Excluding ALP)	**410,125**	**458,968**	**517,859**	**580,896**	**580,870**	**636,980**

Table 7.3. Summary of average annual depletions[a] for each model scenario with a peak release of 5,000 cfs (continued).

	CURRENT[b] (AF)	DEPLETION BASE[c] (AF)	DB+59,000 (AF)	DB+122,000 (AF)	DB+210,000 (AF)	DB+280,000 (AF)
COLORADO DEPLETIONS						
COLORADO DEPLETIONS - Upstream of Navajo Dam						
Upper San Juan	9,270	10,858	10,858	10,858	10,858	10,858
Navajo-Blanco	6,972	7,865	7,865	7,865	7,865	9,282
Piedra	7,178	8,514	8,514	8,514	8,514	9,211
Pine River	67,658	69,718	69,718	69,718	69,718	69,718
Subtotal - Upstream of Navajo Dam	**91,078**	**96,955**	**96,955**	**96,955**	**96,955**	**99,070**
COLORADO DEPLETIONS - Downstream of Navajo Dam						
Florida	27,293	28,602	28,602	28,602	28,602	29,729
Animas and La Plata Rivers	36,500	39,569	39,569	39,569	39,569	39,569
Mancos	15,580	19,913	19,913	19,913	19,916	30,778
Subtotal	**79,374**	**88,085**	**88,085**	**88,085**	**88,088**	**100,076**
Total Colorado Depletions (Excluding ALP)	**170,452**	**185,039**	**185,039**	**185,039**	**185,042**	**199,145**
Colorado & New Mexico Combined Depletions	580,577	644,008	702,898	765,935	765,912	836,125
ALP[g]	0	55,610	55,610	55,610	143,514	143,514
Subtotal	**580,577**	**699,617**	**758,508**	**821,545**	**909,426**	**979,639**
Utah Depletions[h]	10,929	10,929	10,929	10,929	10,925	10,921
Arizona Depletions[e]	12,419	12,419	12,419	12,419	12,419	12,419
NET New Mexico, Colorado, Utah, Arizona Depletions	**603,925**	**722,965**	**781,856**	**844,893**	**932,770**	**1,002,979**
New Mexico Off-Stream Depletions						
Chaco River[e]	4,608	4,608	4,608	4,608	4,608	4,608
Whiskey Creek[e]	649	649	649	649	649	649
GRAND TOTAL	**609,182**	**728,222**	**787,113**	**850,150**	**938,027**	**1,008,236**
McElmo Basin Imports	(19,517)	(15,176)	(15,176)	(15,176)	(15,176)	(15,176)
NET TOTAL DEPLETIONS	**589,665**	**713,046**	**771,937**	**834,974**	**922,851**	**993,060**

[a] Depletions shown are those that directly affect flow in the San Juan River. Total depletions associated with some off-stream projects may be greater than the values shown.
[b] Historic Tribal water, other than those for the Navajo Nation Projects listed, are included in the non-Navajo depletion categories.
[c] The "Depletion Base" condition is based on depletion levels used in recent Section 7 Consultations for ALP and NIIP with certain "corrections" made by the states of Colorado and New Mexico and adjustments made to reflect natural flow study assumptions. These corrections and adjustments have not been agreed to by the participants of the SJRIP nor approved by USFWS. Therefore, this "depletion base" should not be construed as the "Environmental Baseline" for purposes of Section 7 Consultation.
[d] New Mexico provided the acreage base upon which irrigation depletions were computed but has not agreed to the method of computing consumptive use or the resulting depletion values.
[e] Indicates off-stream depletion accounted for in calculated natural gains.
[f] Actual water rights settlement is 25,500 af without designation as to the nature of the depletion. Modeled as 25,000 af with a typical M&I demand pattern.
[g] Actual planned average depletion is 57,000 and 149,200 af, respectively. Depletion shown is from the Bureau daily model output used in RiverWare.
[h] 1,705 San Juan River depletion, 9,224 off-stream depletion - Utah total = 10,929.

Table 7.4. Summary of average annual depletions[a] for each model scenario with a peak release of 6,000 cfs.

	CURRENT[b] (AF)	DEPLETION BASE[c] (AF)	DB+59,000 (AF)	DB+122,000 (AF)	DB+210,000 (AF)	DB+280,000 (AF)
NEW MEXICO DEPLETIONS[d]						
NAVAJO LANDS IRRIGATION DEPLETIONS						
Navajo Indian Irrigation Project	135,330	149,403	209,402	272,642	272,642	272,642
Hogback	9,535	12,100	12,100	12,100	12,100	12,025
Fruitland	6,147	7,898	7,898	7,898	7,891	7,849
Cudei	715	900	900	900	900	895
Subtotal - Indian Lands	**151,727**	**170,302**	**230,301**	**293,541**	**293,534**	**293,411**
NON-NAVAJO LANDS IRRIGATION DEPLETIONS						
Above Navajo Dam	925	1,189	1,189	1,189	1,189	1,187
Animas River	24,873	36,725	36,725	36,725	36,725	36,725
La Plata River	8,276	9,639	9,639	9,639	9,639	9,639
Upper San Juan	6,680	9,137	9,137	9,137	9,128	9,079
Hammond Area	7,507	10,268	10,268	10,268	10,257	10,202
Farmers Mutual Ditch	7,462	9,559	9,559	9,559	9,447	9,443
Jewett Valley	2,379	3,088	3,088	3,088	3,088	3,068
Westwater	110	110	110	110	110	110
Subtotal - Non-Navajo Lands	**58,212**	**79,715**	**79,715**	**79,715**	**79,583**	**79,442**
Total New Mexico Irrigation Depletions	**209,939**	**250,017**	**310,016**	**373,256**	**373,117**	**372,853**
NON-IRRIGATION DEPLETIONS						
Navajo Reservoir Evaporation	28,817	27,622	26,660	26,411	26,883	26,340
Utah International	31,388	39,000	39,000	39,000	38,956	38,850
San Juan Power Plant	16,200	16,200	16,200	16,200	16,189	16,138
Industrial Diversions near Bloomfield	2,500	2,500	2,500	2,500	2,500	2,500
Municipal and Industrial Uses	6,945	8,963	8,963	8,963	8,961	8,954
Scattered Rural Domestic Uses[e]	1,400	1,400	1,400	1,400	1,400	1,400
Scattered Stockponds & Livestock Uses[e]	2,200	2,200	2,200	2,200	2,200	2,200
Fish and Wildlife[d]	1,400	1,400	1,400	1,400	1,400	1,400
Total New Mexico Non-Irrigation Depletions	**90,850**	**99,286**	**98,323**	**98,074**	**98,490**	**97,781**
San Juan Project Exportation	107,514	107,514	107,514	107,514	107,514	107,514
Unspecified Minor Depletions[e]	1,500	1,500	1,500	1,500	1,500	1,500
Navajo-Gallup						32,000
Jicarilla Apache[f]						25,000
Total New Mexico Depletions (Excluding ALP)	**409,803**	**458,316**	**517,354**	**580,344**	**580,622**	**636,649**

Table 7.4. Summary of average annual depletions[a] for each model scenario with a peak release of 6,000 cfs (continued).

	CURRENT[b] (AF)	DEPLETION BASE[c] (AF)	DB+59,000 (AF)	DB+122,000 (AF)	DB+210,000 (AF)	DB+280,000 (AF)
COLORADO DEPLETIONS						
COLORADO DEPLETIONS - Upstream of Navajo Dam						
Upper San Juan	9,270	10,858	10,858	10,858	10,858	10,858
Navajo-Blanco	6,972	7,865	7,865	7,865	7,865	9,282
Piedra	7,178	8,514	8,514	8,514	8,514	9,211
Pine River	67,658	69,718	69,718	69,718	69,718	69,718
Subtotal - Upstream of Navajo Dam	**91,078**	**96,955**	**96,955**	**96,955**	**96,955**	**99,070**
COLORADO DEPLETIONS - Downstream of Navajo Dam						
Florida	27,293	28,602	28,602	28,602	28,602	29,729
Animas and La Plata Rivers	36,500	39,569	39,569	39,569	39,569	39,569
Mancos	15,580	19,913	19,913	19,913	19,916	30,778
Subtotal	**79,374**	**88,085**	**88,085**	**88,085**	**88,088**	**100,076**
Total Colorado Depletions (Excluding ALP)	**170,452**	**185,039**	**185,039**	**185,039**	**185,042**	**199,145**
Colorado & New Mexico Combined Depletions	580,255	643,356	702,393	765,384	765,664	835,794
ALP[g]	0	55,610	55,610	55,610	143,514	143,514
Subtotal	**580,255**	**698,966**	**758,003**	**820,993**	**909,178**	**979,308**
Utah Depletions[h]	10,929	10,929	10,929	10,929	10,928	10,921
Arizona Depletions[e]	12,419	12,419	12,419	12,419	12,419	12,419
NET New Mexico, Colorado, Utah, Arizona Depletions	**603,603**	**722,314**	**781,351**	**844,341**	**932,525**	**1,002,648**
New Mexico Off-Stream Depletions						
Chaco River[e]	4,608	4,608	4,608	4,608	4,608	4,608
Whiskey Creek[e]	649	649	649	649	649	649
GRAND TOTAL	**608,860**	**727,571**	**786,608**	**849,598**	**937,782**	**1,007,905**
McElmo Basin Imports	(19,517)	(15,176)	(15,176)	(15,176)	(15,176)	(15,176)
NET TOTAL DEPLETIONS	**589,343**	**712,395**	**771,432**	**834,422**	**922,606**	**992,729**

[a] Depletions shown are those that directly affect flow in the San Juan River. Total depletions associated with some off-stream projects may be greater than the values shown.
[b] Historic Tribal water, other than those for the Navajo Nation Projects listed, are included in the non-Navajo depletion categories.
[c] The “Depletion Base” condition is based on depletion levels used in recent Section 7 Consultations for ALP and NIIP with certain “corrections” made by the states of Colorado and New Mexico and adjustments made to reflect natural flow study assumptions. These corrections and adjustments have not been agreed to by the participants of the SJRIP nor approved by USFWS. Therefore, this “depletion base” should not be construed as the “Environmental Baseline” for purposes of Section 7 Consultation.
[d] New Mexico provided the acreage base upon which irrigation depletions were computed but has not agreed to the method of computing consumptive use or the resulting depletion values.
[e] Indicates off-stream depletion accounted for in calculated natural gains.
[f] Actual water rights settlement is 25,500 af without designation as to the nature of the depletion. Modeled as 25,000 af with a typical M&I demand pattern.
[g] Actual planned average depletion is 57,000 and 149,200 af, respectively. Depletion shown is from the Bureau daily model output used in RiverWare.
[h] 1,705 San Juan River depletion, 9,224 off-stream depletion - Utah total = 10,929.

modeled condition differed from "current" by including depletions from projects that had completed Consultations and any depletion that could occur without further federal action. In terms of private water rights, the states of Colorado and New Mexico assessed the probability of future use of water rights that, at present, were not fully utilized for inclusion into this depletion base. Those rights that the two states believed were likely to be developed were included in the depletion base. This "depletion base" condition is not necessarily equivalent to the "environmental baseline" used by USFWS in conducting Consultations. The depletion base was developed from the environmental baseline used for the ALP and NIIP Consultations, but the corrections made have neither been reviewed by all parties involved nor approved by USFWS. The participants of the SJRIP have not agreed that the corrections made are accurate or appropriate for future Consultations or for any other purpose. This condition is only an approximation of a level of development against which to measure future development potential and assist in defining reservoir operating rules that will allow the conditions of the flow recommendation to be met. When finally determined, the environmental baseline may be larger or smaller than the depletion base condition and, as a result, the future allowable depletion may be larger or smaller than represented by the scenario descriptions.

For the remaining hypothetical future development scenarios, certain assumptions were necessary to simulate future water development. Rather than merely increase depletions by a set amount (which would require myriad arbitrary assumptions regarding actual use, return flows, points of diversion, time of use, etc.), the assumptions were based on particular water uses that have been proposed and/or potentially could occur within the San Juan River Basin. Since these uses of water have not yet actually occurred, and may or may not actually occur, modeling of these uses also involved certain assumptions which do not imply any priority for development or priority for any actual future Consultation. For instance, the 59,000 af hypothetical future development scenario was simulated as partial completion of NIIP, and the 122,000 af hypothetical scenario was based on full development of NIIP without restoration of water borrowed from other Navajo projects. The 210,000 af hypothetical development scenario includes all of NIIP and the balance of full project ALP not presently in the depletion base. The 280,000 af hypothetical development scenario includes everything in the 210,000 af scenario plus Southern Ute and Ute Mountain Ute water rights settlement acreage, Jicarilla-Apache water rights settlement, and the Navajo/Gallup Pipeline. Depletions associated with each of these scenarios are shown in Table 7.3 when modeled with a 5,000-cfs peak release and in Table 7.4 when modeled with a 6,000-cfs peak release. Values for McElmo Imports are not valid for current conditions, so depletions without this adjustment should be used for correct comparisons. All comparative analyses have used the Four Corners gage that is above this inflow. The values shown are annual averages that vary year-to-year, depending on climatic conditions, reservoir levels, etc. The actual computed monthly values for the period of record, considering this variability, were used in modeling. Table 7.5 lists the average depletion and range of depletions from each modeled scenario.

It should be emphasized that these modeled scenarios do not imply any particular priority of development. They are simply hypothetical scenarios selected to represent a range of future depletions while preserving a semblance of practical reality in the nature of how the depletions could be taken. Further, the results, in terms of what levels of development might be allowed while still

Table 7.5. Range of annual depletions for each modeled scenario.

Development Scenario	Depletion (not including Dolores return flow) af per year		
	Average	Minimum	Maximum
Modeled with 5,000-cfs peak release			
Current Condition	609,182	398,959	757,656
Depletion Base Condition	728,222	490,202	916,163
Depletion Base plus 59,000 af	787113	520,864	967,919
Depletion Base plus 122,000 af	850,150	573,594	1,040,525
Depletion Base plus 210,000 af	938,027	588,155	1,230,366
Depletion Base plus 280,000 af	1,008,236	638,360	1,287,523
Modeled with 6,000-cfs peak release			
Current Condition	608,860	398,512	757,541
Depletion Base Condition	727,571	488,340	916,019
Depletion Base plus 59,000 af	786,608	521,399	967,988
Depletion Base plus 122,000 af	849,598	573,098	1,040,487
Depletion Base plus 210,000 af	937,782	590,083	1,230,367
Depletion Base plus 280,000 af	1,007,905	638,346	1,287,544

meeting the recommended conditions for the fishes, are specific to the hypothetical development scenarios listed and do not imply any priority for development or priority for actual Consultations. The potential for any particular project to proceed will depend on its specific impact on the flows and the ability to continue to meet the requirements for the fishes. Additional information from ongoing and new research or management may prompt a reevaluation of the biological feasibility of different actual depletion scenarios.

With these models in place, and the conditions listed in Table 7.2 specified, the results in Chapter 8 were developed. Upon completion of each successive set of runs, results were reviewed and discussed by the Biology Committee, and recommendations for other parameters to examine were specified. Tradeoffs between competing flow requirements were discussed and decisions were made to optimize recovery while allowing water development to proceed.

Some level of error is inherent in any simulation model. First, the flow data upon which the operational analyses are based are usually only about 90% accurate on a daily basis. Uncertainty exists in irrigated acreage estimates, cropping pattern, adequacy of irrigation, and estimation of irrigation water requirement. Further error is introduced in daily flow estimates through the modeling process where daily flows are computed from monthly model output for the tributary inflows, diversions, and return flows below Navajo Dam. The error for many of these parameters is not known or measurable. Given the potential uncertainty, it is unlikely that the daily flow presented as model output has an accuracy higher than about 80%. However, most of these errors are random, and the actual flow may be higher or lower than the estimated flow with the model averages matching the expected averages. The errors do not necessarily accumulate in terms of predicting the average condition, but the error band broadens. Since a water balance is always maintained and everything is calibrated to gage data, the long term average model results will match actual conditions very well.

The flow recommendations specify threshold conditions (e.g., a flow of 9,999 cfs does not qualify in meeting the average frequency requirement of 10,000 cfs for 5 days). Therefore, this inherent model error could cause the model to predict success in meeting the flow requirements in a year when they may actually not be met. However, since the error has equal probability of being high or low, using the model output places the same risk to over- and under-estimating compliance with the flow requirements. This uncertainty was considered as conditions of magnitude, duration, and frequency were examined in completing the flow requirement. An adjustment to this threshold condition is provided in the form of a reduction of 3% of the required flows (e.g, 9,700 cfs for the 10,000 cfs requirement). The reduction was applied to duration between occurrences because this is the controlling condition in all cases.

CHAPTER 8: FLOW RECOMMENDATIONS FOR THE RECOVERY OF ENDANGERED FISHES

Mimicry of the natural hydrograph is the foundation of the flow recommendation process for the San Juan River. The linkages between hydrology, geomorphology, habitat, and biology were used to define mimicry in terms of flow magnitude, duration, and frequency for the runoff and base flow periods. The flow characteristics of these linkages were compared with the statistics of the pre-Navajo Dam hydrology to assist in fine-tuning the recommendations. The flow recommendations require mimicry of statistical parameters of flow based on the linkages developed and the statistical variability of the pre-dam hydrology rather than mimicry of each annual hydrograph. A 65-year period of record (1929 to 1993) was used to assess the relationship between water development scenarios and the ability to meet the flow recommendations.

The flow recommendations are made in two parts. The first part contains the conditions of the hydrograph that will promote endangered fish recovery. These flow/duration/frequency recommendations will result in a naturally varying hydrograph, providing high-flow and low-flow years. These recommendations also provide for adequate base flow conditions and peak flow conditions of sufficient magnitude, duration, and frequency to provide suitable conditions for the endangered species. They can be achieved by using the operating criteria for Navajo Dam outlined in the second part of this chapter. By recommending operating rules, natural variability in the hydrograph is maintained and decision making for annual releases from Navajo Dam is simplified. Results of the flow recommendations on future water development is discussed in the third part of this chapter.

These flow recommendations are based on the best available information at this time given the present status of the two endangered fish species. These recommendations are not final, however, because there are still life stages of the two endangered species that have not been studied in the San Juan River because of low fish numbers, and additional information may be gathered in the future. Therefore, these recommendations may be altered through the adaptive management program envisioned in Section 5.7 of the LRP. Adaptive management will allow for refinement of these recommendations as fish populations increase or as water depletion in the basin changes. It is recommended that the model and flow recommendations be reviewed by the SJRIP at least every 5 years, thus keeping the model as an accurate working tool for basin fish recovery and water development.

RECOMMENDED HYDROGRAPH CONDITIONS

This chapter discusses the results of operating the model with the hypothetical development scenarios discussed in Chapter 7 and for a variety of hydrologic parameters that make up the flow recommendations. As summarized in Chapter 6, flows of 2,500, 5,000, 8,000, and 10,000 cfs were important to create or maintain various habitats used by the native fishes or to maintain habitat complexity. These flow levels also provide a reasonable spectrum of flows to use in defining mimicry of a natural hydrograph. Several model iterations were completed to determine various hydrologic and habitat implications. These iterations were reviewed by the Biology Committee and were refined as additional information developed and as deemed appropriate by committee members' professional opinions. Using the information available, the goal of this process was to develop the most accurate flow recommendations to aid the recovery of the endangered fish species, recognizing that continued water development in the basin was also a goal of the SJRIP.

These hydrograph recommendations are designed to meet the conditions required to develop and maintain habitat for Colorado pikeminnow and razorback sucker, and to provide the necessary hydrologic conditions for the various life stages of the endangered and other native fishes. The conditions are listed in terms of flow magnitude, duration (days at or above specified magnitude), and frequency (average recurrence of the conditions specified, expressed as a percent and a maximum allowable duration of years without meeting the condition). To allow for the difference between the flows at the historical gage at Bluff, Utah, and the Four Corners gage used for modeling, maximum allowable durations are computed for 97% of the target flow rate. In most cases, the primary recommendation is for a specified flow rate (i.e., 10,000 cfs) of a minimum duration (i.e., 5 days) for a specific frequency of occurrence (i.e., 20% of the time). Duration is determined as the number of days that the specified flow magnitude is equaled or exceeded during the spring runoff period of March 1 to July 31. Frequency is the average recurrence of the conditions specified (magnitude and duration), expressed as a percent of the 65 years of record analyzed (1929 to 1993). The underlying assumption in the flow conditions is that, over a long period of time, history will repeat itself: if the conditions were met during the past 65 years, they will also be met in the future. To the extent that the water supply is different in the future, then the natural condition would also be altered and the conditions of mimicry would be maintained, although the exact flow recommendation statistics may not be met.

In addition to the primary recommendation, variability in duration is desirable to mimic a natural hydrograph. Therefore, a frequency table (Table 8.1) for a range of durations for each flow rate is recommended. A maximum duration between occurrences is also specified to avoid long periods when conditions are not met, as such long periods could be detrimental to the recovery of the species. The maximum period without reaching a specified condition was determined as twice the average required interval (except for the 80% recurrence of the 2,500-cfs condition, where 2 years is used). For example, if the average interval is 1 year in 3, then the maximum period between meeting conditions would be 6 years. The maximum periods were based on the collective judgment of Biology Committee members after review of historical pre-dam statistics. The biological basis of the recommendations is summarized in Chapter 6. The recommendations are based on statistics

Table 8.1. Frequency distribution table for flow/duration recommendations.

Duration	Discharge			
	>10,000 cfs	>8,000 cfs	>5,000 cfs	>2,500 cfs
	Minimum Average Frequency for Period of Record			
1 day	30%	40%	65%	90%
5 days	20%	35%	60%	82%
10 days	10%	33%	58%	80%
15 days	5%	30%	55%	70%
20 days		20%	50%	65%
30 days		10%	40%	60%
40 days			25%	50%
50 days			20%	45%
60 days			15%	40%
80 days			5%	25%

Note: Primary criteria are shown in shaded cells.

for the 1929 to 1993 period, assuming that Navajo Dam was in place and reoperated according to the recommendations of this chapter. Those statistics are evaluated against the 1929 to 1961 pre-dam conditions.

Following are the conditions of the flow recommendations:

A. Category: Flows > 10,000 cfs during runoff period (March 1 to July 31).

Duration: **A minimum of 5 days between March 1 and July 31**.

Frequency: **Flows > 10,000 cfs for 5 days or more need to occur in 20% of the years on average for the period of record 1929 to 1993**. Maximum number of consecutive years without meeting at least a flow of 9,700 cfs (97% of 10,000 cfs) within the 65-year period of record is 10 years.

Purpose: Flows above 10,000 cfs provide significant out-of-bank flow, generate new cobble sources, change channel configuration providing for channel diversity, and provide nutrient loading to the system, thus improving habitat productivity. Such flows provide material to develop spawning habitat and maintain channel diversity and habitat complexity necessary for all life stages of endangered fishes. The frequency and duration are based on mimicry of the natural hydrograph, which is important for Colorado pikeminnow reproductive success and maintenance of channel complexity, as evidenced by the increase in the number of islands following high-flow conditions. Channel complexity is important to both Colorado pikeminnow and razorback sucker.

B. Category: Flow > 8,000 cfs during runoff period.

Duration: **A minimum of 10 days between March 1 and July 31**.

Frequency: **Flows > 8,000 cfs for 10 days or more need to occur in 33% of the years on average for the period of record 1929 to 1993**. Maximum number of consecutive years without meeting at least a flow of 7,760 cfs (97% of 8,000 cfs) within the 65-year period of record is 6 years.

Purpose: Bankfull discharge is generally between 7,000 and 10,500 cfs in the San Juan River below Farmington, New Mexico, with 8,000 cfs being representative of the bulk of the river. Bankfull discharge approximately 1 year in 3 on average is necessary to maintain channel cross-section. Flows at this level provide sufficient stream energy to move cobble and build cobble bars necessary for spawning Colorado pikeminnow. Duration of 8 days at this frequency is adequate for channel and spawning bar maintenance. However, research shows a positive response of bluehead sucker and speckled dace abundance with increasing duration of flows above 8,000 cfs from 0 to 19 days. Therefore, the minimum duration was increased from 8 to 10 days to account for this measured response. Flows above 8,000 cfs may be important for providing habitat for larval razorback sucker if flooded vegetation and other habitats formed during peak and receding flows are used by the species. This flow level also maintains mimicry of the natural hydrograph during higher flow years, an important feature for Colorado pikeminnow reproductive success.

C. Category: Flow > 5,000 cfs during runoff period.

Duration: **A minimum of 21 days between March 1 and July 31**.

Frequency: **Flows > 5,000 cfs for 21 days or more need to occur in 50% of the years on average for the period of record 1929 to 1993**. Maximum number of consecutive years without meeting at least a flow of 4,850 cfs (97% of 5,000 cfs) within the 65-year period of record is 4 years.

Purpose: Flows of 5,000 cfs or greater for 21 days are necessary to clean backwaters and maintain low-velocity habitat in secondary channels in Reach 3, thereby maximizing nursery habitat for the system. The required frequency of these flows is dependent upon perturbating storm events in the previous period, requiring flushing about 50% of the years on average. Backwaters in the upper portion of the nursery habitat range clean with less flow but may be too close to spawning sites for full utilization. Maintenance of Reach 3 is deemed critical at this time because of its location relative to the Colorado pikeminnow spawning area (RM 132) and its backwater habitat abundance.

D. Category: Flow >2,500 cfs during runoff period.

Duration: **A minimum of 10 days between March 1 and July 31**.

Frequency: **Flows > 2,500 cfs for 10 days or more need to occur in 80% of the years on average for the period of record 1929 to 1993**. Maximum number of consecutive years without meeting at least a flow of 2,425 cfs (97% of 2,500 cfs) within the 65-year period of record is 2 years.

Purpose: Flows above 2,500 cfs cause cobble movement in higher gradient areas on spawning bars. Flows above 2,500 cfs for 10 days provide sufficient movement to produce clean cobble for spawning. These conditions also provide sufficient peak flow to trigger spawning in Colorado pikeminnow. The frequency specified represents a need for frequent spawning conditions but recognizes that it is better to provide water for larger flow events than to force a release of this magnitude each year. The specified frequency represents these tradeoffs.

E. Category: Timing of the peak flows noted in conditions A through D above must be similar to historical conditions, and the variability in timing of the peak flows that occurred historically must also be mimicked.

Timing: Mean date of peak flow in the habitat range (RM180 and below) for any future level of development when modeled for the period of 1929 to 1993 must be within 5 days ± of historical mean date of May 31 for the same period.

Variability: Standard deviation of date of peak to be 14 to 25 days from the mean date of May 31.

Purpose: Maintaining similar peak timing will provide ascending and descending hydrograph limbs timed similarly to the historical conditions that are suspected important for spawning of the endangered fishes.

F. Category: Target Base Flow (mean weekly nonspring runoff flow).

Level: 500 cfs from Farmington to Lake Powell, with 250 cfs minimum from Navajo Dam.

Purpose: Maintaining low, stable base flows enhances nursery habitat conditions. Flows between 500 and 1,000 cfs optimize backwater habitat. Selecting flows at the low end of the range increases the availability of water for development and spring releases. It also provides capacity for storm flows to increase flows and still maintain optimum backwater area. This level of flow balances provision of near-maximum low-velocity habitat and near-optimum flows in secondary channels, while allowing water availability to maintain the required frequency, magnitude, and duration of peak flows important for Colorado pikeminnow reproductive success.

G. Category: Flood Control Releases (incorporated in operating rule).

Control: Handle flood control releases as a spike (high magnitude, short duration) and release when flood control rules require, except that the release shall not occur earlier than September 1. If an earlier release is required, extend the duration of the peak of the release hydrograph. A ramp up and ramp down of 1,000 cfs per day should be used to a maximum release of 5,000 cfs. If the volume of water to release is less than that required to reach 5,000 cfs, adjust the magnitude of the peak accordingly, maintaining the ramp rates. Multiple releases may be made each year. These spike releases shall be used in place of adjustments to base flow.

Purpose: Historically, flood control releases were made by increasing fall and winter base flows. This elevates flows above the optimum range for nursery habitat. Periodic clean-water spike flows improve low-velocity habitat quality by flushing sediment and may suppress red shiner and fathead minnow abundance.

RECOMMENDED RESERVOIR OPERATING RULES

Mimicry of a natural hydrograph requires maintenance of variability in the hydrograph while maintaining the recommended flows in the San Juan River below Navajo Dam. The following operating rules allow for these conditions to be met. The rules were developed in cooperation with the Bureau, which operates the dam. The rules function within the context of the available water in a given year and what has occurred in previous years, providing for a dynamic flow regime over a period of years as well as within any single year. The rules are based on numerous model runs for real and hypothetical water development conditions ranging from 609,000 af of depletion (approximate current level of development, not including Dolores Project return flows) to 1,008,000 af of depletion (depletion base + 280,000 af). As noted in Chapter 7, the use of these hypothetical water development scenarios does not imply any right to develop, any priority of development, or priority of Consultation. Neither do these scenarios attempt to exclude others from developing. Each of the parameters has been tested for a range of values, and the conditions recommended to provide the closest match to the desired hydrograph conditions over the development range.

Sensitivity analysis demonstrated that the conditions of the flow recommendation and the goals for continuation of water development could best be met by maintaining a peak release from Navajo Dam of 6,000 cfs. Studies conducted by the Bureau and the Corps in 1998 indicated that the channel capacity and the dam outlet works capacity may not be sufficient to allow a release of this magnitude. It was concluded that additional studies would be required before dam releases could be increased above 5,000 cfs. Therefore, operating rules have been developed that include both 5,000-cfs and 6,000-cfs peak release. If the actual channel and release capacity is between 5,000 and 6,000 cfs, the rules can be adjusted to match the determined capacity.

Figures 8.1 and 8.2 are flow charts showing the process that could be used by the Bureau to determine the magnitude and timing of flow releases from Navajo Dam. The first decision to be made is whether or not there is sufficient water for a peak release. If there is sufficient water (> 114,000 af), then the magnitude of the release is determined. The minimum peak release of about 114,000 af would provide a release peak for 1 week. The primary peak release provides a peak release flow for 3 weeks. The actual flow in the river below the mouth of the Animas River will depend on the flow in the Animas River during the peak release from Navajo Dam. In addition to the amount of water available (through precipitation forecasts in the spring), the history of recent peak releases also is important in determining the size and timing of a peak release.

In describing the operating conditions, the definitions of several terms are specific to this flow recommendation. In defining release hydrographs, two conditions are described. The minimum peak release specifies the release conditions that would apply in dry years. Releases smaller than this have shown to be detrimental to nursery habitat because they produce flows below the threshold necessary for backwater cleaning and they allow sediment berms to form in the mouths of backwaters. The primary peak release has the most desirable shape and magnitude characteristics, given adequate water availability. When the water supply allows a release volume between the minimum and primary peak releases, the conditions for adjusting the hydrograph are specified accordingly to optimize the utility of the release. In some wet years, water in excess of the primary peak release must be released in order to prevent reservoir spills and downstream flooding. The impacts to the endangered fishes, their habitat, and the need to safely operate Navajo Dam were taken into consideration when developing the conditions given for releasing excess water.

The decision to make a release of a given magnitude, or to store water for a larger future release, is related to the condition of the nursery habitat. If the nursery habitat has been affected by sediment-laden storm events, it would be considered a perturbation year. A perturbation year will be determined from the results of the monitoring program, and the results will be provided to the

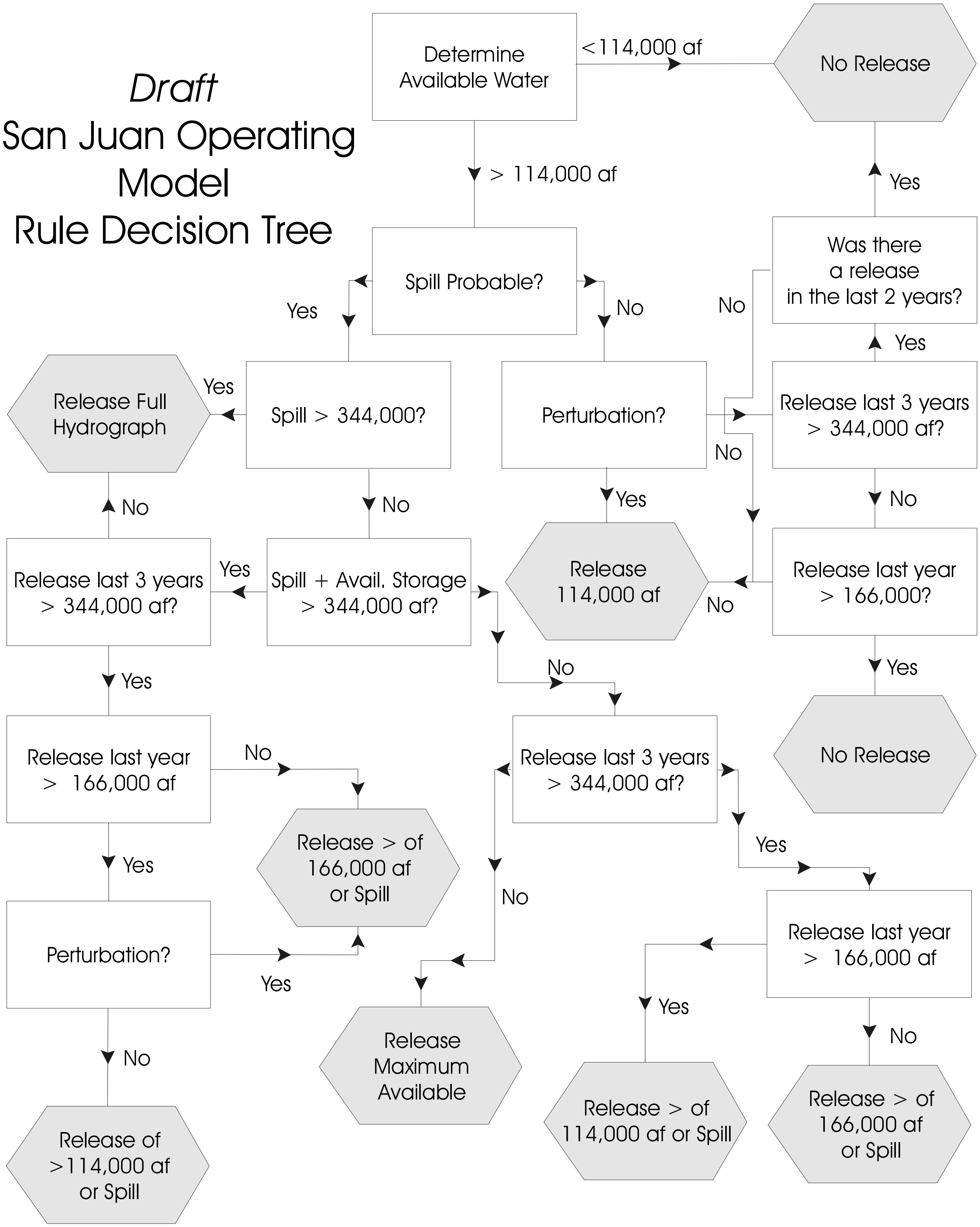


Figure 8.1. Flow chart of Navajo Dam operating rules for a 5,000-cfs peak release.

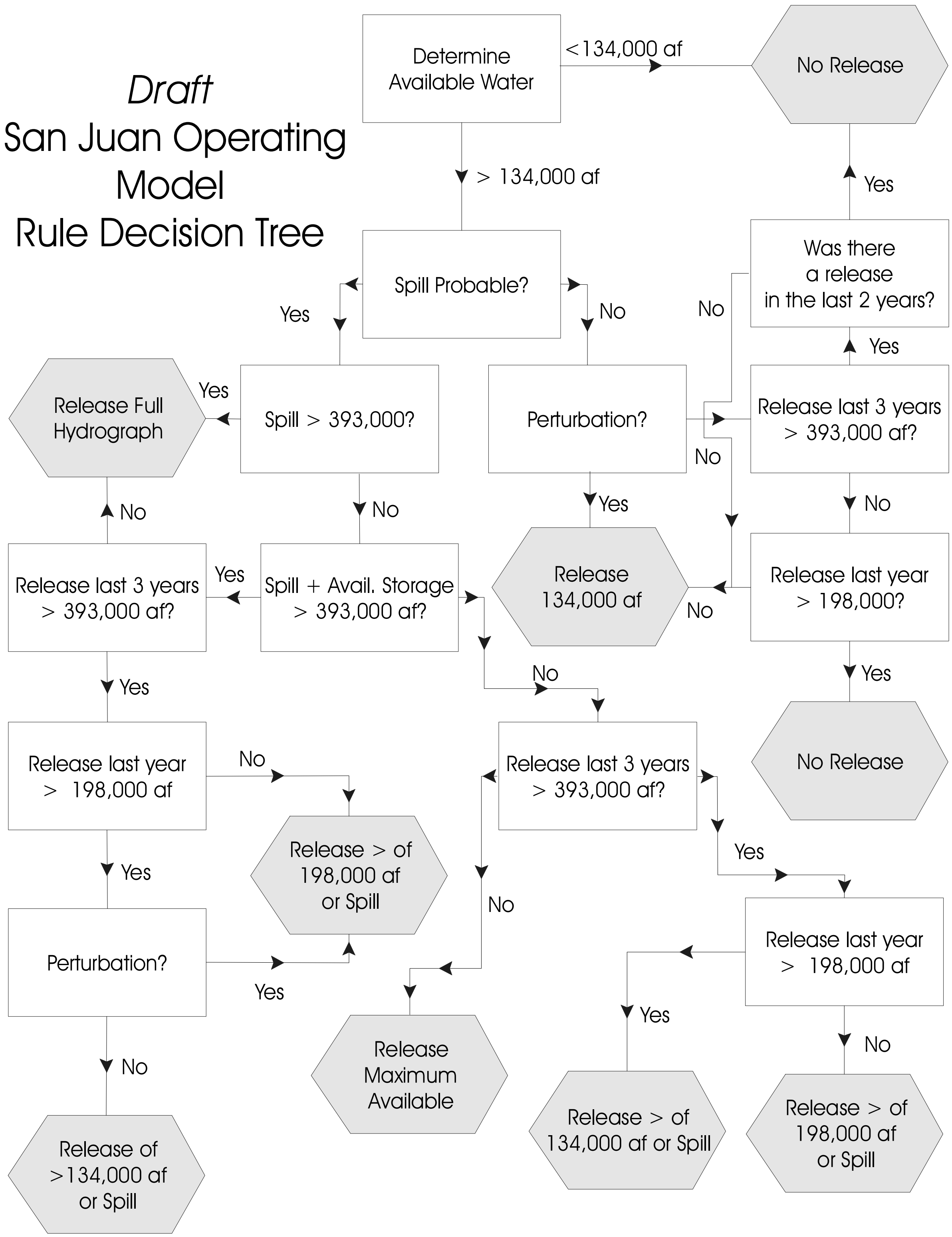


Figure 8.2. Flow chart of Navajo Dam operating rules for a 6,000-cfs peak release.

Bureau by the SJRIP in January of each year for inclusion in the decision-making process. In the absence of a direct observation, a perturbation year will be declared if there are more than 13 storm event days as defined on page 7-3 between August 1 and December 31.

In the following rules, the first value given relates to a 5,000-cfs peak and the second to a 6,000-cfs peak.

- Minimum peak release consists of 1 week ramp up to 5,000 to 6,000 cfs, 1 week at 5,000 to 6,000 cfs, and 1 week ramp down. Daily flow rates for ramping are given in Table 8.2 for 5,000 cfs and in Table 8.3 for 6,000 cfs. Volume is 114,000 to 134,000 af above average base release of 600 cfs.

- Primary peak release hydrograph consists of 4 week ramp up to 5,000 to 6,000 cfs, 3 weeks at 5,000 to 6,000 cfs, and 2 weeks ramp down. Ramp rates are given in Table 8.2 for 5,000 cfs and in Table 8.3 for 6,000 cfs. Volume is 344,000 to 393,000 af above average base release of 600 cfs.

- Median peak on the Animas River is June 1. No correlation between volume or runoff magnitude and peak date exists. Sensitivity analysis indicates the best results are achieved with a peak release from Navajo Dam centered on June 4 for a 5,000-cfs peak release and June 2 for a 6,000-cfs peak release. Fix the center of the 5,000-cfs release on June 4 and the center of the 6,000-cfs release on June 2 every year.

- Use the attached decision tree (Figure 8.1 for 5,000 cfs and Figure 8.2 for 6,000-cfs peak release) to determine magnitude of release. Available water on the chart is defined as: *"predicted inflow less base release plus available storage*," where available storage is reduced from full storage by the amount of carry-over storage necessary to prevent shortages in future years and all storage volumes include inactive storage. "*Release last 3 years > 393,000 af,*" means that a release of at least 393,000 af occurred during at least 1 out of the last 3 years. Table 8.4 lists the model calibrated values for carry-over storage to be used in this calculation for a development range. When new development is proposed, the model should be operated to verify the value to be used.

- In years when the spill is predicted to be greater than 344,000 to 393,000 af, adjust the hydrograph by first adding an earlier release of 2,000 cfs to the front of the ascending limb and extending it to as early as March 1. Increase this early release by 500 cfs and increment calculation of duration until time extension is March 1, if necessary, to use all of the release flow volume computed by application of Figures 8.1 or 8.2. Ramp up on the beginning of the early release from base flow cannot exceed 1,000 cfs per day.

Table 8.2. Recommended daily ramp rates for 1-week, 2-week, 3-week, and 4-week ramps for a 5,000-cfs peak release.

DAY	FLOW RATE (cfs)			
	1 WEEK	2 WEEK	3 WEEK	4 WEEK
1	1,000	1,000	1,000	1,000
2	1,500	1,000	1,000	1,000
3	2,000	1,500	1,000	1,000
4	2,500	1,500	1,000	1,000
5	3,000	2,000	1,500	1,000
6	3,500	2,000	1,500	1,000
7	4,000	2,500	1,500	1,000
8	5,000	2,500	2,000	2,000
9		3,000	2,000	2,000
10		3,000	2,000	2,000
11		3,500	2,000	2,000
12		4,000	3,000	2,000
13		4,000	3,000	2,000
14		4,500	3,000	2,000
15		5,000	3,000	3,000
16			4,000	3,000
17			4,000	3,000
18			4,000	3,000
19			4,000	3,000
20			4,000	3,000
21			4,000	3,000
22			5,000	4,000
23				4,000
24				4,000
25				4,000
26				4,000
27				4,000
28				4,000
29				5,000

Table 8.3. Recommended daily ramp rates for 1-week, 2-week, 3-week, and 4-week ramps for a 6,000-cfs peak release.

DAY	FLOW RATE (cfs)			
	1 WEEK	2 WEEK	3 WEEK	4 WEEK
1	1,000	1,000	1,000	1,000
2	1,500	1,000	1,000	1,000
3	2,000	1,500	1,000	1,000
4	2,500	1,500	1,000	1,000
5	3,000	2,000	1,500	1,000
6	4,000	2,500	1,500	1,000
7	5,000	2,500	1,500	1,000
8	6,000	3,000	2,000	2,000
9		3,000	2,000	2,000
10		3,500	2,000	2,000
11		4,000	2,000	2,000
12		4,000	3,000	2,000
13		4,500	3,000	2,000
14		5,000	3,000	2,000
15		6,000	4,000	3,000
16			4,000	3,000
17			4,000	3,000
18			4,000	3,000
19			4,000	3,000
20			4,000	3,000
21			5,000	3,000
22			6,000	4,000
23				4,000
24				4,000
25				4,000
26				4,000
27				4,000
28				5,000
29				6,000

Table 8.4. Minimum carry-over storage for modeled levels of development for use in determination of available water per Figures 8.1 and 8.2.

DEVELOPMENT LEVEL	CURRENT	DEPLETION BASE	DEPLETION BASE +59,000	DEPLETION BASE +122,000	DEPLETION BASE +210,000	DEPLETION BASE +280,000
Carry-over Storage for 5,000 cfs (af)	900,000	1,000,000	1,288,200	1,453,200	1,700,000	1,700,000
Carry-over Storage for 6,000 cfs (af)	900,000	1,000,000	1,125,500	1,453,200	1,700,000	1,700,000

- In years when the release will be greater than 114,000 to 134,000 af but less that 344,000 to 393,000 af, use the following adjustment rules in this order of selection:

    1. Decrease time of descending limb by as much as 1 week to achieve necessary reduction.

    2. Decrease time of ascending limb by as much as 3 weeks to achieve necessary reduction.

    3. Reduce duration of peak by as much as 2 weeks.

    4. Ramping rates are shown in Tables 8.2 and 8.3 for 5,000- and 6,000-cfs peak releases, respectively. Rates shown are ideal rates and may be adjusted within reasonable limits to accommodate dam operating procedures and flood control requirements. Changes should not exceed 1,000 cfs per day.

- Target base flow (average weekly) following spring peak is 500 cfs at Farmington, Shiprock, Four Corners, and Bluff gages, measured as the average of any two of these gages. Minimum release is 250 cfs. The target flow should be maintained between 500 and 600 cfs, attempting to maintain target flow closer to 500 cfs.

- Handle flood control releases as a spike (high magnitude, short duration) and release when flood control rules require, except the release shall not occur earlier than September 1. If an earlier release is required, extend the peak duration of the release hydrograph. A ramp up and ramp down of 1,000 cfs per day should be used to a maximum release of 5,000 cfs. If the released volume is less than that required to reach 5,000 cfs, adjust the magnitude of the peak accordingly, maintaining the ramp rates. Multiple releases may be made each year. These spike releases shall be used in place of adjustments to base flow.

- In no case shall the reservoir be allowed to fall below the elevation that allows full diversion of water to NIIP.

These operating rules are presented as recommendations and were used in the modeling process to assess the system's ability to maintain the flow recommendations. Other operating rules may be employed to achieve the desired river conditions specified in this chapter, if the natural variability provided by the rules presented above is maintained.

MODEL RESULTS

Hydrologic Results

Table 8.5 summarizes the hydrologic condition for the six modeled levels of hypothetical development discussed in Chapter 7 with comparisons to historical conditions at the Bluff gage for pre-dam (1929 to 1961), post-dam (1962 to 1991), and study (1992 to 1997) periods for a 5,000-cfs peak release. The same information is shown in Table 8.6 for a peak release of 6,000 cfs. The six modeled conditions use the modeled Four Corners daily flow for the 1929 to 1993 period. The Four Corners gage is used rather than the Bluff gage, since it better represents the average condition in Reaches 4 and 5, important areas for the endangered fishes, and it is upstream of the Dolores Project inflows to McElmo Creek which are problematic in the model. Because of local inflow during the runoff period, the average peak magnitude and volume of the flows at Bluff are about 3% higher than at Four Corners. However, the difference is within gage error, so the comparisons are considered reasonable.

Flow statistics for all levels of development are equal to or better than post-dam conditions for nearly all parameters at all levels of development studied through depletion base plus 280,000 af, demonstrating the negative effect on the hydrograph and habitat as a result of Navajo Dam operation prior to 1992. Compared with pre-dam conditions, all levels of development reduce the peak magnitude and volume of the runoff period flows. Flow/duration conditions, identified as important for habitat development and biological response, show a somewhat different relationship. The frequency of meeting minimum durations of 10,000-cfs flows are better than pre-dam historical conditions for levels of development through the depletion base plus 59,000 af condition with a 6,000-cfs release but for no future condition with a 5,000-cfs release. Frequency for 8,000-cfs minimum durations are better for all levels of development through depletion base plus 122,000 af with a 6,000-cfs peak release, but only through current conditions for a 5,000-cfs release. Frequency for 5,000-cfs minimum durations are better than pre-dam conditions for current depletion levels only, regardless of peak release. Frequency of meeting minimum durations for 2,500- and 5,000-cfs flow recommendations are somewhat reduced for all levels of development. Figures 8.3 through 8.6 show the flow/duration/frequency relationships for flows above 2,500, 5,000, 8,000, and 10,000 cfs, respectively, for a peak release of 5,000 cfs. Figures 8.7 through 8.10 show the same information for a 6,000-cfs peak release.

A major change from pre-dam conditions is the maximum years between meeting flow/duration conditions, partly because the natural peak runoff relative to the earlier record was reduced for the period from 1952 through 1972. All of the maximum intervals between meeting conditions occur

Table 8.5. Comparison of hydrograph statistics for six levels of development and three historical periods for the period 1929 to 1993 for 5,000 cfs peak release.

PARAMETER	PRE-DAM	POST-DAM	RESEARCH PERIOD	CURRENT	DEPLETION BASE	BASE +59,000	BASE +122,000	BASE +210,000	BASE +280,000
Average Peak Runoff - cfs	12,409	6,749	8,772	10,041	9,795	9,403	8,827	7,969	7,438
Average Runoff - af	1,263,890	891,712	1,132,899	1,042,635	963,549	916,510	869,386	790,314	728,215
	Frequency	Frequency	Frequency	Frequency	Frequency	Frequency	Frequency	Frequency	Frequency
Peak>10,000 cfs	55%	20%	33%	43%	43%	43%	42%	32%	32%
Peak>8,000 cfs	67%	37%	83%	77%	72%	68%	62%	52%	45%
Peak>5,000 cfs	91%	53%	83%	97%	97%	88%	77%	65%	57%
Peak>2,500 cfs	100%	90%	100%	100%	100%	98%	97%	91%	88%
AF>1,000,000	55%	40%	67%	42%	40%	35%	34%	31%	28%
AF>750,000	67%	47%	83%	63%	58%	58%	54%	45%	40%
AF>500,000	91%	67%	83%	82%	74%	71%	68%	60%	51%
>10,000 cfs for 5 days	39%	**13%**	33%	35%	34%	31%	31%	23%	22%
>8,000 cfs for 8 days	48%	**27%**	50%	48%	46%	45%	43%	34%	32%
>8,000 cfs for 10 days	45%	**17%**	50%	46%	45%	42%	40%	**32%**	**32%**
>5,000 cfs for 21 days	64%	**37%**	83%	68%	62%	62%	58%	**55%**	**42%**
>2,500 cfs for 10 days	100%	83%	100%	97%	97%	91%	86%	**72%**	**69%**
Maximum years between flow events for minimum duration									
10,000 cfs - 5 days	4	**14**	n/a	6	6	9	9	**14**	**14**
8,000 cfs - 10 days	4	**7**	n/a	6	6	6	6	**14**	**14**
5,000 cfs - 21 days	4	**7**	n/a	3	4	3	4	43	**7**
2,500 cfs - 10 days	0	1	n/a	1	1	2	2	**3**	**4**
Non-corrected Perturbation	12%	27%	0%	17%	18%	18%	22%	23%	28%
Average Date of Peak	31-May	01-Jun	07-Jun	04-Jun	04-Jun	05-Jun	04-Jun	04-Jun	05-Jun
Standard Dev of Peak Date	23 days	35 days	8 days	12 days	12 days	14 days	14 days	16 days	20 days
Days>10,000 cfs	14	3	2	6	5	5	5	4	3
Days>8,000 cfs	23	8	10	16	14	13	13	11	10
Days>5,000 cfs	46	28	51	43	38	35	32	30	26
Days>2,500 cfs	82	67	90	71	65	61	55	50	44
Meets recommendation				yes	yes	yes	yes	no	no

Note: Bold values indicate recommendation not met. Baseline + 280,000 is water short 174,000 af in 1956; 83,000 af in 1957. Maximum years between meeting minimum conditions are computed at 97% of the target flow rate to account for differences between Bluff and Four Corners flows.

Table 8.6. Comparison of hydrograph statistics for six levels of development and three historical periods for the period 1929 to 1993 for 6,000 cfs peak release.

PARAMETER	PRE-DAM	POST-DAM	STUDY PERIOD	CURRENT	DEPLETION BASE	BASE +59,000	BASE +122,000	BASE +210,000	BASE +280,000
Average Peak Runoff - cfs	12,409	6,749	8,772	10,882	10,553	10,502	9,319	8,378	7,738
Average Runoff - af	1,263,890	891,712	1,132,899	1,055,365	973,577	925,841	874,521	793,829	730,812
	Frequency	Frequency	Frequency	Frequency	Frequency	Frequency	Frequency	Frequency	Frequency
Peak>10,000 cfs	55%	20%	33%	48%	45%	46%	43%	40%	32%
Peak>8,000 cfs	67%	37%	83%	89%	83%	80%	65%	57%	49%
Peak>5,000 cfs	91%	53%	83%	97%	95%	92%	75%	60%	55%
Peak>2,500 cfs	100%	90%	100%	100%	100%	98%	98%	91%	88%
AF>1,000,000	55%	40%	67%	49%	40%	35%	35%	31%	28%
AF>750,000	67%	47%	83%	62%	60%	57%	54%	43%	37%
AF>500,000	91%	67%	83%	78%	72%	69%	69%	58%	51%
>10,000 cfs for 5 days	39%	**13%**	33%	43%	42%	40%	37%	34%	26%
>8,000 cfs for 8 days	48%	**27%**	50%	68%	65%	63%	57%	49%	40%
>8,000 cfs for 10 days	45%	**17%**	50%	63%	60%	57%	52%	43%	**35%**
>5,000 cfs for 21 days	64%	**37%**	83%	65%	60%	57%	57%	**52%**	**40%**
>2,500 cfs for 10 days	100%	83%	100%	97%	97%	95%	85%	**69%**	**69%**
Maximum years between flow events for minimum duration									
10,000 cfs - 5 days	4	**14**	n/a	6	9	9	10	**14**	**14**
8,000 cfs - 10 days	4	**7**	n/a	3	4	4	4	**7**	**8**
5,000 cfs - 21 days	4	**7**	n/a	3	4	4	4	4	**7**
2,500 cfs - 10 days	0	1	n/a	1	1	1	2	**3**	**4**
Non-corrected Perturbation	12%	27%	0%	18%	22%	23%	22%	25%	28%
Average Date of Peak	31-May	01-Jun	07-Jun	03-Jun	03-Jun	04-Jun	04-Jun	04-Jun	05-Jun
Standard Dev of Peak Date	23 days	35 days	8 days	11 days	9 days	11 days	15 days	17 days	19 days
Days>10,000 cfs	14	3	2	8	7	7	6	5	4
Days>8,000 cfs	23	8	10	19	17	16	15	13	11
Days>5,000 cfs	46	28	51	41	37	34	31	28	24
Days>2,500 cfs	82	67	90	69	62	58	53	48	43
Meets recommendation				yes	yes	yes	yes	no	no

Note: Bold values indicate recommendation not met. Baseline + 280,000 is water short 174,000 af in 1956; 83,000 af in 1957. Maximum years between meeting minimum conditions are computed at 97% of the target flow rate to account for differences between Bluff and Four Corners flows.

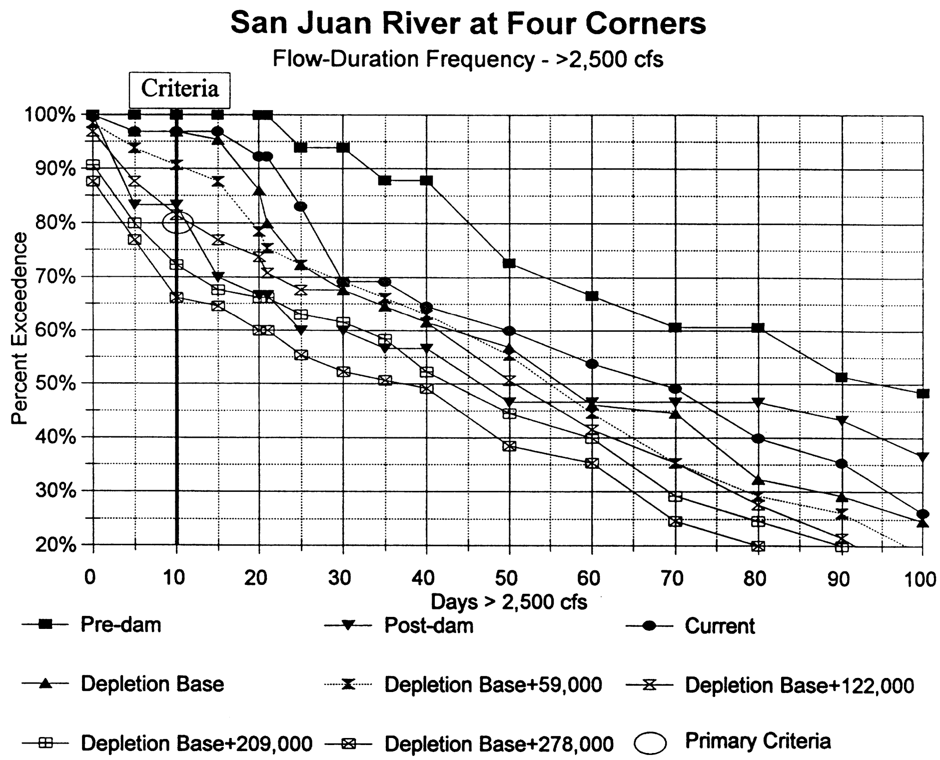


Figure 8.3. Frequency/duration relationship for flows exceeding 2,500 cubic feet per second (cfs) with a peak release of 5,000 cfs.

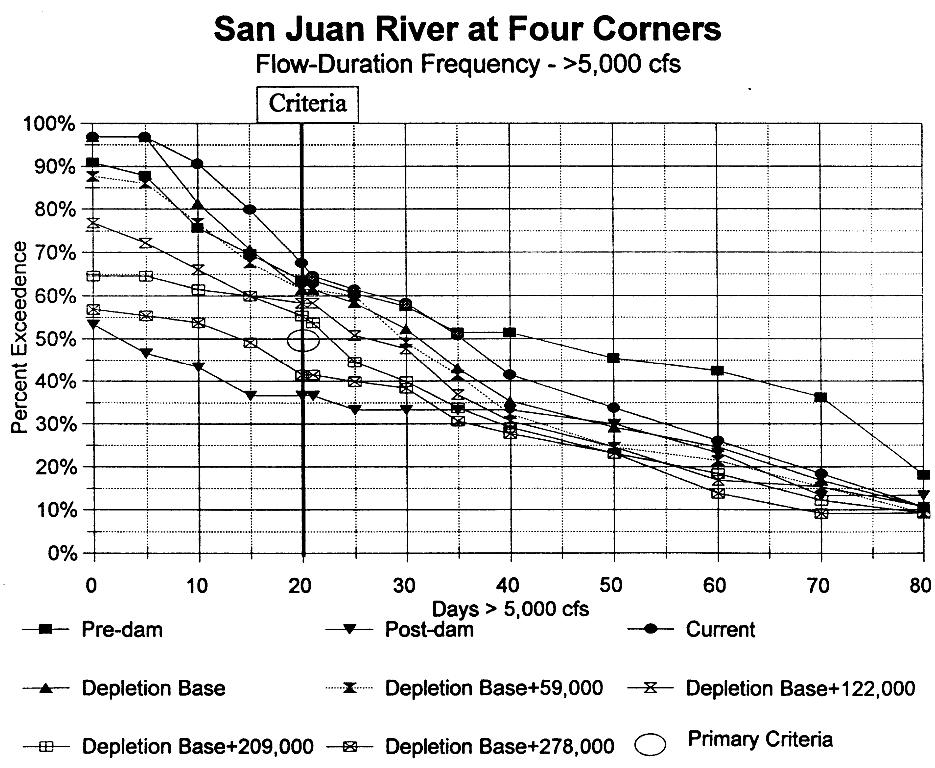


Figure 8.4. Frequency/duration relationship for flows exceeding 5,000 cubic feet per second (cfs) with a peak release of 5,000 cfs.

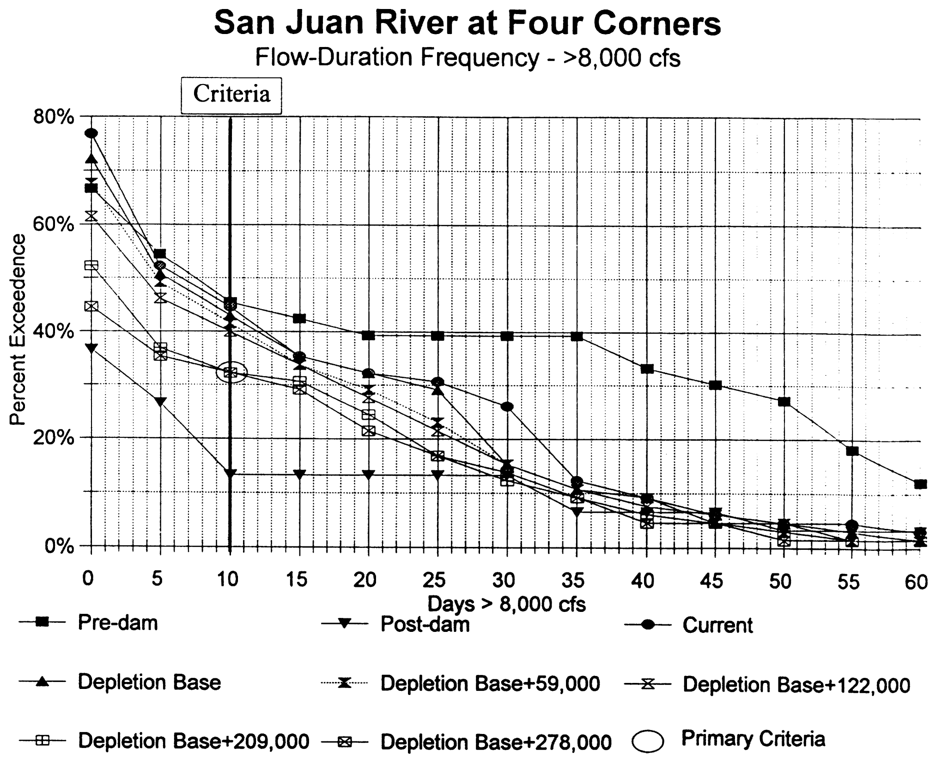


Figure 8.5. Frequency/duration relationship for flows exceeding 8,000 cubic feet per second (cfs) with a peak release of 5,000 cfs.

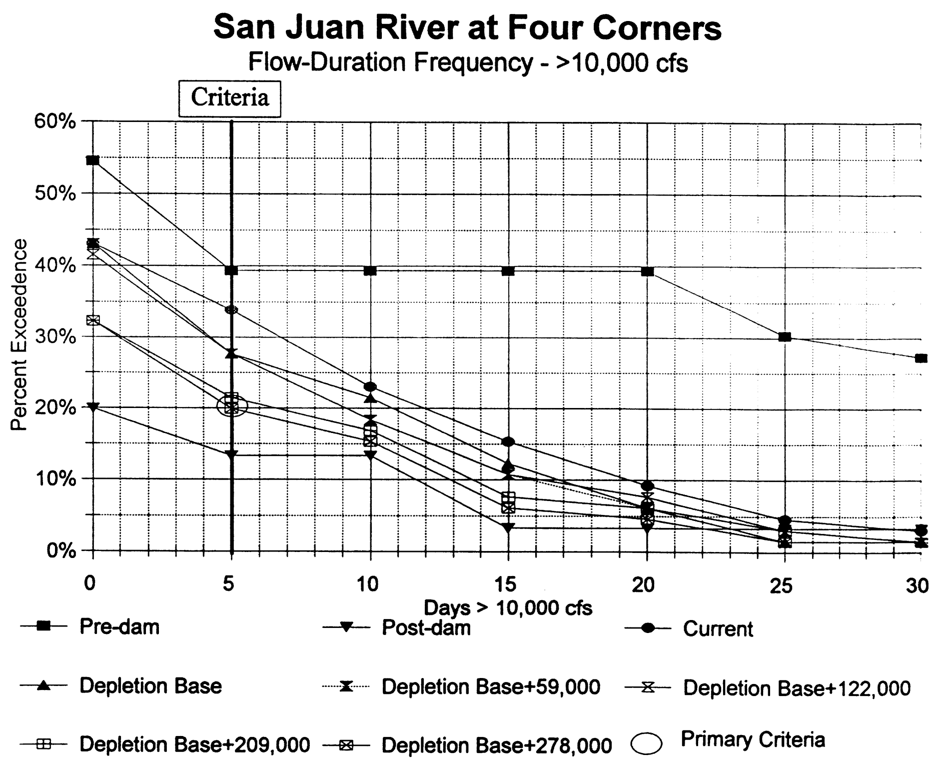


Figure 8.6. Frequency/duration relationship for flows exceeding 10,000 cubic feet per second (cfs) with a peak release of 5,000 cfs.

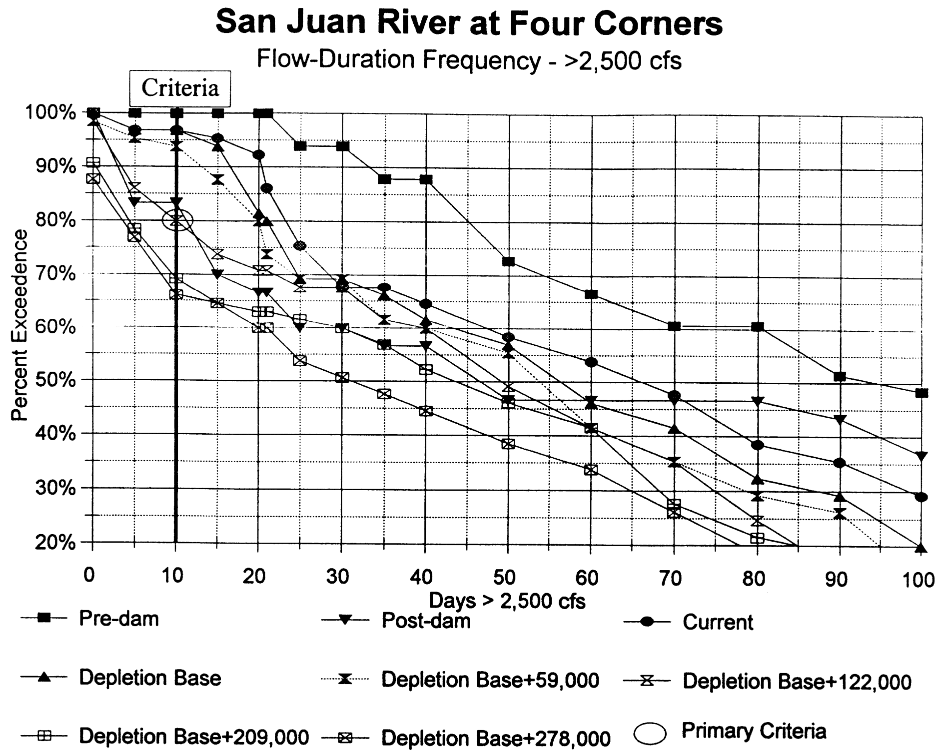


Figure 8.7. Frequency/duration relationship for flows exceeding 2,500 cubic feet per second (cfs) with a peak release of 6,000 cfs.

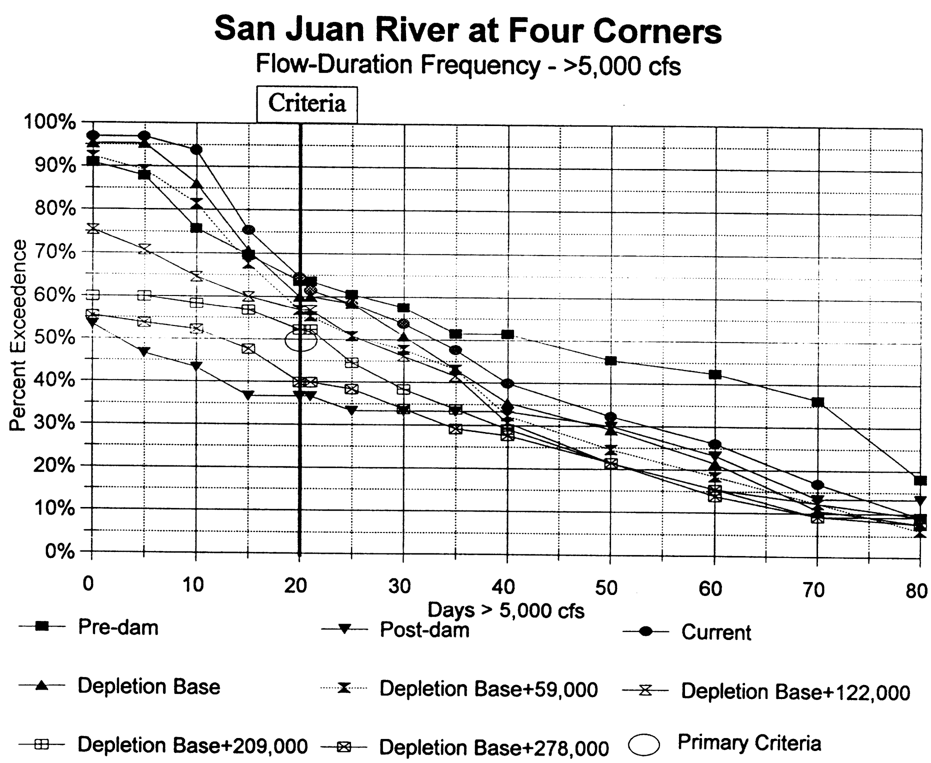


Figure 8.8. Frequency/duration relationship for flows exceeding 5,000 cubic feet per second (cfs) with a peak release of 6,000 cfs.

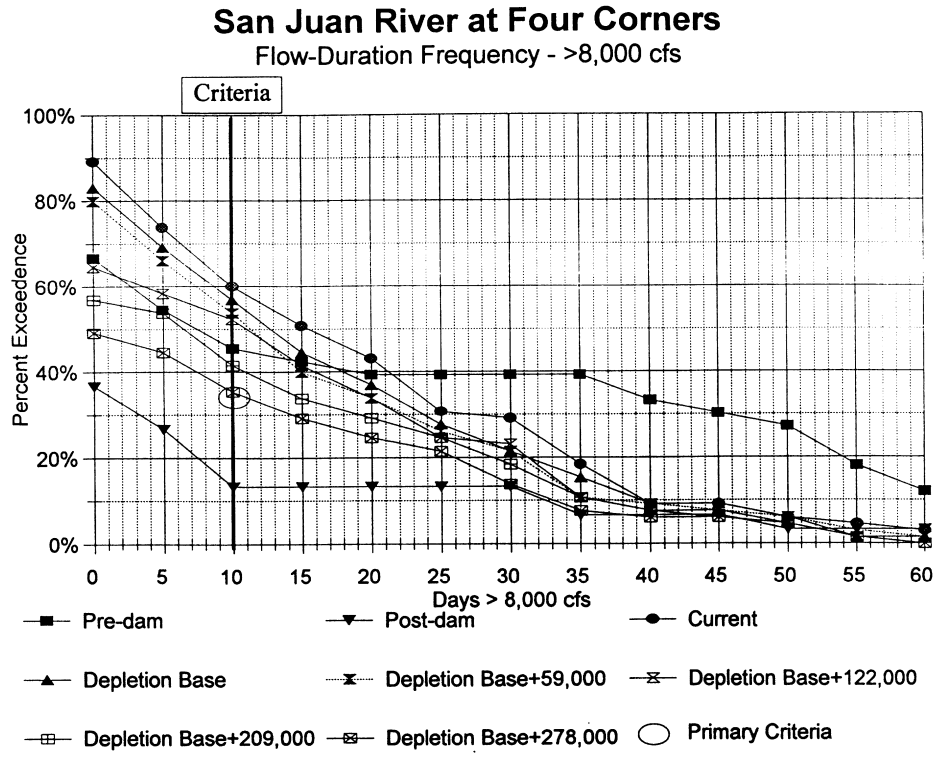


Figure 8.9. Frequency/duration relationship for flows exceeding 8,000 cubic feet per second (cfs) with a peak release of 6,000 cfs.

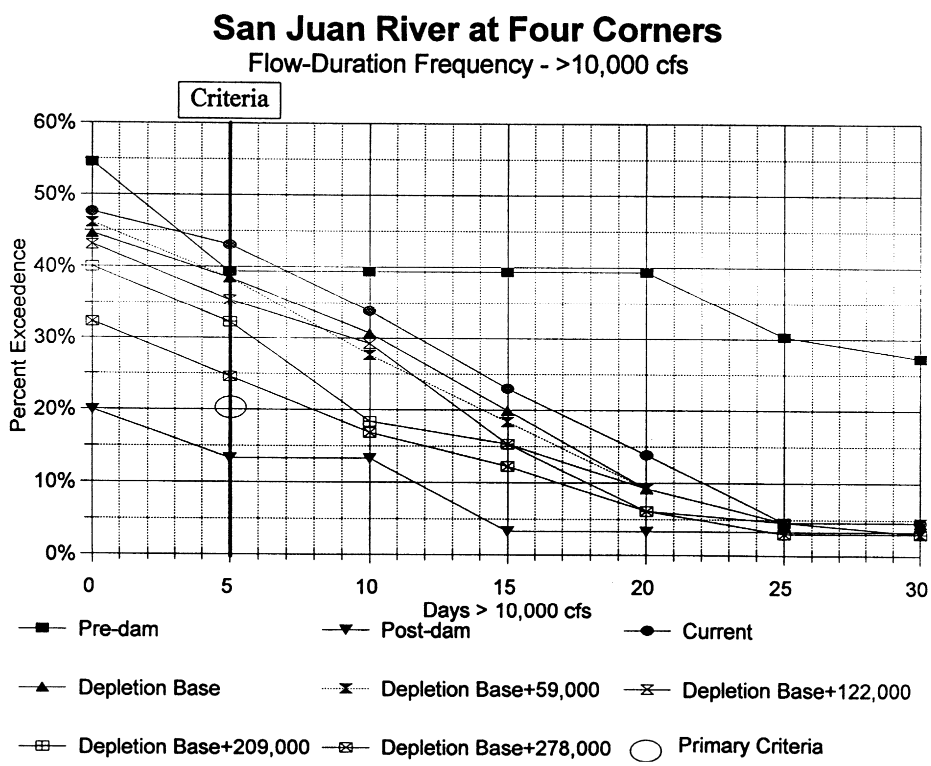


Figure 8.10. Frequency/duration relationship for flows exceeding 10,000 cubic feet per second (cfs) with a peak release of 6,000 cfs.

during this period. Because the dam is in place, the statistics for historical conditions without dam interference could only be assessed for this period by modeling the post-dam period to predict the conditions that would have occurred without the dam. Such modeling was not completed. Figures 8.11 through 8.18 show the time line of meeting the flow/duration criteria for each of the target flow levels listed above for 5,000 and 6,000-cfs peak release levels.

Another change in hydrograph statistics is in the average duration of flows above the target rates of 2,500, 5,000, 8,000, and 10,000 cfs. This reduction in average duration reflects the level of additional depletions from the system.

Backwater Habitat Results

The results of the flow/habitat model, applied to each of the model runs and historical periods, are shown in Table 8.7 for a peak release of 5,000 cfs and in Table 8.8 for a peak release of 6,000 cfs. The first two sets of values show average backwater area for late summer through early winter for Reaches 1 to 4 and 1 to 5. The second two sets show average area for peak runoff months after typical expected razorback sucker spawning for Reaches 1 to 4 and 1 to 5. The values reflect all conditions of the backwater model, including flow/habitat relationships and perturbation conditions. The backwater area in Reaches 1 to 4 is available to YOY spawned in Reach 5, where Colorado pikeminnow spawning presently occurs. If spawning could occur in Reach 6 through barrier removal and expansion of range, then the values for Reaches 1 to 5 would apply.

The worst conditions for backwater habitat occurred post-dam when habitat-flushing flows were limited and base flows were maintained in the range that produced the minimum backwater habitat. The average backwater area for Reaches 1 to 5 during the pre-dam period was 20.24 acres (ac), compared with the post-dam area for Reaches 1 to 4 of 11.07 ac. Since this was the only portion of the river available to young Colorado pikeminnow below a spawning area, Reaches 1 to 4 were used during the post-dam period, whereas Reach 5 and perhaps even Reaches 6 to 8 were available during the pre-dam period. This comparison of post-dam and pre-dam periods indicates there was at least a 45% loss of backwater habitat in the upper San Juan River. In addition, the creation of Lake Powell in the early 1970s at the other end of the San Juan River also resulted in the loss of potential backwater habitat, thus increasing the impact to YOY Colorado pikeminnow habitat.

Modeled backwater habitat area for levels of development through depletion base plus 122,000 af are better than those for the pre-dam period for the same range, because of better control over flows in the base-flow months.

Fish Recovery, Water Development, and Flow Recommendations

The recommended flow conditions can be met by applying the rules outlined in this chapter to the reoperation of Navajo Dam under current depletion levels and under some level of future development. The amount of future depletion that is possible while still meeting the conditions of the flow recommendations depends upon the magnitude, timing, and location of the depletion and the effect of these factors upon the operation of the entire river system. While the tools developed can analyze the impact of any collection of development projects on the ability of the system to meet

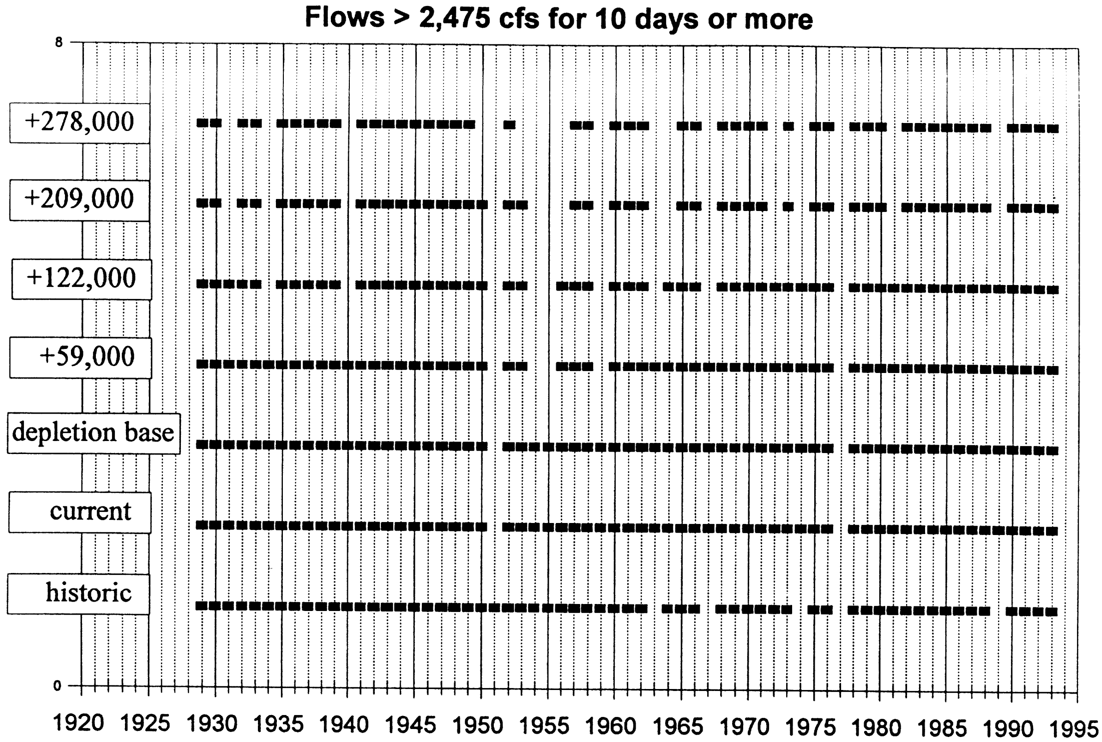


Figure 8.11. **Time line for meeting minimum duration of flows > 2,475 cubic feet per second (cfs) (97% of 2,500) with a peak release of 5,000 cfs.**

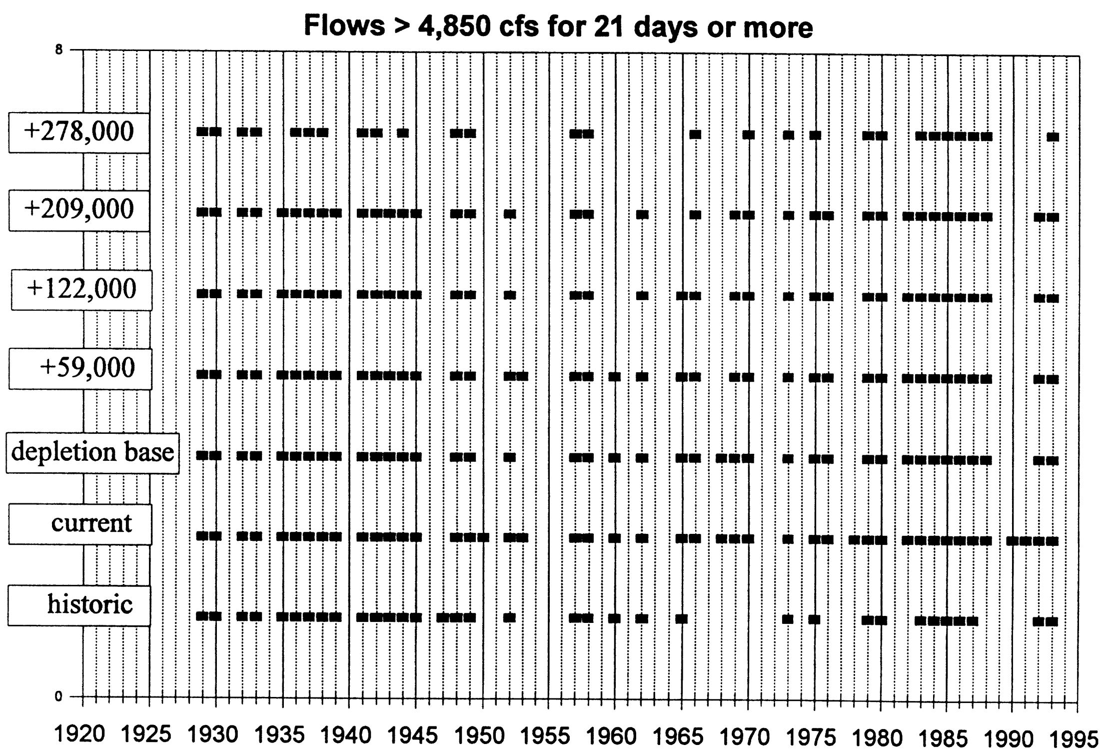


Figure 8.12. **Time line for meeting minimum duration of flows > 4,850 cubic feet per second (cfs) (97% of 5,000) with a peak release of 5,000 cfs.**

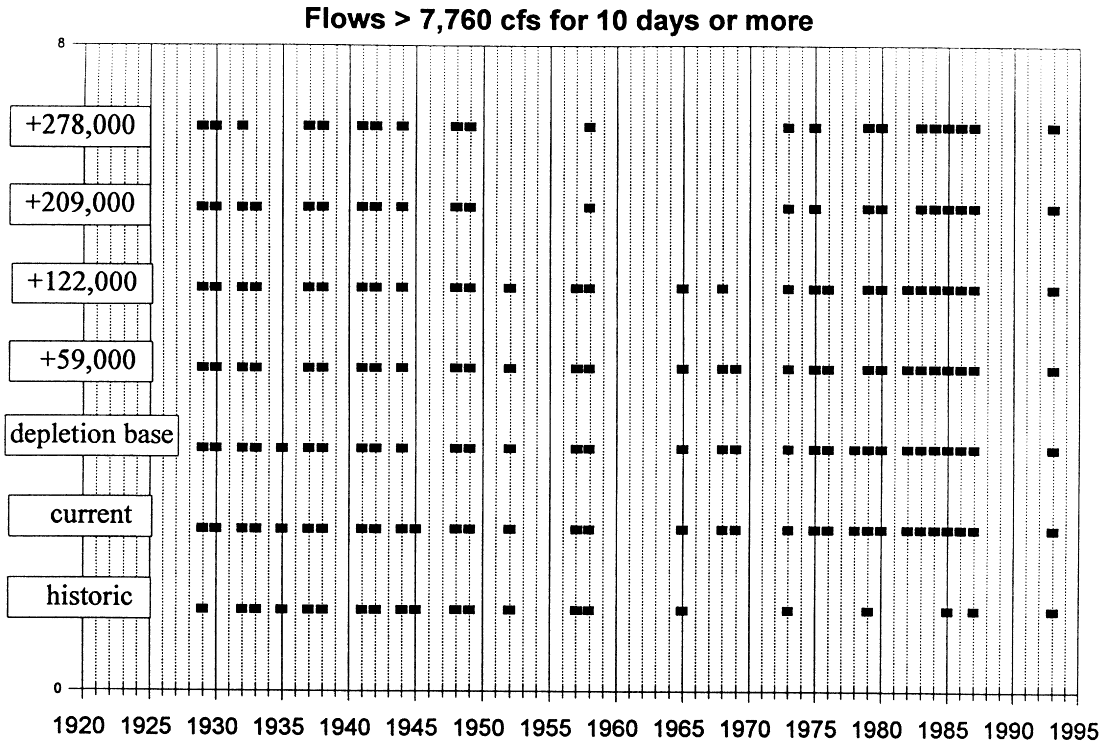


Figure 8.13. Time line for meeting minimum duration of flows > 7,760 cubic feet per second (cfs) (97% of 8,000) with a peak release of 5,000 cfs.

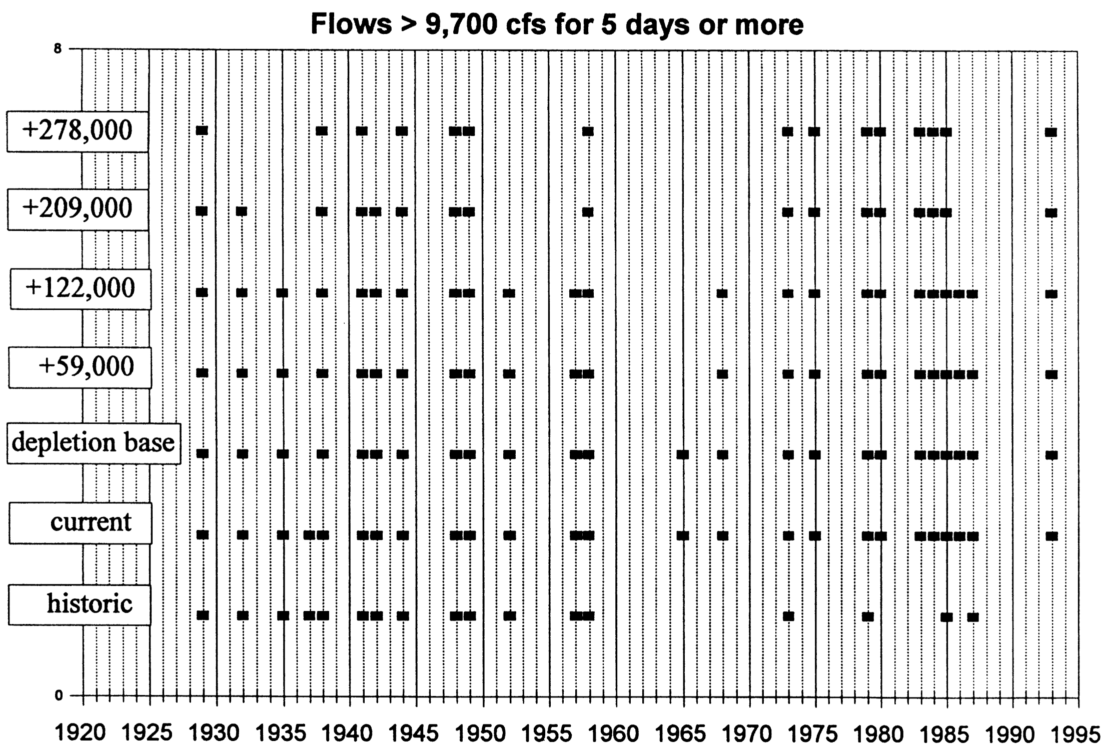


Figure 8.14. Time line for meeting minimum duration of flows > 9,700 cubic feet per second (cfs) (97% of 10,000) with a peak release of 5,000 cfs.

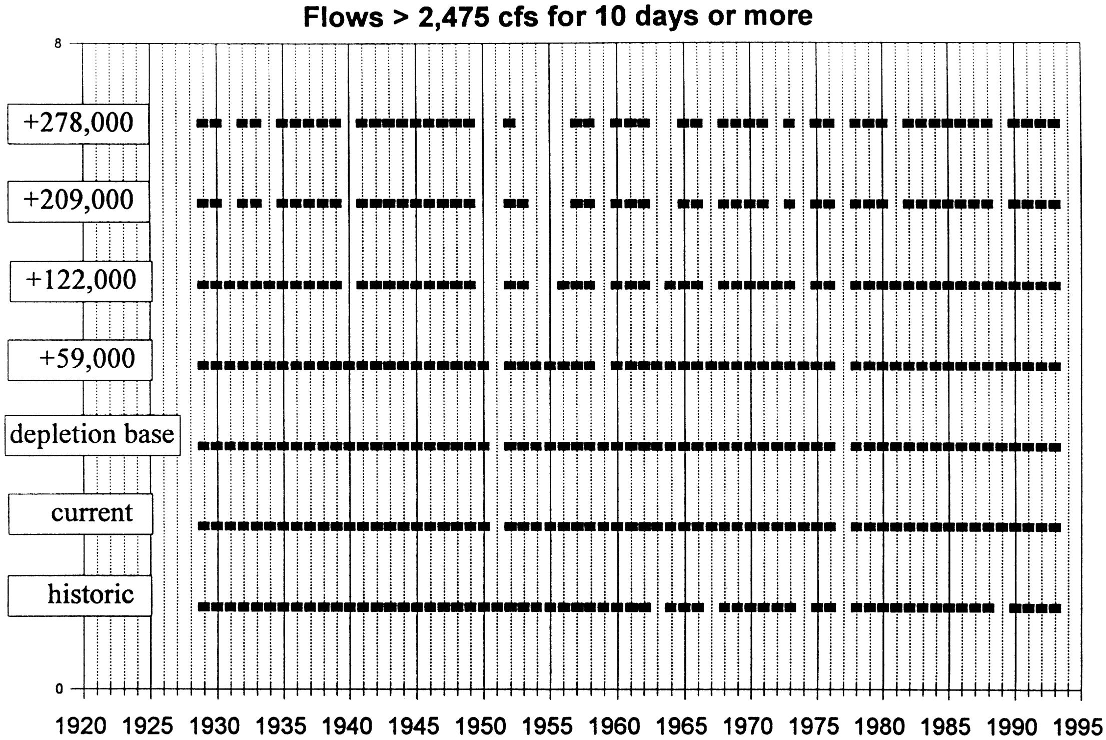


Figure 8.15. Time line for meeting minimum duration of flows > 2,475 cubic feet per second (cfs) (97% of 2,500) with a peak release of 6,000 cfs.

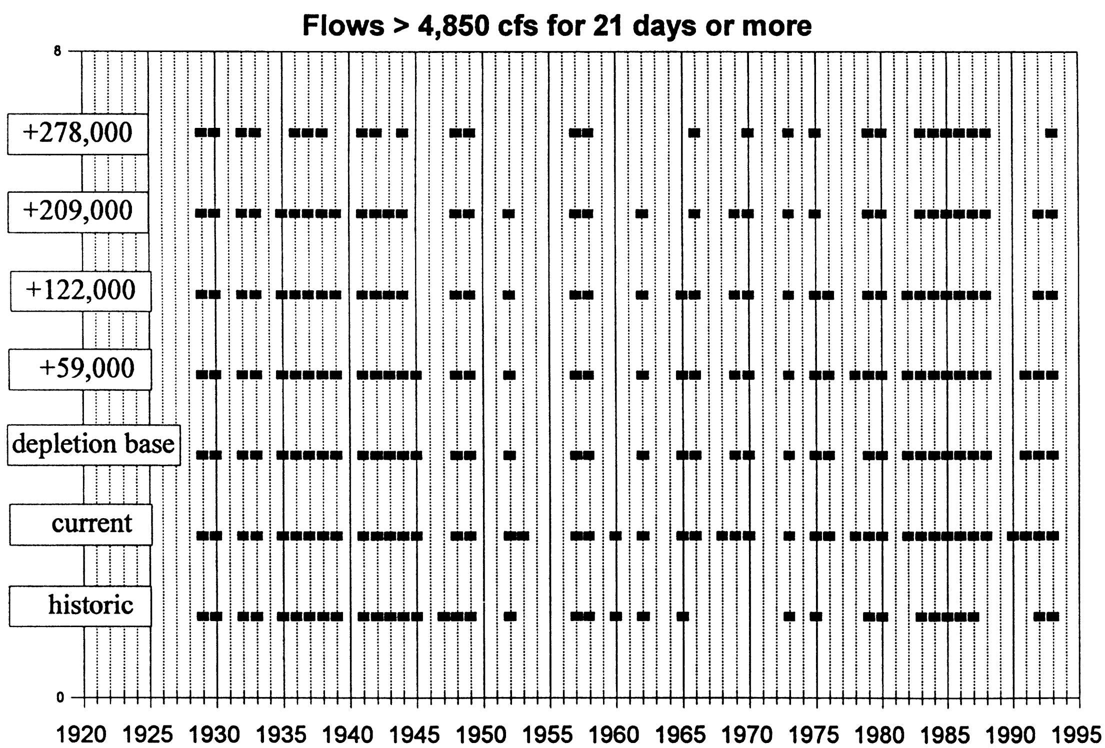


Figure 8.16. Time line for meeting minimum duration of flows > 4,850 cubic feet per second (cfs) (97% of 5,000) with a peak release of 6,000 cfs.

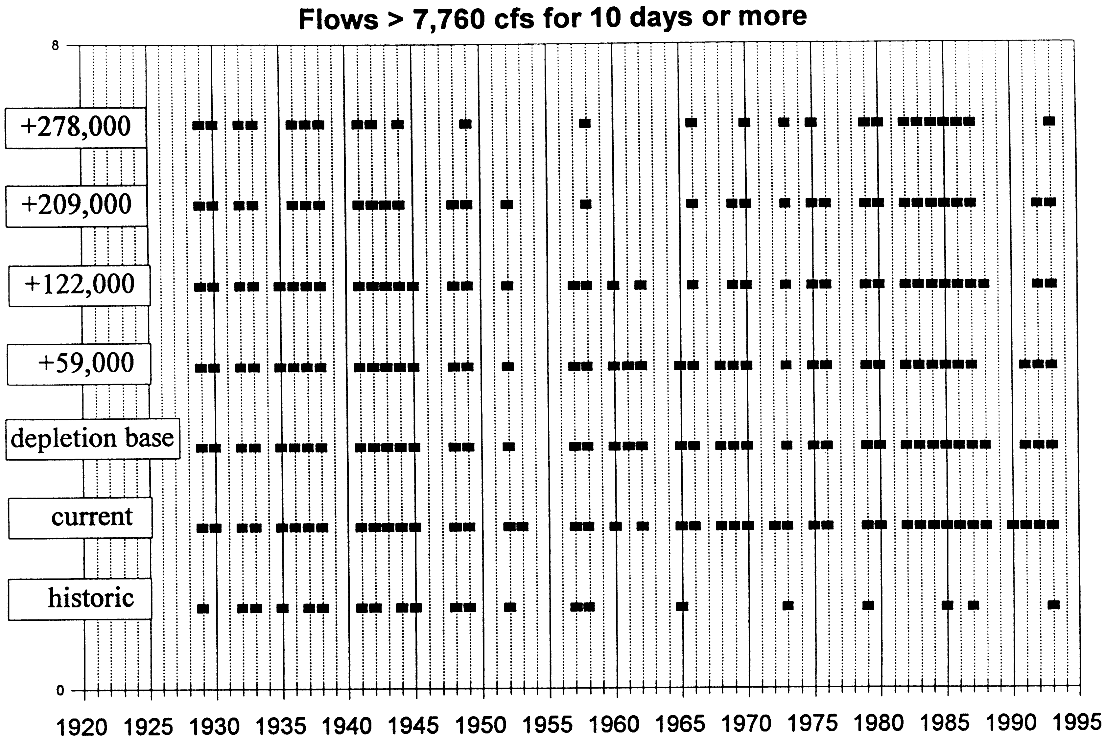


Figure 8.17. **Time line for meeting minimum duration of flows > 7,760 cubic feet per second (cfs) (97% of 8,000) with a peak release of 6,000 cfs.**

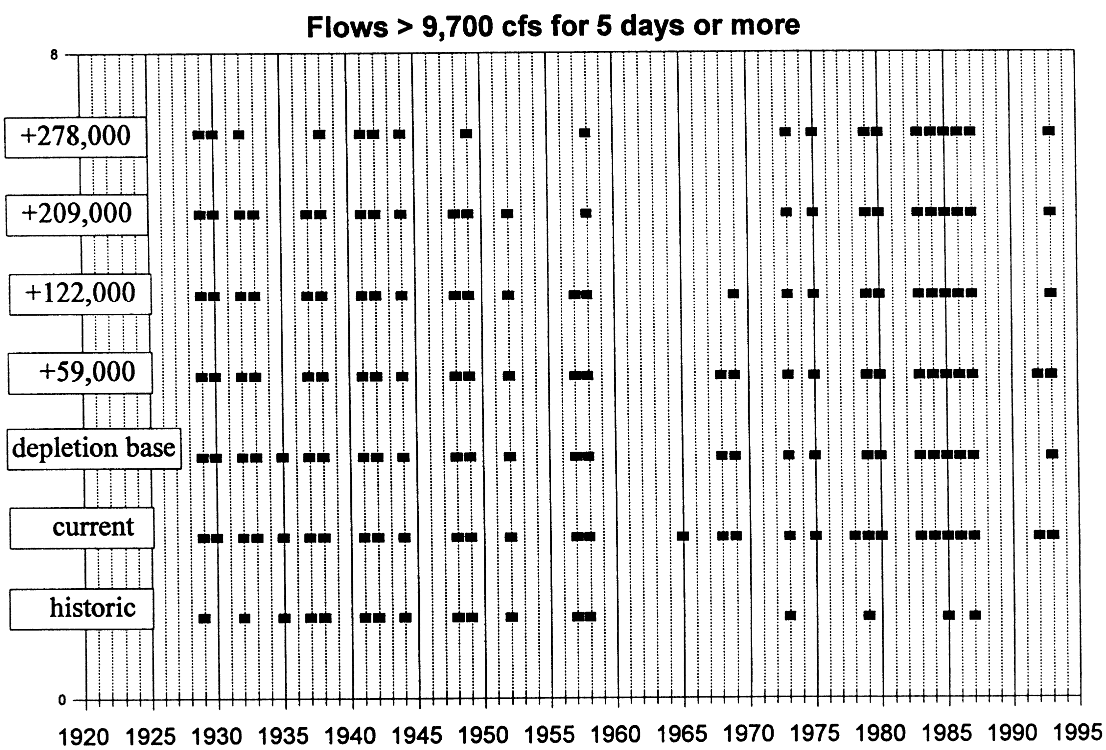


Figure 8.18. **Time line for meeting minimum duration of flows > 9,700 cubic feet per second (cfs) (97% of 10,000) with a peak release of 6,000 cfs.**

Table 8.7. Comparison of modeled backwater area for six levels of development and three historical periods with a peak release of 5,000 cfs.

PARAMETER	PRE-DAM	POST-DAM	STUDY PERIOD	CURRENT	DEPLETION BASE	BASE +59,000	BASE +122,000	BASE +210,000	BASE +280,000
Backwater availability, Reach 1-4 - acres									
Average before storms	21.32	14.34	23.05	23.53	24.16	23.68	22.69	21.71	20.22
August	16.94	11.89	17.69	18.65	19.19	18.73	18.14	17.51	16.36
September	14.92	11.69	15.22	17.08	17.66	17.14	16.50	15.52	14.49
October	13.75	10.46	14.61	16.16	16.76	16.33	15.52	14.91	14.15
November	14.78	11.04	14.10	16.26	16.74	16.39	15.72	14.98	14.02
December	15.92	10.29	15.66	15.61	16.28	16.05	15.63	14.67	13.73
Average (Aug-Dec)	15.26	11.07	15.46	16.75	17.33	16.93	16.30	15.52	14.55
Average Perturbation[a]	28%	23%	33%	29%	28%	29%	28%	29%	28%
Change from pre-dam		-27%	1%	10%	14%	11%	7%	2%	-5%
Backwater availability, Reach 1-5 - acres									
Average before storms	26.36	19.39	26.51	28.36	29.35	29.00	28.29	27.19	25.55
August	21.67	17.35	21.24	23.48	24.30	23.91	23.41	22.85	21.72
September	19.89	17.53	18.28	22.20	22.92	22.41	21.64	20.72	19.67
October	18.36	15.21	17.69	20.99	21.74	21.49	20.58	19.97	19.28
November	19.76	15.36	17.15	21.37	22.18	21.90	21.26	20.24	19.38
December	21.54	14.76	19.80	20.47	21.68	21.53	21.27	19.87	19.10
Average (Aug-Dec)	20.24	16.04	18.83	21.70	22.56	22.25	21.63	20.73	19.83
Average Perturbation[a]	23%	17%	29%	23%	23%	23%	24%	24%	22%
Change from pre-dam		-21%	-7%	7%	11%	10%	7%	2%	-2%
Razorback sucker backwater availability, Reach 1-4 - acres									
May	14.64	15.29	18.53	15.67	16.10	15.80	15.56	15.70	14.72
June	14.11	14.72	17.22	17.21	16.54	16.42	16.19	16.55	15.12
July	16.35	17.34	14.56	19.50	20.74	20.00	18.91	19.43	18.25
Razorback sucker backwater availability, Reach 1-5 - acres									
May	21.65	19.02	20.34	21.80	21.85	21.62	21.37	21.64	20.48
June	21.24	18.60	22.48	23.96	23.13	22.79	22.47	22.58	20.86
July	22.20	21.57	25.58	23.84	25.41	24.77	23.52	24.23	23.11

[a]Average loss in habitat area due to sediment laden storm events over the period of record computed as one minus the average habitat available for August-December divided by the average before storms.

Table 8.8. Comparison of modeled backwater area for six levels of development and three historical periods with a peak release of 6,000 cfs.

PARAMETER	PRE-DAM	POST-DAM	RESEARCH PERIOD	CURRENT	DEPLETION BASE	BASE +59,000	BASE +122,000	BASE +210,000	BASE +280,000
Backwater availability, Reach 1-4 - acres									
Average before storms	21.32	14.34	23.05	23.72	24.31	24.09	22.67	20.88	19.96
August	16.94	11.89	17.69	18.79	19.26	19.11	18.05	16.88	16.10
September	14.92	11.69	15.22	17.14	17.75	17.55	16.32	14.91	14.19
October	13.75	10.46	14.61	16.26	16.85	16.55	15.48	14.37	13.96
November	14.78	11.04	14.10	16.40	16.82	16.74	15.47	14.40	13.85
December	15.92	10.29	15.66	15.95	16.47	16.49	15.60	14.12	13.60
Average (Aug-Dec)	15.26	11.07	15.46	16.91	17.43	17.29	16.23	14.93	14.34
Average Perturbation[a]	28%	23%	33%	29%	28%	28%	28%	29%	28%
Change from pre-dam		-27%	1%	11%	14%	13%	6%	-2%	-6%
Backwater availability, Reach 1-5 - acres									
Average before storms	26.36	19.39	26.51	28.65	29.54	29.41	28.21	26.25	25.24
August	21.67	17.35	21.24	23.70	24.31	24.40	23.29	22.22	21.35
September	19.89	17.53	18.28	22.20	23.03	22.86	21.49	20.06	19.36
October	18.36	15.21	17.69	21.00	21.95	21.64	20.52	19.33	19.05
November	19.76	15.36	17.15	21.64	22.22	22.31	21.18	19.61	19.11
December	21.54	14.76	19.80	21.00	21.90	21.98	21.25	19.42	18.96
Average (Aug-Dec)	20.24	16.04	18.83	21.91	22.68	22.64	21.55	20.13	19.56
Average Perturbation[a]	23%	17%	29%	24%	23%	23%	24%	23%	22%
Change from pre-dam		-21%	-7%	8%	12%	12%	6%	-1%	-3%
Razorback sucker backwater availability, Reach 1-4 - acres									
May	14.64	15.29	18.53	15.48	15.54	15.48	15.44	15.54	14.44
June	14.11	14.72	17.22	16.67	16.24	16.26	15.89	15.93	14.70
July	16.35	17.34	14.56	19.53	20.86	20.43	18.83	18.59	18.09
Razorback sucker backwater availability, Reach 1-5 - acres									
May	21.65	19.02	20.34	21.89	21.72	21.50	21.51	21.65	20.19
June	21.24	18.60	22.48	23.41	22.78	22.70	22.10	21.86	20.37
July	22.20	21.57	25.58	23.89	25.52	25.11	23.38	23.32	22.91

[a]Average loss in habitat area due to sediment laden storm events over the period of record computed as one minus the average habitat available for August-December divided by the average before storms.

the flow requirements, they cannot provide an accounting of what is already "approved" for development and what would be considered as "future" development. The results reported in Chapters 7 and 8 discuss an approximation of what has been "approved" for development as the "depletion base." Since this depletion base has neither been reviewed and agreed upon by the SJRIP participants nor accepted by the responsible agencies, it stands only as an estimate of the level of depletion to which future projects must be added to determine impact. The "depletion base" should not be equated with the "Environmental Baseline" used in Consultations by the USFWS. It is only an unapproved estimate of that level of depletion.

With this clarification, the results of the modeling reported in this chapter indicate that the flow recommendations can be met when applying the suggested operating rules for all hypothetical development scenarios tested through depletion levels of "depletion base" plus 122,000 af. Hypothetical scenarios tested with depletion levels of 210,000 af and 280,000 af above "depletion base" were not able to meet the required flow conditions, and the development scenario with depletions of 280,000 af beyond "depletion base" experienced severe water shortages. These tests have been completed on specific hypothetical scenarios and have not assessed the ability of any specific project to meet the flow requirements, and they do not imply any specific order of priority of development. Further, they do not precisely define the level of allowable development, which is dependent upon the nature of the development as well as the volume of depletion. The tests were only completed to develop and optimize operating rules and analyze the relationship between levels of hypothetical water development and the ability to meet recommended flow requirements.

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GLOSSARY

7-year research period - The period from 1991 to 1997 when research activities occurred on the San Juan River. For hydrology summaries, the period was 1992-1997 since no change in dam operation occurred in 1991.

Acute toxicity - A level of toxicity that results in death of the organisms being studied.

Adaptive management - Management of a given system using the most current information to continuously evaluate the planned course of action.

Aeolian - The erosion, transport, and deposition of material due to the action of the wind at or near the Earth's surface.

Aerial videography - The process of flying low over sections of river to video tape geographic features. Video tapes are subsequently digitized into GIS data systems for quantification.

Age class - A developmental or temporal delineation of a population of fish; includes age-0, age-1, age-2, etc.

Annual flow regime - The average flow of a stream as measured by the volume of water passing different cross sections over a 1-year time period.

Anthropogenic - Of, relating to, or influenced by the impact of humans on nature.

Augmentation - To increase, as to increase fish density by adding hatchery-reared fish.

Bankfull discharge - The stream discharge and corresponding stage at the incipient point of flooding. It is expressed as the momentary maximum or instantaneous peak flows rather that the mean daily discharge.

Bar - A ridge-like accumulation of sand, gravel, or other alluvial material formed in a channel, along a stream bank, or at the mouth of a stream where a decrease in velocity induces deposition.

Base release - The Navajo Dam release required to meet downstream water right demands during the runoff and summer base flow periods. The release volumes shown in Figures 8.1 and 8.2 assume a base release of 600 cfs during the runoff period. If the base release is not 600 cfs, then a volume adjustment is required to provide the correct release pattern.

Basin - Total land area draining to any point in a stream, as measured on a major aerial photo, also called catchment area, watershed, and drainage area.

Bathymetry - The measurement of the depth contours of a river bottom.

Bedload - The coarser fraction of a river's total sediment load, which is carried along the bed by sliding, rolling, and saltation.

Benthic - Of, relating to, or occurring at the bottom of a body of water.

Bioavailability - A description of the potential of a chemical or nutrient to be used or consumed by an organism.

Bioaccumulation - The accumulation of certain chemicals such as PCBs, mercury, and some pesticides in organisms which in turn are eaten by other organisms. This process can result in toxic levels of chemicals in animals.

Biomass - The amount of living matter in a given area.

Catch-per-unit-effort (CPUE) - The number of fish caught per given amount of effort (time or area); often used as an index of fish abundance.

Catch rate - The number of fish captured within a given area or time; often used as an index of fish abundance.

Cobble - Stream substrate particles between 64 and 256 mm in diameter.

Community - A well-defined assemblage of plants and/or animals that is biologically distinguishable from other such assemblages.

Competition - The general struggle for existence in which living organisms compete for a limited supply of the necessities of life.

Congener - A member of the same taxonomic genus as another plant or animal (e.g., Colorado squawfish and northern squawfish, humpback chub and roundtail chub).

Demersal - Living near, deposited on, or sinking to the bottom of a body of water (e.g., demersal fish eggs).

Depletion base condition - The river depletions considered in modeling simulations that represent all present depletions, all depletions for which Section 7 Consultations under the Endangered Species Act (ESA) have been completed, and depletions that could be reasonably be made without further federal action. Depletion base condition is the depletion level above which future development is measured. While the depletion base condition was determined in a manner similar to the "environmental baseline" discussed in the ESA as the basis for Section 7 Consultations, the depletion base condition has not been through the approval process and is not meant to be equated with the environmental baseline.

Detritus - Loose material such as rock fragments or organic particles that results directly from disintegration, or a product of disintegration or wearing away.

Diel - Involving a 24-hour period that usually includes a day and the adjoining night (e.g., diel temperature fluctuations).

Electrofishing - A method of capturing fish in which probes are used to discharge electrical currents into an area of water, resulting in stunned, immobile fish that can scooped out of the water with nets.

Endangered - Any species that is in danger of extinction throughout all or a significant portion of its range. Such species are often protected under the federal Endangered Species Act of 1978.

Endemic - Restricted in native range to one area—for fish typically one river basin.

Fish habitat - The aquatic environment and the immediately surrounding terrestrial environment that in combination offer the necessary biological and physical support systems required by fish species during various life history stages.

Flood - Any flow that exceeds the bankfull capacity of a stream and flows out on the flood plain.

Floodplain - Any flat, or nearly flat lowland that borders a stream and is covered by its waters at flood stage.

Flow - (a) The movement of a stream of water and other mobile substances from place to place.
(b) The volume of water passing a given point per unit of time. (Synonym: Discharge)

Base flow - The portion of the stream discharge that is derived from natural storage; i.e., not a result of direct runoff. As used here, base flow refers to the portion of the hydrograph not affected by snowmelt or storm runoff.

Enhancement flow - An improvement of flow conditions that provides improvement over natural conditions for aquatic, terrestrial, and recreational resources.

Minimum flow - The lowest discharge recorded over a specified period of time.

Peak flow - The highest discharge recorded over a specified period of time. Often thought of in terms of spring snowmelt or summer, fall, or winter rainy season flow. For this report, it is the maximum average daily flow.

Flushing - The removal of fine sediments from riverine habitats; this is usually accomplished during high flow events.

Geomorphological - The physical form of the river.

Ground truthing - The process of manually checking aerial photos for errors in the field.

Habitat - The place where a population lives, feeds, and reproduces; including its surroundings, both living and nonliving.

Habitat complexity - Refers to the number of different habitat types found in a portion of river. High habitat complexity refers to an area with several habitat types or more, whereas low habitat complexity refers to an area with few habitats.

Habitat type - A terrestrial or aquatic unit, consisting of habitats have equivalent structure, function, and responses to disturbance.

Hydrograph - A graph depicting, for a given point on a stream, the discharge, stage, velocity, or other property of water with respect to time.

Hypolimnetic - Related to the lower, cooler, non-circulating water in a thermally stratified lake in the summer.

Indigenous - Naturally occurring in a particular location. When referring to fish, this has the same meaning as "native."

Inflow - The areas where a river flows into a lake or another river.

Lentic - Of, relating to, or living in still waters.

Life history study - The study of factors (such as food, environment, other organisms) that influence an organism or population during its lifetime.

Lotic - Of, relating to, or living in moving waters.

Low-velocity habitat - Habitat that can be identified by flow speeds less than that of the main channel. Low-velocity habitat includes slackwaters, shoals, eddies, pools, and backwaters.

Macrohabitat - Large hydraulic units that describe areas used by fish, e.g., eddies, runs, riffles, pools, backwaters.

Macroinvertebrate - An invertebrate (animal without a backbone) large enough to be seen by the human eye without magnification.

Main channel habitat - Habitat generally occurring in the deepest cross-sectional area of a river where current speed is highest.

Metabolites - A substance that is essential to the metabolism of a particular organism or to a particular metabolic process.

Minimum peak release - The minimum peak release referenced in the reservoir operating recommendations refers to the smallest Navajo Dam release that will be made during runoff, defined as a 1-week ramp up, 1-week peak, and 1-week ramp down. The actual total volume depends on the magnitude of the peak (e.g., 5,000 to 6,000 cfs).

Native species - A species that evolved in the system in which it was naturally found.

Near shore habitat - Habitat that occurs in areas between the main channel and the still water areas adjacent to shore.

Nonnative species - A species that did not evolve in the system in which it is currently found.

Omnivorous - Species that is not restricted in its food habits to a single type of food.

Overbank flow - The stream discharge that leaves the stream channel and flows into the floodplain.

Passive Integrated Transponder (PIT) Tag - A small, glass-encapsulated, individually numbered tag implanted in a fish's body cavity with a hypodermic needle that can be read with a PIT tag reader each time the fish is captured.

Periphyton - The growth of organisms, primarily algae and diatoms, on rocks and other surfaces in streams.

Perturbation year - A year in which the nursery habitat has been deteriorated by storm events to a level requiring flushing. In the absence of a direct observation, a perturbation year is any year in which there are more than 13 sediment event days, as defined herein, between August 1 and December 31.

Piscivory - Of or relating to fish eating.

Population - A reproducing, self-sustaining aggregation.

Post-dam period - The period between Navajo Dam's completion in 1962 and the advent of the 7-year research period. In summarizing hydrology information, the post-dam period refers to 1962 to 1991.

Pre-dam period - The period before Navajo Dam was completed in 1962. In summarizing hydrology information, the pre-dam period refers to 1929 to 1961.

Predation- The act of catching another organism and eating it after it is dead or while it is still living

Primary peak release - As referenced in the reservoir operating recommendations, primary peak release refers to the largest Navajo Dam release required during runoff, which is defined as a 4-week ramp up, 3-week peak, and 2-week ramp down. The actual total volume depends on the magnitude of the peak (e.g., 5,000 to 6,000 cfs).

Radio-tag - A battery-powered electronic device of varying size that emits a radio signal and can be surgically implanted in a fish's body cavity. Radio-tagged fish can be tracked using a variety of receivers. Radio tags typically last from 0.5 to 2.0 years, depending on battery size.

Reach - A length of stream channel that is relatively uniform with respect to geomorphic characteristics.

Recruitment - Replacement of adults within a population through growth and maturity of young individuals.

Reproductive success - The ability of a given population to produce viable offspring that can continue on to further reproduce.

Riparian - Pertaining to anything connected with, or immediately adjacent to the banks of a stream or other body of fresh water.

Roughness (Manning's n) - A measure of resistance to flow due to channel contact geometry (roughness), expressed as a coefficient used in flow equations to predict depth when slope, cross-sectional area, and discharge are known. One such equation that is used widely in water resources is the Manning equation. The Manning roughness coefficient (n) has been computed for a wide range of bed material and channel configuration for both constructed and natural channels and for floodplains.

Runoff - The portion of rainfall, melted snow or irrigation water that flows across ground surfaces and eventually is returned to streams.

Secondary channel - A channel of a river separated from the main channel by an island.

Sediment load - A general term that describes the movement of sediment by a stream, either in a suspension (suspended load) or at the bottom (bedload).

Spawning - The act of reproduction by which adult male and female fish combine egg and sperm to produce fertilized eggs.

Species - The smallest natural population of organisms permanently separated from all others by more or less complete sexual isolation.

Storm event day - A day when the daily gain in flow between Farmington, New Mexico, and Bluff, Utah, and the daily flow at Bluff, Utah, were each more than 150 cfs greater than the preceding 5-day average. (A storm event day was given a weight of 2 if the gain in flow was 3,000 cfs or more.)

Suspended load - The portion of the total sediment load that moves in suspension and is made up of particles having such a density or grain size as to permit movement disassociated from the stream bed.

Stage - The elevation of a water surface above or below and established reference or datum.

Thalweg - The line connecting the lowest or deepest points along a streambed.

Total dissolved solids (TDS) - A measure of inorganic and organic dissolved in water (able to pass through a 0.45 F filter).

Total suspended solids (TSS) - The organic and inorganic material left on a standard glass fiber filter (0.45 F filter)

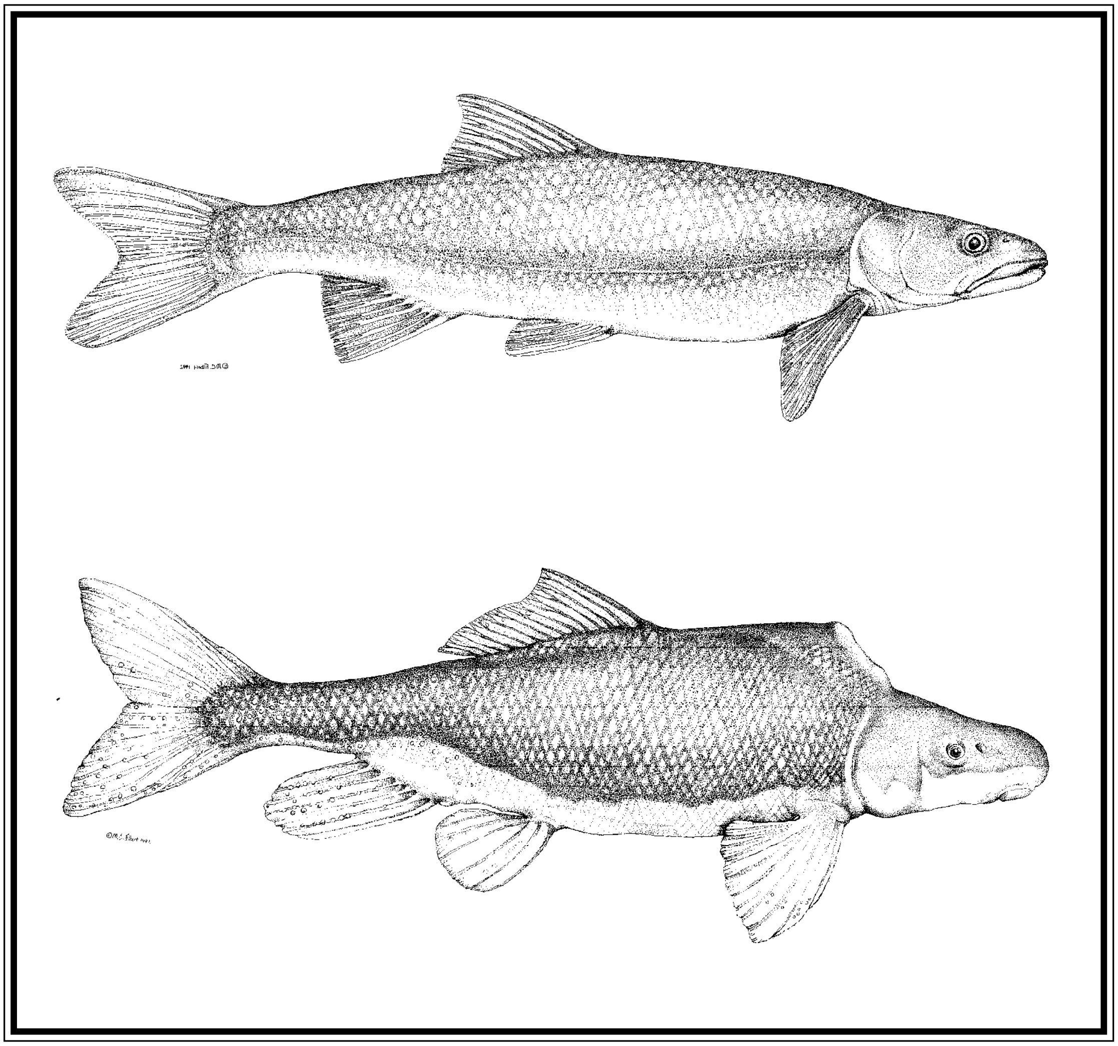
Tributary - A stream feeding, joining, or flowing into a larger stream.

Water quality - A general description of the condition of a body of water described in terms of the chemical (e.g., nitrogen, phosphorous), physical (e.g., temperature, conductivity) and biological (e.g, type and abundance of vegetation) components.

Young-of-the-year (YOY) - Fish less than 1 calendar year of age.

ABBREVIATIONS

af acre-feet
ALP Animas-La Plata Project
ANOVA analysis of variance
As arsenic
ARCCAD ARC Computer Aided Drafting and Design
BIA Bureau of Indian Affairs
BLM Bureau of Land Management
Bureau Bureau of Reclamation
cfs cubic feet per second
cm centimeter
Compact Colorado River Compact
Consultation Section 7 Consultation
Corps U.S. Army Corps of Engineers
CPUE catch-per-unit-effort
CRSS Colorado River Simulation System
Cu copper
D_{50} median substrate size
DDE dichlorodiphenyldichloroethane
DDT dichlorodiphenyltrichloroethane
EPA Environmental Protection Agency
ft feet
ft^2 square feet
fps feet per second
GIS Geographic Information System
gpm gallons per minute
GUI graphical user interface
IFIM Instream Flow Incremental Method
in. inch(es)
ISMP Interagency Standardized Monitoring Program
lbs pounds
LOD limit of detection
Lower Basin Lower Colorado River Basin
LRP Long Range Plan
m meter(s)
m^2 square meter(s)
M&I Municipal and Industrial
maf million acre-feet
mi mile(s)
MIPS Map and Image Processing System
mm millimeter
m/s meters per second
NFH National Fish Hatchery
NIIP Navajo Indian Irrigation Project
NMISC New Mexico Interstate Stream Commission
NMGF New Mexico Department of Game and Fish
PAHs polycyclic aromatic hydrocarbons
PCBs polycholrinated biphenyls
PHABSIM Physical Habitat Simulation System
PIT Passive Integrated Transponder
ppb parts per billion
ppm parts per million
RIP Recovery Implementation Program
RM River Mile
RT(s) river transect(s)
Se selenium
SL standard length
SJRIP San Juan River Basin Recovery Implementation Program
SPMD semi-permeable membrane device
study area SJRIP study area
SWA Horsethief State Wildlife Area
TL total length
TDS total dissolved solids
TSS total suspended solids
TVA Tennessee Valley Authority
TWA total wetted area
Upper Basin Upper Colorado River Basin
UCRRIP Upper Colorado River Recovery Implementation Plan
UDWR Utah Division of Wildlife Resources
USFWS U.S. Fish and Wildlife Service
USGS U.S. Geological Survey
YOY young-of-the-year



The endangered Colorado pikeminnow (top) and razorback sucker (bottom) of the San Juan River.

Response to Comments on the Flow Recommendations for the San Juan River Draft Report (December 4, 1998)

May 1999

Responses Prepared by:
Paul B. Holden and
Ronald D. Bliesner

Prepared for:
The San Juan River Basin Recovery Implementation Program
Biology Committee

PREFACE

This appendix is a response to comments that were submitted by the Peer Review Panel and members of the Coordination Committee on the final draft version of the Flow Recommendations for the San Juan River, dated December 4, 1998. Many of the comments were responded to by making changes in the main document, thus creating this final document. Many other comments did not elicit a change in the document, but required a response to answer the comment. Many of these latter types of comments questioned assumptions in the document, or wondered why certain features were not included in the document. The responses have been reviewed by the Biology Committee and they are in agreement that the responses reflect the overall thinking of that committee.

To respond to comments, electronic versions of comment letters were obtained and responses were made to each comment that warranted a response. Comment letters were reproduced in their entirety except for some letterheads that were not obtained electronically. Where page numbers are noted, they refer to pages in the December 4, 1998, draft document rather than this final document.

Comments were received from the following individuals:

Peer Review Panel

Dr. Ellen Wohl (did not require a response)
Dr. David Galat
Dr. Ron Ryel
Dr. Clark Hubbs (did not require a response)

Coordination Committee

John Whipple, State of New Mexico
Les Taylor and Jessica Aberly, Jicarilla-Apache Tribe
Errol Jensen, Bureau of Reclamation
Tom Pitts, Water Development Interests
Randy Seaholm, State of Colorado

COMMENT LETTERS AND RESPONSES

Paul Holden
BIO/WEST, Inc.
1063 West 1400 North
Logan, UT 84321

Dear Paul: 28 Sep. 1998

I have now had a chance to read the draft report on “Flow Recommendations for the San Juan River” (16 Sep 1998). I focused my attention on the portions of the report relating to hydrology and geomorphology. In general, I think that the report is well-organized and written, and represents a great deal of very thorough, careful work. My concerns following the last meeting of the review panel, in May 1998, were addressed in this document with the explanation of how bankfull discharge was determined, and the list of habitat types designated for the San Juan River. I think that the process followed for developing flow recommendations on the San Juan River represents a model that can be usefully applied to other regulated rivers with endangered species concerns.

I realize that the process of making flow recommendations for the San Juan River will involve on-going changes and adaptive management, as stressed throughout the flow recommendations report. My suggestions for continued future research related to geomophology are (1) to develop a system-wide sediment budget, and 92) to use 2-dimensional flow and sediment transport modeling to study the effect of changing water and sediment discharge regimes on backwater habitats. At present, the conceptual models of how the San Juan River adjusts to changing flow regimes are black-box in that they are based on observed changes and historical information, rather than specific, quantitative knowledge of processes such as sediment movement and channel response. Even as approximate quantification of sediment inputs, storage, and outputs from the San Juan River corridor would help to explain long-term trends or different channel responses through time to the same discharge level, for example. A system-wide sediment budget could be used in a manner analogous to the RiverWare model in that it would be more feasible than at present to evaluate the system-wide effects of changes in one component (such as tributary sediment input). Similarly, 2d models which simulate the secondary flow patterns that are likely responsible for creating and maintaining backwater habitats could be used to more effectively evaluate the response of these habitats to changes in flow regime.

In closing, I would like to reiterate that I am ver impressed with the hydrologic and geomorphic studies conducted on the San Juan River in connection with developing flow recommendations for endangered species recovery. My only specific comments at this point are suggestions for possible future directions for the program.

Sincerely,

Ellen Wohl

Ellen Wohl
Associate Professor of Geology
Colorado State University

Review of Draft Report:
Flow Recommendations for the San Juan River
David L. Galat, Ph.D.

This review covers the 16 September 1998 Draft for Chapters 1-6 and the 4-December 1998 Draft for Chapters 7 and 8. It treats only the technical aspects of the Report as they relate to the project objectives.

Strengths

My professional emphasis on large river ecology has familiarized me with research on many large rivers throughout the world. The thoroughness, goal orientated approach, and overall research quality of this effort rank it very high among those I've encountered. The greatest strength of the effort is linking hydrology, geomorphology and life history requirements of the listed fishes to recommend flow requirements. A second strength is that the flow recommendations incorporate statistical variability rather than relying on mimicry of any specific annual hydrograph. Importantly, the approach is adaptive in that modifications in recommendations are incorporated in the plan based on new information. Additionally, the SJRIP Biology Committee recognized the difficulty of evaluating responses of wild endangered fishes to changes in Navajo Dam flows in the San Juan and proactively responded by stocking squawfish and razorbacks. While some might find fault with this approach, in my opinion, it was the best strategy to maximize information learned from controlled flow releases.

The amount and detail of life-history information briefly summarized for the Colorado squawfish and razorback sucker is impressive compared with many non-game species. The authors have capitalized on this knowledge base to compensate for the low numbers of these fishes currently present in the San Juan River and provided a most comprehensive analysis of flow and habitat effects on critical life-history events. They abstracted relevant portions of detailed studies (e.g., invertebrates, detritus and periphyton biomass) to determine flow needs of fishes, without dwelling on the details.

The San Juan and Green and Colorado rivers were contrasted whenever possible to show similarities and differences. This placed the SJRIP effort into a regional context, but also emphasized its uniqueness.

This report does an excellent job of summarizing and integrating what is known about the target fishes life histories from a wide variety of sources and relating them to the San Juan. Moreover, it presents realistic and objective conclusions which, it is acknowledged, may not always be clear cut. For example, the authors state based on a thorough review of the evidence that photoperiod, temperature, and flow all play a role in cuing squawfish spawning.

Chapter 7 was very helpful to a non-hydrologist like myself to understand the fundamentals of the modeling process without too much detail. Sufficient qualifications were included to assure the reader that what is presented is a range of possibilities given probable conditions and that the recommendations made are preliminary and based on best available information at the time.

Success of the San Juan Recovery Program depends upon a positive response of the targeted fishes to the flow recommendations. A standardized monitoring program that focuses on specific biological response variables (e.g., larval fish density below known spawning areas, juvenile density in autumn from critical habitats, numbers of adult fishes on spawning areas) within a hydrologic and geomorphic context is essential for at least a decade. Because the Program uses an adaptive approach the models and flows can be adjusted during the monitoring as information is gained.

General Suggestions for Improvement

Non-native fishes. The report does an excellent job of describing the documented and suspected impacts of non-native fishes to the targeted fishes. Additionally, it is indicated that a more natural hydrograph may benefit native over non-native fishes. However, it is unlikely that non-natives will be extirpated by a natural flow regime and their continued impact may remain an impediment to achieving the full restoration potential of the native San Juan fish fauna. I suggest this reality be considered in relation to expectations of the benefits of restoring a natural hydrograph and incorporated into your adaptive management strategies. **RESPONSE:** *The Biology Committee is well aware of this potential and has incorporated it into its future activities.*

The amount of methodological details in Chapter 4: Response to Research Flows, seems excessive and out of balance relative to the biological information presented elsewhere. I believe it detracts from the reader grasping the main geomorphic effects of what the research flows accomplished. Perhaps methodological details and the hydrological nuances should be summarized elsewhere. In general, a bit more even treatment of biological and physical information is suggested. Having biologists edit the physical sections and visa-versa is a good approach to accomplish this. **RESPONSE:** *We understand the basis of the concern. However, since the flow recommendations are based so heavily in the hydrology/geomorphology relationships, earlier drafts were criticized by others for not including sufficient detail. The detail was added in response to those criticisms.*

If high flows are required to move materials and they ultimately move through the system. Where do new materials (e.g. cobble) come from? Contrasting the relative importance of lateral sources (some of which may come from bank erosion of adjacent private lands) and downstream transport in a system where Navajo Dam has reduced supply is an important consideration. What will be a range of projected channel configurations in 50 years and where will cobble come from if the system is laterally and longitudinally constrained, or is it? **RESPONSE:** *Navajo Dam cut off the upstream cobble source. The Animas River still provides a small cobble source from upstream as does the LaPlata River (both unregulated). It is likely that the bulk of the new cobble in the system will come from bank erosion and newly formed secondary channels created during over-bank flow events. With a flow regime reduced from historic pre-dam conditions, cobble transport is also reduced. Fortunately, the channel is not laterally constrained over much of its length once on the Navajo Reservation (Below RM 158). While we have not attempted to predict the long term cobble balance,* *an examination of the channel configuration since 1934 compared to the changes we have seen during the research period, indicate that the general nature of the channel should not markedly change over what we see today for a very long time. Continued monitoring will help evaluate any trends that may be of concern. No change in the report was made in response to this comment.*

There is increasing evidence that in addition to backwaters, main channel margins, especially in areas of complex point and lateral bars supply important nursery habitat for age 0 fishes. (e.g., Schiemer and Waidbacher 1992. River Cons. & Manage. Boon, Calow and Petts [eds] and references therein). I believe these equate to the term "slackwaters" in Table 2.1. Have the contributions of these areas been investigated for larval and juvenile squawfish and razorback suckers in the San Juan or other Colorado River tributaries? **RESPONSE:** *Yes, young squawfish used low velocity habitats such as slackwaters in the San Juan River. This information is discussed on pages 3-10 and 4-48. These channel margin habitats will be sampled more frequently under the proposed long term monitoring protocols being developed by the Biology Committee.*

Much of the fish sampling reported in Chapter 4, including specific species and life stages, was done by a variety of agencies (WDWR, NMGF, USFWS, USBR, UNM, etc.) using a variety of gears, various personnel, and at different times and flows within and among years. How standardized sampling protocols were for the same species and life stages among agencies within and across years is an issue that could influence interpretation of the results. **RESPONSE:** *Standardization of collecting methods was implemented throughout much of the 7-year research period. The primary sampling factors that varied were sampling times and sampling intensity. We have noted this concern on page 4-40, 4-53, and other pages in Chapter 4.*

It is particularly important that any monitoring program instituted on the San Juan be consistent so that differences or similarities observed can be attributed to habitat, flow and species traits rather than gear or researcher variability. I'm involved in a 7 group consortium that has just completed sampling benthic fishes along the 3,300 km Missouri River for three years. We've used a set of standard operating procedures (SOPs) to accomplish this (to illustrate the approach they can be found at www.cerc.cr.usgs.gov/pubs/benfish/title_page.htm). While the details for the San Juan would differ greatly from the Missouri the need for standardization is evident. **RESPONSE:** *We agree and have attempted to correct any problems with the Monitoring Plan that is presently being developed by the Biology Committee.*

I'm concerned at the amount of "grey" literature referenced to substantiate recommendations when many of these reports were completed several years ago. While it should not be the intent of this project to publish peer reviewed papers in professional journals, establishing scientific credibility of the research (e.g., Ryden and Alm 1996 on San Juan and numerous papers cited on Green and Yampa Rivers) is important if your recommendations are to be accepted by the various interest groups. **RESPONSE:** *For one reason or the other, much of the Colorado River information has been reported in agency reports rather than peer reviewed journals. We have used peer reviewed citations as much as possible, but some information remains in final report format.*

There are many terms that are specific to this Report that do not appear in the Glossary. Presently it contains general biological and hydrological terms but lacks those specific to the Report. For example, the essence of the Report is the modeled flow scenarios, yet essential terms like pre-dam, post-dam, study period, baseline, etc. aren't in the Glossary. I include a few terms that stood out to me. **RESPONSE:** *We have expanded the glossary to include more terms.*

SPECIFIC COMMENTS

Inside Cover

Include a format for citing the document and chapters within it someplace up front. This is important so that others can accurately reference the document or portions therein.
Here's one sample format.
Citing the entire Report: Holden, P. B. (Ed). 1999. Flow recommendations for the San Juan River. SJRIP Biology Committee. Where published and available??

Chapter in Report: R. Bliesner and V. Lamarra. 1999. Chapter 2: Geomorphology, hydrology and habitat of the San Juan River. Pages 2.1-2.29. *In* P. B. Holden (ed)....

This is just an example and may not be correct. However, do whatever is required to be sure appropriate credit is given to contributors, but don't avoid a formal citation format for fear someone will be offended because of the order of their appearance. **RESPONSE:** *We have added a page to show a suggested citation format after the front cover.*

Executive Summary

S-1. I suggest repeating here (S-1) an abbreviated summary of the importance of the natural flow regime and the coupling of hydrology, geomorphology and biology (pg 1-4). This is the rationale underlying the entire SJRIP effort and the lay reader needs to be better educated as to its underpinnings. **RESPONSE:** *This has been inserted.*

S-5--S-8. Flow Recommendations A.-G. Despite the preparatory paragraph explaining these recommendations, they are still not very clear to me. The entire Report depends on everybody understanding these recommendations. Avoid hydrological and statistical jargon here and don't skimp on text to sacrifice clarity for brevity.

Duration and frequency terms need clarification. Duration terms are days per what? Month, year, decade? I think for A. you mean: 5 days minimum between 3/1 and 7/31? The expression of frequency is too arcane for the non-hydrologist. 20% on average of what? Do you mean 20% of the years on average per decade? "Maximum period without...is 10 years", is Greek. Frankly, even with the text explanation I don't know what this means, so I doubt your general reader will either. Perhaps giving an example would help? Much of this is explained in Chapter 8, but not everyone will read it, so sufficient background must be provided in the Ex. Sum. for it to stand alone.

E. Saying, "similar to historical conditions", is vague. Tell what the historical conditions are? **RESPONSE:** *We have followed your above suggestions and have expanded the definitions in both the Executive Summary and in Chapter 8.*

I don't agree that maintaining a similar peak of Q max timing to historical conditions will necessarily yield ascending and descending hydrograph limbs similar to historic conditions. You can achieve the date of Qmax by opening the gates completely for three days and then shutting them off which results in steep ascending and descending hydrograph limbs, or your could increase and decrease flows more gradually achieving the same date of Q max but with more gradual rising and falling hydrograph limbs. I think, if you want a rate of hydrograph rise and fall then providing rate of change of flow (e.g., + or - cfs/day) is what's needed (i.e. the ramp up and ramp down volumes ?). **RESPONSE:** *Since Navajo Dam only controls about 50% of the flow in the area of concern, the nature of the release shape is influenced both by release ramp rates and timing of the peak. The result of this recommendation must be taken in the context of the other recommendations being met. Specifying the mean date and acceptable range of standard deviation is important to mimic the historic timing of the ascending and descending limbs. The language has been edited to include this qualification and make in clearer.*

Chapter 1

1-1. Correct use of fish versus fishes. **RESPONSE:** *We have checked usage of these terms again throughout the document.*

1-4. Try and cite more primary literature. Richter et al. 1998 (Reg. Rivers 14:329-340) and other papers of his cited therein are more credible than an abstract for an oral paper. Richter's papers preach the natural flow regime in a very articulate and convincing manner. **RESPONSE:** *We have added better references per your suggestion.*

Chapter 2

2-26. "Production" was not either measured nor "estimated". Standing crop or biomass (gm/m^2) was measured. Production is a rate, e.g. gm/m^2/day. Equating standing crop to production is similar to saying volume (cf) equals discharge (cfs). Call it biomass. **RESPONSE:** *We have made this change.*

Chapter 3

3.3. P. 4. Saying temperature "was less variable" than date of spawning is somewhat misleading, particularly when you later say that photoperiod may be more important than temperature for cuing spawning. Its comparing apples and oranges. Just say temperature varied from 16 to 19C. **RESPONSE:** *We have corrected this sentence to conform to the conclusions developed by Bestgen et al. (1998).*

3-16. I'd be a bit careful in implying studies from Lake Mohave are applicable to a riverine system without a word of caution. Research by Papoulias and Minckley (TAFS, 1989?) indicated starvation

might also be a contributing factor to low larval survival.. The 30 mm razorback suckers reported by Minckley from a predator free environment also were in a food rich environment where growth was very rapid. Obviously, a food rich environment where growth is fast reduces the window where larval fishes are susceptible to intense predation. Like spawning cues, its likely a combination of factors such as food availability, habitat and introduced predators that result in low larval survival and this should be acknowledged.
RESPONSE: *We agree and have added a sentence on page 3-17 to make this point clearer.*

Chapter 4

4-5, p3. Avoid using terms like "is obvious". If it's so obvious, why was it necessary to measure? More importantly the scour/fill pattern associated with runoff/non-runoff periods is not obvious to me since there is no indication on the Figure which dates are runoff and which are non-runoff. I can approximate by referring back to annual hydrographs, but should not have to do this. Summarize what the figure represents, beyond the details: High flows deepen the channel and expose large bed materials while during low flows the channel fills with finer sediments? You do this in the next paragraph for Fig 4.2. Summarize the overall pattern for both. **RESPONSE:** *Language has been edited. Runoff periods have been noted on Figures 4.2 and 4.3.*

4-18--4-20. Is all this gory detail really needed? I believe the objective is to define what the timing, duration, frequency and magnitude of discharges are needed to construct and maintain cobble bars. I know this is a complex subject and the recommendations are preliminary because of only a few years of data. However, I suggest just referencing the approach used, provide the methodological details elsewhere, and focus on the relevant results given on pgs 4-21--4-22. The reader was spared the details of how squawfish spawning dates were estimated on Fig 3.1, a similar level of abstraction should hold for the hydrologic and geomorphic sections. **RESPONSE:** *Much of this detail was added in response to earlier comments relating to the foundation for the flow recommendation. The imbalance that resulted between the level of detail in geomorphology and biology sections is justified by the heavy weight of the hydrology/geomorphology relationships in the development of the flow recommendation.*

4-34--4-37. These figures present a good evaluation of how flow events affect backwater "productivity". In order to examine the relative importance of resources in backwater habitats to age 0 fishes it would have been valuable to contrast them with other potential nursery habitats. Without information on relative differences in periphyton, detritus and invertebrates between backwaters and other locations how do I know whether the amounts of these indicators you report in Figs 4.11-4.13 are high or low? **RESPONSE:** *We agree that additional habitat quality data would have been nice to have, but this area of study was not a major emphasis during the 7-year research period.*

4-44. How habitat complexity was determined is vague. Either provide a reference or define the size of "contact area" so the reader can better understand what habitat complexity is. Better yet, show on Fig 4.15 an example of how habitat complexity is determined by drawing circles of contact areas. See remarks on Table 4.15 and Figure 4.15. These need additional clarification in their captions. **RESPONSE:** *We have added additional sentences to clarify how habitat complexity was determined.*

4-44--4-48. While the results of the squawfish radiotagging are provocative the sample size (9 wild fish total) is quite small compared with 56 stocked razorback suckers. I suggest a caveat be inserted acknowledging the small sample size, but that the fish were wild and they are rare. **RESPONSE:** *While sample size is acknowledged on p. 4-42, since the results fit so well with habitat use in other areas we see little reason to suggest it may not be accurate due to small sample size.*

4-51. Low winter flows presumably were the "natural " condition, so it is not surprising that they had, "no observable detrimental effect" on razorback suckers. Perhaps a more relevant question is do post-dam higher winter flows show a "detrimental" effect or not? **RESPONSE:** *We agree but the test was of a low winter flow that was proposed primarily to conserve water rather than provide something for the native fish. The effect of high winter flows may become more obvious if future flow management includes extended low winter flow periods.*

4-53--4-72. Other native Fish (should be Fishes). This section could benefit from some serious editing. There is a lot of data, but its unclear what the objectives were. This yields a rambling section where lots of information is related with little attention directed to causal factors. Showing a negative relation between CPUE and discharge could just as easily tell us that you are less effective at catching fish at high flows (I know we are) or that they move to different habitats, rather than high flows somehow reduce fish numbers. Relating condition to river flow is also a suspect analysis. A fishes condition at any instant is the integration of numerous factors that occurred **prior** to the instant and should be minimally affected by flow on the date you caught it. For example, typically condition increases from fall to spring if females developing gonads are included in the analysis. There are many such instances of over-generalization and speculation (e.g., relating high discharge to reduced productivity and decreased flannel mouth condition as well as the converse) without any direct causal evidence. I suggest shortening this section by looking at the main conclusions for each and revising the preceding material to delete that which does not directly relate to these points. For example, report the pertinent info showing the decline in YOY flannelmouth suckers catch rates over the study. However, to do this you need to have replicate samples from similar habitats, collected using the same gears and effort, at the same season over multiple years. This information needs to then be tested for a significant decline with time, etc. Additionally, if population size were decreasing over seven years this might be reflected in a shift in size classes (Fig 4.17), i.e., lack of recruitment. Does Fig 4.17 suggest such a trend? **RESPONSE:** *We agree that these sections may be long, but that is one result of multiple authors of a document such as this. We have left the information intact since it was important to show that these types of tests were made. The conclusions drawn were generally not clear. Since these fish were not the focus of the 7-year research effort, sampling was not designed to clearly show what was happening to their populations. Although not a focus of future monitoring, the Long-term Monitoring Plan is addressing sampling of other native fishes in the main channel.*

Non-native Species

4-82. It's stated that "Presumably,..." temperatures increased earlier and remained optimal longer in 1996. Why is this a presumption when you have temperature data for multiple years? Examine temperature/flow trends among years and determine if this supposition is valid before making conclusions about how spawning patterns were affected. **RESPONSE:** *We agree and have corrected this sentence.*

4-85. Negative correlations between red shiner density and flow could be causal as suggested or partially a consequence of decreased sampling efficiency as indicated on pg 4-47 for other non-natives. This should be acknowledged. **RESPONSE:** *As noted on p. 4-82, this analysis does not include all data but only that collected by NMGF in secondary channels, which were more consistent between years. But flow level may have been a factor in the correlations.*

What impact would an August low temperature spike of >3000 cfs have on native fishes? Is such a spike part of the "natural hydrograph" that is considered so important. It's somewhat contradictory, and perhaps self-defeating, to stress a natural hydrograph as the critical management tool for restoring native fishes and then suggest modified flow/temperature pulses to control non-natives without first rigorously evaluating their effects on YOY razorbacks and squawfish. Fortunately, on pg 6-6 the potential impacts of artificial flow pulses on natives fishes are acknowledged. **RESPONSE:** *Many members of the Biology Committee agree with your overall comment. A detailed study of the effect of natural flow spikes on red shiner numbers is presently being conducted to help clarify this situation and the monitoring program should allow an evaluation of the effect of flow spikes on young endangered fishes, once they become common in the system.*

Chapter 8

8-1. Somewhere in this document I think it would be valuable to give the reader a brief summary of the adaptive management program presented in Section 5.7 of the LRP. It is one of the keystones of your Program and not everyone (like me) will be familiar with it. **RESPONSE:** *Adaptive management is discussed more on p. 1-5, but it has not been developed in detail yet by the Program. A more detailed explanation will be developed for the Synthesis Report where other milestones, such as adaptive management, will be discussed in detail.*

8-6. Explain the differences between "minimum releases" and "primary releases" before detailing on page 8-7. Also, it would be helpful to remind the reader of the terms used in Chap 8 Figures and Tables. For example is "baseline" flow explained? What is "Current" and how does it differ from Study Period"? These should be generic definitions and referenced to Table 7.3. To those who are steeped in the Project these terms are probably obvious, but many of your readers might be more like me and need some repetition. This is the critical Chapter of the Report,; it must be explicit even if a bit redundant. **RESPONSE:** *We have added a paragraph to help clarify the various types of peak flow. The term "baseline" has been replaced by "depletion base" and it, as well as "current", are well defined in Chapter 7.*

Words to Consider Adding to Glossary

General: Very few of the technical hydrological terms used throughout the text are defined in the Glossary relative to biological terms.

"Nose" Table 4.9, pg. 8-7 **RESPONSE:** *We have replaced the use of this word in the text with "early release." The following words have been added to the Glossary along with other hydrological terms.*

Roughness (Manning's n)

Habitat complexity (pg. 4-44)

Ramp up and ramp down (used throughout, but never defined)

Minimum peak release (pg. 8-7)

Primary peak release (pg. 8-7)

Depletion base condition

Tables

S1 and 6.1. That is the most important Table of the Report and must therefore be explicitly clear.

Change: Adult Colorado squawfish and razorback sucker ~~prefer~~ use complex river areas. Preference requires demonstration that fish use exceeds availability of a particular area within the system. Text doesn't indicate preference was determined.

Flow Requirement.

Number of spring runoff... (2 boxes).These sentences are unclear. What number of days?

Temperature flow requirement. This box should tell what is needed for fish, not what is wrong. **RESPONSE:** *Your proposed changes to Tables S.1 and 6.1 have been made except that related to temperature. Due to the location of intakes on Navajo Dam, the water cannot be warmed up to meet historical temperatures but releases still provide sufficient temperature for the endangered fishes to spawn.*

2.1. Why are there so many blanks for various terms? They should all be defined, no matter how obvious (e.g. island) they may seem to us. Define "pocket water". Define "cutback", see next comment. **RESPONSE:** *This table has been revised to include definitions for all habitats.*

2.2. Stream channel contact. What's a "cutback"? Its not listed or defined in Table 2.1. **RESPONSE:** *This was a typographical error. The term is "cutbank", denoting an unstable, eroding bank, often with overhanging vegetation. Category has been changed to "eroding bank."*

4.15. and 4.16. Explain what selection is here., i.e. >0 and how a number like 30 relates to 10 , etc. All values of habitat selection should be reported, not just positive numbers. For example, in the text you say that run habitat was the most used in Feb 1994, but eddies were the most selected. There is no number for runs in the Table, so how do I know if they were selected for or against? If habitat selection is a mean, say so, and give the number of fishes sampled to derive the mean The Table should be self-explanatory, now its somewhat vague. **RESPONSE:** *We have added additional language to clarify these tables.*

4.18. You need to be careful interpreting significance within such massive correlation tables such as this. The 9x15 matrix yields 135 potential values, 6.75 of which will be significant by chance at the $p<0.05$ level (i.e., 5% of 135). There are 6 reported values in the Table that were significant. There are statistical approaches to adjust the p level for multiple comparisons (e.g., Bonferoni correction). I suggest consulting with a statistician before interpreting the results from this Table. **RESPONSE:** *You have misinterpreted the table. Each box is a single comparison rather than multiple comparisons.*

5.1. The text indicates that variability of data were high, but this Table only reports mean values. It would be informative to include some estimate of variability (e.g., SD, SE) so the reader can determine how high it actually was. **RESPONSE:** *Extremes are also included for the base flow period. Standard deviations have been added.*

8.7. Tell in a footnote what "Average Perturbation" means. **RESPONSE:** *Explanation has been added.*

Figures

2.6. Making this in color like previous Figures would make it easier to read and enable you to delete the symbols which add clutter. **RESPONSE:** *We agree and have made it in color.*

4.1. Nice figure, but it's not immediately clear from the caption that the horizontal substrate bars match the channel x-section above them. Explain a bit better in the caption what the figure illustrates. **RESPONSE:** *The explanation has been added in the caption.*

4.15. Tell the reader what all the numbers in this figure represent (e.g., specific habitat types). Better yet, number the habitats in Table 2.1 to match these so the reader can refer back to them. **RESPONSE:** *We have added language to make the figure more understandable.*

8.3-8.10. The legend and figures don't exactly match. There is an ellipse symbol in the Figs that isn't in the legend, unless it is a typo in "Current". Also, Baseline + 59000 and Baseline + 122000 have the same symbols. **RESPONSE:** *The large ellipse denotes the "primary criteria" for flow/duration/frequency. It has been added to the legend and the other corrections made.*

Dr. RONALD J. RYEL
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December 11, 1998

Dr. Paul Holden,
Bio/West, Inc.
1063 West 1400 North
Logan, UT 84321

Dear Paul,

Attached are my comments on the draft report: "Flow Recommendations for the San Juan River", dated 16-September-1998. I have tried to keep my comments general, but have indicated a few specific points.

I apologize for not being able to attend the Biology Committee meeting, December 14-15, 1998. I would have enjoyed discussing these and other points with members of the committee. I would also have liked to participate in discussions concerning the monitoring plan. Perhaps in the future, the Biology Committee should inquire about the schedules of the review panel members, or schedule their meetings further in advance. I would like to thank the Biology Committee for allowing me to review this report.

Sincerely,

Ronald Ryel

Comments on draft report: "Flow Recommendations for the San Juan River", dated 16-September-1998. Dr. Ronald J. Ryel

(1) The Biology Committee is to be commended for producing a much improved document. Many of the comments provided by reviewers have been incorporated which show a receptiveness of the committee to outside review. The document is much easier to follow, and the objectives, logic, and data analyses are much more clearly presented. The document is not perfect, but it is getting much closer to a final form. The Executive Summary is quite well done and readable.

(2) The document can still use some final editing to address the following (and perhaps more): a) missing definitions in Table 2.1 (e.g., pocket water); b) missing units (e.g., p. 2-4, sediment loads in last paragraph); c) difficult to read graphs (e.g., Fig. 2.6); d) problems with number alignment in tables (e.g., Table 2-27, column of D50, mean and line of Feb. 96); e) lack of site reference for biological data (e.g., p 3-20, first sentence of first full paragraph–"...were commonly found in ..." [where was this found?]); poor sentence structure (e.g., p 6-3, last full paragraph, second to last sentence: "... these habitats appear to have lower survival compared ..." [habitats do not have survival rates]). A very careful reading by 2 editors could catch many of these things. Also the literature cited should be checked with the list in the back if this has not been done. **RESPONSE:** *We have made most of the changes you have suggested and many had been made in the last draft.*

(3) The document should be checked again for statements with missing citations. Two examples are: p 2-26, last sentence of second to last full paragraph: "Cobble substrates are typically more productive than sand substrates, and more embeddedness generally is related to poorer biological productivity"; and p 3-7, first sentence of first paragraph under Eggs: "It is assumed that eggs are deposited in cobbles and gravels within riffles and chutes during spawning events" [assumed by whom?]. It is important to provide citations for such statements as these are carried on as important concepts in developing flows. **RESPONSE:** *Some of the statements that may not have citations are the conclusions of the Biology Committee in this report, and hence, do not have other citations.*

(4) A reasonably good 'first cut' of statistical analyses were performed to evaluate the biological relationships to flows and the test flow period. Certainly more could be done (and should be done), but it appears from these analyses that few really convincing relationships could be found in the data. Further analyses may find a few more, but I don't feel that would significantly change the hypothesized relationships shown in Fig. 6-1. If this table represents the state of knowledge about these fish, then it provides the best basis for the flow model (as opposed to relying heavily on site specific data analyses). Concurrence of these relationships of the fisheries experts on the Biology Committee (and perhaps others) is thus important since the flow recommendations are based on these perceived habitat needs. I feel that since these relationships and those assumed for non-native fishes provide the basis for the flow recommendations, these need to be the common ground of assumptions of how to improve the system for the fish. Justification for the flow model and recommendations becomes the relationships in Table 6.1 (and others for non-natives and perhaps for other trophic levels), and not simply the statistical strength of measured relationships within the

river. It is important that everyone understand this concept. **RESPONSE:** *Most of the Biology Committee members understand this premise.*

(5) I definitely do not like the use of the term "Flow Requirement" as a column heading in Tables S.1 and 6.1 (same table). First, it is not a flow "requirement" that resulted in the decline of flannelmouth suckers. The decline may have coincided with the return to a more natural hydrograph, but this action does not require such an event. Also, the term "requirement" is a bit strong for many of the hypothesized relationships between the biology and habitat, as the same habitat characteristic may result with different flows characteristics. I suggest changing the heading to "Flow Characteristic". This works consistently for "Biological Responses" and "Habitat Requirements", and is a better description of what is being stated. **RESPONSE:** *We agree and have made this change.*

The following are some additional minor comments:

(6) Error bars should be included on many figures (e.g., 4-10, 4-11, 4-12, 4-13). **RESPONSE:** *Your comment is noted and we have edited some figures, specifically the ones you mention, to include indication of the error involved.*

(7) On page 6-6, last sentence under section, "Relationship between flow and nonnative species" states that "Summer spikes designed to suppress red shiner would detract from mimicry of a natural hydrograph...". What about summer thunderstorm-induced high flow spikes? These may not occur on an annual basis, but surely they occur in July-September (see Table 2.3). **RESPONSE:** *Natural summer flow spikes do not detract from a natural hydrograph, but man-made spikes may both in timing and temperature.*

(8) In Chapter 2, habitat versus flow is only expressed as percent of the total. It would be nice to see the data presented as total wetted area as well. It is difficult to determine the amount of habitat really available. Perhaps only a list of the TWA is needed for each flow and the reader can calculate the actual areas using the percentages. **RESPONSE:** *Total wetted area has been added to figures 2.7 and 2.8.*

(9) Results of contaminant study were listed for YOY razorbacks, but not Colorado squawfish. They should be listed for CS as well. **RESPONSE:** *See page 5-4. Toxicity studies for both species are listed.*

(10) In introduction to other native fishes, it would be nice to list all the native species in the river (both past and present) and perhaps all the nonnatives in the same table. **RESPONSE:** *We are not sure where this would go and the discussion in chapters 3 and 4 clearly define the native fish, especially the introduction to Other Native Fishes in Chapter 3.*

(11) In Table 4.5, the multiple R^2 results could be left out. They are likely not significant due to the high degree of correlation between the flow variable. I imagine the condition number for these regressions are very high resulting in invalid regressions. **RESPONSE:** *We agree that the correlations are not significant, but disagree that they are invalid. The condition numbers are not so high as to invalidate the regressions and they are not as auto-correlated as you may think. The significance is discussed in the text. It is clear that little, if any, weight can be given to the relationships in terms of quantification, but we believe that the general conclusion that cobble movement increases with increased volume and duration of runoff is indicated, although not quantified.*

(12) This regards the sparse YOY data for CS (p 4-40). We have discussed this before and I am not entirely comfortable with the perceived relationship between flows and numbers collected. However, I would suggest that you change the first sentence of the last paragraph ("The general trend in the collections, when considering absolute catch ...") to: "Higher collections coincided with years with higher flows. If such a relationship is valid, then higher flow years (...) may have been better reproduction years than low flow years (...). **RESPONSE:** *This has been changed as of the December 4, 1998 draft to be similar to your comments.*

(13) Page 4-60, top of page: I do not follow the logic behind: "This indicated that even given the apparent negative influence of flow on flannelmouth sucker CPUE, juvenile and adult CPUE still appeared to decline over the study period". This needs further explanation. **RESPONSE:** *We have added more language to clarify this statement..*

(14) Could the decline in flannelmouth suckers over the course of the study flow period be due to reduced base flow and TWA? Reduced base flows would reduce the total habitat area of the river and would likely result in lower numbers of the most common fish (which inhabits many of the habitats). The increasing condition factor over the course of the study could correspond to the population coming into equilibrium at a lowered carrying capacity. **RESPONSE:** *This hypothesis may be reasonable although numbers of suckers are highest in upper, smaller portions of the river, suggesting TWA is not a major factor in this relationship..*

(15) If flannelmouth suckers declined in numbers and blueheads increase, is the total biomass similar or decreasing? This could affect CS carrying capacity. **RESPONSE:** *Total biomass appears fairly similar. As noted in several locations in the report, flannelmouth sucker remain the most abundant large-bodied fish in the river.*

DEPARTMENT OF ZOOLOGY
THE UNIVERSITY OF TEXAS AT AUSTIN

Austin, Texas 78712-1064

8 December 1998

Paul Holden
1063 West 1400 North
Logan, UT 84321

Dear Paul:

I received the San Juan River Flow Report. I have no substantial problems with this version. The major problem would be to ascertain the effects of varying peak flows. Is 6000 cfs better (or worse) than 5000 cfs? That is now predicted, but needs to be grounded in truth, i.e., try it and see what occurs.

I think some reference to GCES might help with the background materials. Two books come out of that exercise.

I note one minor problem. Tyus 1990 and 1987 have the same volume and page numbers. I know Harold has lots of skills, but two papers in the same issue on the same pages stretches the imagination.

Sincerely,

Clark Hubbs
The Clark Hubbs Regents Professor Emeritus
The 1998 Texas Academy of Sciences Distinguished Scientist

CH/dm
Enclosures

January 14, 1999

VIA TELEFAX AND FIRST-CLASS MAIL

Ron Bliesner, Chair
Biology Committee
San Juan River Basin Recovery Implementation Program 78 East Center
Logan, Utah 84321-4619

Dear Mr. Bliesner:

The New Mexico Interstate Stream Commission, on behalf of the State of New Mexico, submits for consideration the following comments on the Flow Recommendations for the San Juan River, Draft Report, prepared by the San Juan River Basin Recovery Implementation Program's Biology Committee and dated December 4, 1998. The flow recommendations themselves were adopted by the Program's Coordination Committee at its October 15, 1998, meeting. Pursuant to the deliberations of the Coordination Committee at its December 15, 1998, meeting, these comments are limited to the draft report's treatment of technical issues relating to the determination of the recommendations of flows to provide for habitat for endangered fish in the San Juan River. The Commission also has many concerns regarding application and implementation of the flow recommendations, including future modifications to the flow recommendations. The Commission reserves these concerns for future discussion with Implementation Program participants (see my August 20, 1998, and November 2. 1998, letters to Joseph Dowhan).

Page 2-2, last incomplete paragraph. The flow recommendations assume that San Juan River flows alone can and should be used to maintain the river channel and channel complexity needed to provide for endangered fish habitat. However, the draft report indicates that changes in watershed conditions in the San Juan River Basin and changes in river channel vegetation, along with changes in flow regimes in the river, have caused substantial changes to the river channel. The report should discuss the possibility of maintaining the river channel for fish habitat using vegetation control in the river channel and floodplain, watershed management measures that would reduce sediment loading to the river channel, and physical river channel modifications. Implementation of such actions might reduce the amount of streamflow needed to maintain adequate fish habitat in the San Juan River. The minutes of the February 25, 1998, meeting of the Coordination Committee indicate that flow management to attain recovery of endangered fish populations in the river was to be reviewed in consideration of non-flow recovery actions that could be implemented within the basin (see third page, first non-indented paragraph). The report should discuss how this review was or will be conducted. **RESPONSE:** *Both of the actions you suggest have been considered. Removal of non-native vegetation, primarily tamarisk and Russian olive, would help restore the flood plain to early 1950's condition. It is not known what effect this would have on the present channel dynamics or flow requirement. It could require more or less flow than the present recommendation. An* *extensive research program would be required to determine (1) if it is possible, and (2) what the effects would be. Watershed management to reduce sediment load would make storm perturbation less of a problem and would likely reduce flow requirement for habitat maintenance. It has merit, but is vast in scope and cost considering the size of the basin and the magnitude of the problem. Both are future possibilities that should be discussed in terms of future actions that can be taken, but have no bearing on the present flow recommendation. They would be a part of adaptive management.*

Page 2-4, first complete paragraph, and page 2-15, first complete paragraph. The San Juan River and its channel were modified from its natural form for decades prior to construction of Glen Canyon and Navajo dams in the early 1960s. The report should discuss the history of declines in populations of the endangered fish in the river. If the fish populations were in decline under pre-dam conditions due to deteriorated watershed conditions affecting fish habitat, then watershed management measures should be evaluated as possible contributors to enhancing recovery of the populations. If the fish populations were stable under pre-dam conditions when flows below 50-100 cfs were not uncommon, then the report should discuss why the target base flow criterion for the summer through winter months of 500 cfs is not reduced to take into account observed biological responses. **RESPONSE:** *See page 3-2, second paragraph for a discussion on the Colorado pikeminnow. Very little is known of the historic abundance of razorback sucker in the San Juan River, other than anecdotal accounts. Declines for some of the species may have started prior to the large dams since smaller tributary dams and mainstem depletions occurred since the 1800s. Watershed deterioration may have been a factor in pre-large dam population decline, but the major declines in the native fish occurred following large dam construction. Hence, it is not clear if watershed enhancement would improve conditions sufficiently to see an improvement in native fish numbers. The irrigation depletions that occurred pre-large dams are primarily responsible for depressing the flows to the levels you list. The 500 cfs used represents the low 8% flow for natural, non-depleted conditions and the approximate median flow for pre-dam historical conditions. Given the channel conditions and other man-made influences (e.g. contaminants), the Biology Committee was not comfortable with base flows below 500 cfs.*

Page 2-10, second paragraph, second sentence, and page 2-26, first complete paragraph. The flow recommendations include criteria based on the amount, duration and frequency of flow considered necessary to clean backwaters and maintain low-velocity habitat in secondary channels in reach 3. However, it is not clear that meeting these criteria with releases from Navajo Reservoir would be an effective use of the water supply because the beneficial effect of the spring releases on fish habitat in reach 3 is extremely vulnerable to being negated by perturbations to the fish habitat in the reach which occur due to runoff from summer and fall storms. The draft report at page 4-37, second complete paragraph, states that storm events, not spring runoff conditions, appear to be the dominant factor regulating backwater and other low-velocity habitat quality and productivity. The report should present data or information indicating how often backwaters are perturbated by summer storms and how often such perturbations render backwater habitat unsuitable for larval and young-of--year Colorado squawfish. Again, the report should discuss the possibility of maintaining the river channel for fish habitat using measures other than large amounts of streamflow. **RESPONSE:** *As evidenced by use of backwaters by stocked YOY Colorado pikeminnow, even after storm perturbation, the backwaters do not become unusable. While productivity of backwaters is most strongly related to perturbating storm events, abundance of backwaters is heavily influenced by the runoff hydrograph. No non-flow related action has been identified to maintain backwater habitat and its effect quantified to be considered in making the flow recommendation.*

Also, the flow/backwater habitat area relationships given in the draft report at figures 7.2 and 7.3 suggest that if the criteria for full cleaning of backwaters in reach 3 is not met, there still would be backwater habitat in reach 3 as well as in other reaches of the river. The report should discuss why the amount and quality of backwater habitat in the San Juan River would be sufficient under the conditions where reach 3 is fully-flushed but insufficient under non-flushed or less than fully-flushed conditions. Further, most of the larval and young-of-year squawfish that have been found in the San Juan River were caught outside of reach 3. The report should discuss the flow rates and frequencies required to maintain backwaters in reaches other than reach 3. The report also should discuss whether near-annual maintenance to a near-optimal condition of backwaters in reach 3 through the use of spring runoff flows is both appropriate in light of the possibility of habitat perturbations soon following the spawning season and critical to recovery of squawfish because the fish use backwaters in other reaches as well as different habitats. The draft report at page 4-48 indicates that young-of-year and juvenile squawfish can use low-velocity habitats other than backwaters. Accordingly, it is not clear why full flushing of backwaters in all reaches is necessary to provide adequate nursery habitat for squawfish. The report should discuss why less flushing action with a flow rate and duration of less than 5,000 cfs and 21 days, respectively, and less flushing frequency with a frequency less than 50 percent of the years would not provide adequate nursery habitat for the endangered fish. **RESPONSE:** *The flushing frequency is based on the best judgement of the researchers based on the seven years of data available. Given the status of the fish, to make a flow recommendation that would provide less backwater habitat than existed in the system pre-dam would be irresponsible, especially when considering we can maximize nursery habitat in only about one half their former range. The recommendation predicts that the backwater habitat conditions, in terms of abundance will be about the same as they were for the same reaches pre-dam (See Tables 8-7 and 8-8).*

In addition, removal of, or construction of passages around, barriers to fish movement between Cudei and Farmington would allow endangered fish to have improved access to potential spawning and rearing habitat further upstream in the San Juan River, which might lessen the need to try to maintain temporary or questionable quality rearing habitat in reach 3. Any losses in backwater habitat in reach 3 might be offset by creating more access to backwater habitat in reach 5 via opening up access to possible spawning habitat in reach 6 above Shiprock (see page 8-24, third paragraph). The report should discuss how this was considered in the determination of flow recommendations. **RESPONSE:** *The recommendations were made assuming that such barrier removal would occur. The flow recommendations were made to maximize all potential nursery habitat in all reaches since only about one half of the former range is available to the fish. About 50 miles of habitat has been* *lost by Navajo Reservoir and the cool tailwater, and another 77 miles of habitat is under Lake Powell. To suggest at this stage that the fish will not need nursery habitat in Reach 3 is not supported by any data we have, especially since we have found stocked Colorado pikeminnow using this area.*

Page 2-14, last sentence. This sentence should be revised to clearly state that sequential years may have an annual discharge of less than 1,000,000 acre-feet each year. **RESPONSE:** *The sentence has been changed.*

Page 4-14, last incomplete paragraph. The flow recommendations include criteria based on the amount, duration and frequency of bankfull flow, which is assumed to be adequate for channel and spawning bar maintenance. Flows above bankfull spread onto the floodplain and do not add substantial energy for transporting cobble or forming cobble bars.

Habitat mapping data for 1993-1994 for reaches 3, 4 and 5 covering a river length of 86 miles, inclusive, downstream of the Hogback diversion suggests that bankfull flow for the San Juan River generally is in the range of 6,500 cfs to 7,700 cfs (see page 4-9, last paragraph, and page 4-13, first paragraph). However, a hydraulic computer model (HEC-RAS) predicted that bankfull flow for the river generally is in the range of 7,100 cfs to 10,500 cfs, and averages about 8,000 cfs, for four stretches of the river of only 0.25-mile length (see page 4-15, last paragraph). Of the four stretches modeled, one was in reach 5 upstream from the Mixer spawning area and three were in reach 6 above the Hogback diversion. In addition, bankfull flow calculations were made using the Manning equation for eleven river transacts measured in 1992 and 1997 at unspecified locations in reaches 3 through 6 (see page 4-14, first paragraph, and page 4-5, first complete paragraph). The Manning equation calculations predicted that the average bankfull flow for the eleven locations was 7,300 cfs in 1992 and 8,200 cfs in 1997, with bankfull flow at individual transect locations ranging from 5,300 cfs to 12,600 cfs.

Given the location of spawning sites and rearing habitats for endangered fish in the San Juan River, it is not clear that the bankfull flow estimate indicated by the habitat mapping field data for reaches 3-5 inclusive should be set aside on the basis of hydraulic models or calculations for small portions of the river. The report should discuss why it was appropriate to give more weight to the hydraulic modeling and Manning equation calculations, both of which contain uncertainties in data and assumptions, than to the habitat field data for estimating a bankfull flow for the river. The report also should discuss whether the modeling is sufficiently calibrated to support this flow recommendation. In addition, the report should discuss why flow rates less than 8,000 cfs could not provide bankfull flow or cobble bars along sufficient stretches of the San Juan River to provide adequate habitat and spawning sites for the endangered fish. **RESPONSE:** *For cobble bar maintenance, Reaches 5 and 6 are the most critical because they cover the area where spawning needs to occur for reasonable drift opportunity. Therefore, the modeled reaches are correctly located for the purpose of critical cobble bar maintenance. Actually the three data sets, habitat, modeling and Manning equation calculations for cross-sections, all support each other. The* *modeling and later Manning estimates agree and the habitat mapping and early Manning estimates agree. The cross-section measurement clearly indicate an increase in channel cross-sectional area which equates to increased channel capacity. Further, if a lower number for channel capacity would have been used, the frequency and duration conditions would have been greater to accomplish the objectives since the frequency and duration were established based on an analysis of post-dam channel response to flows compared to the research period. It is likely that the flow recommendation overall may not have been much different. The results of monitoring and adaptive management will allow for any necessary adjustments to these recommendations.*

Page 4-18, first paragraph. The flow recommendations include criteria based on the amount, duration and frequency of flow considered necessary to produce clean cobble and resculpt bars for spawning. The available data indicates that sufficient cobble movement to resculpt bars occurs at 2,500 cfs. However, the threshold minimum flow rate actually needed to move cobble for cleaning and reshaping bars might be significantly less than 2,500 cfs. The report should discuss the threshold minimum flow rate needed for cobble movement on bars or how this threshold flow rate can be determined. **RESPONSE:** *As noted in the paragraph you reference, we have no data to assess the effectiveness of flows less than 2,500 cfs. Further, flows lower than this may be ineffective in terms of hydrograph shape to cue spawning.*

Page 4-22, first incomplete paragraph. The flow recommendations include criteria for the duration and frequency of flow greater than 10,000 cfs. Periodic flows above 10,000 cfs below Farmington are recommended for maintaining channel complexity and providing new cobble sources. Lesser flow for a duration of less than 5 days may perform this function adequately. The recommendations that flow of 10,000 cfs for 5 days be provided in 20 percent of the years are only inferred from data on island counts during the research period. Yet, the draft report recognizes that five years of island count data are not sufficient for evaluating long-term trends or flow needs for maintaining channel complexity (see page 4-12, last two sentences). The report should discuss why less flow for less duration less frequently would not provide sufficient channel complexity and fish habitat in the San Juan River. **RESPONSE:** *10,000 cfs is recommended first as restoration of the most modified portion of the natural hydrograph and is verified based on the island count data. Future monitoring and adaptive management will assess the effectiveness of this recommendation and whether it needs to be adjusted up or down.*

Page 4-22, first complete paragraph. The report should discuss how often the pre-Navajo Dam channel capacity was exceeded during the pre-dam period so that such information could be compared to the frequency criterion for the flow recommendation for the occurrence of bankfull flow. Primary criteria for flow recommendations are based on current geomorphology and secondary criteria are based on modeled flow statistics, both of which may not give pre-dam geomorphology or the desired habitat. Also, the frequency criterion for flow above 8,000 cfs considered the frequency of bankfull flow needed to prevent loss in channel capacity. Specifically, the frequency of bankfull flow needed to maintain channel capacity is assumed based on channel capacity changes during the research period at selected cross-sections located primarily in reaches 5 and 6 (see page

4-21, last incomplete paragraph). It should be noted that the river transect channel data and Manning equation calculations do not illustrate that a significant change in channel capacity occurred during the research period throughout the river as a whole or that small changes in channel capacity at the river transect locations over a period of a few years constitute long-term trends rather than short-term variations (see page 4-8, first complete paragraph). The report should clearly indicate uncertainties and assumptions in the development of the flow recommendations. **RESPONSE:** *The pre-dam channel capacity is not known. The cross-sections measured in 1962 did not include any underwater survey data. The flow recommendation criteria are based on the existing channel configuration. If a desire exists to restore the pre-dam channel, then the flow recommendations would have to be larger. Both pre- and post-dam hydrographs were considered in making duration and frequency recommendations (Page 4-21, last paragraph, 4-22, second paragraph). The cross-section data do indicate that there has been a system wide increase in channel capacity, but do not indicate whether this is a long or short term response. Similar changes likely occurred during wet periods, even post-dam. Nearly every flow-response result includes the caveat you suggest, in addition to numerous references to adaptive management and the need to periodically evaluate the recommendations.*

Page 4-40, last incomplete paragraph, first sentence; page 4-41, first complete paragraph, first five sentences; and page 6-1, last paragraph. There were so few Colorado squawfish collected in the San Juan River during the 1987-1996 period that it is not clear how any conclusions can be drawn relating spawning success to spring runoff. There simply are very few fish in the river. Of the thirteen young-of-year and juvenile wild squawfish captured in 1993, eleven were collected in an area sampled only in 1992, 1993 and 1994 (see page 4-40, last complete paragraph, fourth sentence). In addition, two of the squawfish captured in 1993, two of the seven squawfish captured in 1995, and one of the two squawfish captured in 1996 were larvae caught in larval drift nets, a sampling technique apparently not employed until at least 1991 (see page 4-40, first paragraph, first four sentences). The sampling efforts during the years 1991-1995 far exceeded the efforts made during the years 1988-1990 (see page 4-41, table 4.14). Consequently, it is difficult to conclude from the extremely few fish collected using inconsistent sampling protocol that spawning success is significantly and positively correlated to spring runoff volume. This remains an unproven hypothesis due to a lack of fish with which to measure any spawning response to spring flows. The report so indicates at page 4-41, first complete paragraph, first sentence. This should be so clarified elsewhere in the report where biological response of squawfish to research flows is suggested or discussed. **RESPONSE:** *This section has undergone considerable change as the Biology Committee has investigated this information. It is the consensus of the Biology Committee that the way this information is presented is accurate. The fact that it fits with what has been learned in other Upper Basin rivers lends credence to the conclusions in the San Juan Basin.*

Page 4-68, first complete paragraph. The report concludes that flow of 8,000 cfs for 8 days is adequate for constructing cobble bars, but the duration criterion for flow of 8,000 cfs was adjusted to 10 days based on a perceived positive response of bluehead sucker spawning to high spring runoff (see page 8-4, category B). The draft report presents no actual data for captures of larvae or young-of-year bluehead sucker to support its conclusion regarding a relationship between bluehead sucker spawning success and spring runoff flows. However, the draft report presents data indicating increasing catch rates with time from 1993 to 1997 for bluehead sucker for reach 6 only, but lower catch rates for reaches 1-5 inclusive for both juvenile and adult bluehead sucker for the years 1994-1997 as compared to the years 1991-1993 (see page 4-66, figure 4.25, and page 4-58, figure 4.18). Juvenile bluehead sucker may range in age from 2 to 4 years. The report should describe the absolute numbers of juvenile and adult bluehead sucker collected in the different river segments, along with problems in sampling protocol, so as to demonstrate any perceived trend in reproductive success for the population as a whole in response to test spring flows. The report acknowledges that the attribute of runoff to which bluehead sucker responds is unknown. **RESPONSE:** *Table 4.19 is an analysis of young-of-the-year catch data, hence it reflects reproduction success.*

Further, fish collection data for flannelmouth sucker were not consistent with and did not exhibit the same trends as collection data for bluehead sucker. It is not clear that the data are of sufficient quantity and quality to determine that 2 days additional duration is critical to maintaining the populations of native fish species in the San Juan River, particularly endangered fish populations. Nor is it clear that the endangered fish and non-endangered native fish have need of the same flow regimes because they have a different population status in the river and apparently responded differently to past flow regimes, including test spring flows during the research period. The report should discuss more thoroughly why the duration criterion for flow of 8,000 cfs was extended from 8 days to 10 days to presumably accommodate some of the non-endangered fish when the extended criterion has not been shown to be needed to meet the Implementation Program's goal of recovery of endangered fish. **RESPONSE:** *A basic tenant of the SJRIP has been that the native fish community was of concern, not only the two endangered fishes. The Biology Committee believes that changes in the density of non-endangered native fish reflect on environmental factors important to the endangered species. For example, young bluehead sucker may be a major food source for juvenile and adult Colorado pikeminnow so maintaining bluehead sucker populations is an important aspect of the SJRIP.*

Pages 7-10 through 7-16, section entitled "RiverWare Model of the San Juan River." This section discusses features of the RiverWare model for the San Juan River Basin. Although New Mexico has had some input to the development of the RiverWare model for the basin, it must be made clear in the report that the Bureau of Reclamation and Bureau of Indian Affairs developed the model and that the Bureau of Indian Affairs made model application decisions as described in the report for consideration by the Biology Committee. New Mexico still has concerns with the use of the model as it is currently formulated. New Mexico does not fully agree that the model input data and assumptions are appropriate.

New Mexico feels that the original Blaney-Criddle method should be used to compute irrigation demands and consumptive uses in the basin consistent with previously adjudicated and permitted rights in New Mexico. It is our understanding, however, that water rights administration in Colorado is based on the use of the modified Blaney-Criddle method. For the modeling effort to move forward with consistency in data assumptions, the Bureau of Reclamation and Bureau of Indian Affairs used the modified Blaney-Criddle method to calculate irrigation depletions in both states (see page 7-11, third complete paragraph). It was New Mexico's understanding that the model input data and model output generated using this method would be used for the specific modeling purpose of deriving flow recommendations, and that the choice of method did not affect the determination of the flow recommendations. Based on this understanding, New Mexico did not object to this limited use of the modified Blaney-Criddle method; but, it does object to the use of the model input data or the use of this method for any other purposes, including otherwise defining current or future depletions in New Mexico. The report should so state New Mexico's position on this matter. **RESPONSE:** *A footnote has been added to Tables 7.3 and 7.4 indicating that New Mexico does not agree with the method used for computing consumptive use or the depletion values listed.*

The frequency criteria for the flow recommendations given in the draft report are defined largely by matching the frequencies of given flow rates to the frequencies by which those rates occurred prior to 1962 when operation of Navajo Dam commenced. The frequencies of flow using 1929-1993 period hydrology under different operating and depletion scenarios are compared at the Four Comers gage. Flows at Four Comers after 1969 were gaged, but flows at Four Comers prior to 1970 were determined using a constant distribution by reach of the estimated side inflow gains and losses between the Archuleta and Bluff streamflow gages, exclusive of major perennial tributary inflows (see page 7-12, third complete paragraph). Therefore, the variation of flows after 1969 at Four Comers used for the modeling studies is greater than that of flows prior to 1970. The report should discuss how differences in flow determination procedures, data assumptions and gaging inaccuracies affect flow statistics and flow frequency comparisons between periods. **RESPONSE:** *The frequencies were not set to match pre-dam conditions. They would have been much higher (See Tables 8.5 and 8.6). They were compared, not matched. The variation between the two methods of distributing gains and losses for pre- and post-1970 that you reference are not major. The simplifying assumption is that the split between contribution upstream and downstream of Four Corners was the same before 1970 as after. Since the inflow is small and the upstream and downstream conditions have not changed dramatically during this time, the introduced error is also small. We have added a statement in Chapter 7 on the effect of gage, model and data error.*

In addition, the draft report does not describe the assumptions and models used to determine ground-water storage and return flows from the Navajo Indian Irrigation Project, the assumptions used to distribute monthly depletions into quarter-monthly depletions, or the assumptions used to compensate for phreatophyte depletions. For simulating reservoir operations, the draft report does not describe how the inflow forecast error is applied: that is, whether the forecast error results in reservoir operations that are conservative towards reserving water supply for water users or towards releasing water for the endangered fish. The report should describe these items. **RESPONSE:** *Such detail is beyond the scope of this document. It will be discussed in the model documentation.*

Also, for the La Plata River, diversions bypassing the Hesperus gage need to be added to the Hesperus gage records to determine natural flows. Flow of the La Plata River at Hesperus is not indicative of flow of McElmo Creek. Further, it is our understanding that shortages on the La Plata

River were estimated differently than elsewhere in the basin. The report should clarify these items. The report also should clarify the basis for the percentage distribution of gains and losses by reach between Archuleta and Bluff. We suggest that there should be a net loss for the Archuleta to Farmington reach. Also, small depletions on minor ephemeral tributaries far removed from the San Juan River do not deplete river flows. This section of the report should address these issues. **RESPONSE:** *McElmo Creek is problematic for several reasons in the model and the report discusses the need to interpret data from the Four Corners gage rather than the Bluff gage for that reason. See footnote to Tables 7.3 and 7.4 for treatment of off-stream depletions. The added discussion that you suggest is beyond the scope of this report and should be included in the model documentation or documentation of the Bureau natural flow estimates.*

Pages 7-16 through 7-23, section entitled "Parameter Selection and Optimization Process." This section presents various hypothetical water depletion scenarios. The draft report assumes hypothetical water development scenarios for the purpose of illustrating how the modeling might project impacts of different levels of development on flow rate frequencies as related to the primary flow recommendations. However, the modeling results also are used to define the secondary flow recommendation criteria given at page 8-3, table 8.1. 'The report should clearly state that the development scenarios presented in the report are not intended to set the baseline for any future Section 7 consultation or recommend any particular development sequence. **RESPONSE:** *See footnotes on Table 7.3 and 7.4.*

New Mexico does not agree with the depletion figures itemized for different water development scenarios in Tables 7.3 and 7.4, which are used in the RiverWare model. New Mexico previously submitted its data for current and base depletions to the Bureau of Reclamation and Bureau of Indian Affairs for use in the modeling effort. New Mexico's figures include 57,100 acre-feet of depletion for the Animas-La Plata Project, and include a level of depletion historically attained by water uses under existing water rights. Further, it is New Mexico's position that its apportionment of the available water supply is 727,000 acre-feet per year from the Colorado River System above Lee Ferry, including its share of evaporation losses from the Colorado River Storage Project, and that the average annual depletion by the Navajo Indian Irrigation Project will be about 254,000 acre-feet when completed. **RESPONSE:** *We have added a footnote to Tables 7.3 and 7.4 that indicates that New Mexico does not agree to the method of consumptive use calculation nor the resulting depletions. A notation has been added dealing with the 57,100 af depletion for ALP.*

Neither the states nor the Implementation Program participants have agreed to the baseline depletions used in the latest Section 7 consultations for the Animas-La Plata Project or the Navajo Indian Irrigation Project. Also, a portion of the depletions to be made by the Navajo-Gallup Water Supply Project is to be made within the State of Arizona and charged against that state's apportionment of Colorado River System water. In addition, current municipal and industrial water depletions in the New Mexico portion of the basin are understated by the draft report. The discussion in this section of the report should be revised to reflect accurately the input provided by the states and the decisions made by the Bureau of Indian Affairs for its RiverWare modeling. The report also should discuss whether the determination of flow recommendations and recommended operating rules for Navajo Dam would be different if the RiverWare modeling used different itemized depletion figures. **RESPONSE:** *The numerous caveats in Chapters 7 and 8 adequately cover these issues.*

Page 7-22, first incomplete paragraph, last sentence, and last paragraph, fourth sentence. The US Fish and Wildlife Service has not committed as to how the flow recommendations or other factors will be used in Section 7 consultations. Therefore, a level of future allowable depletions may be dependent on other factors, and the flow recommendations should be viewed as recommendations and not requirements. These sentences should be rewritten accordingly. **RESPONSE:** *The wording you discuss references the general requirement under the Endangered Species Act to meet the requirements of the fish, whatever they may be, to avoid jeopardy. The flows in this report are always referred to as recommendations not requirements. This sentence does not reference the recommendations, but whatever USFWS chooses to determine as the requirements for the fish.*

Page 8-1, last paragraph. This paragraph states that the flow recommendations for the San Juan River are not final and suggests a few conditions under which the flow recommendations may be modified in the future. The Coordination Committee has not yet discussed the implementation of the flow recommendations, including criteria for modifying them. Therefore, the report should not speculate on criteria for modifying flow recommendations. If anything, the report simply should state that the flow recommendations should be re-evaluated as necessary to improve the certainty that implementing flow recommendations will help in the attainment of the goals of the Implementation Program. Also, it should be noted that the participants in the Implementation Program have agreed to participate in the Program only through the year 2007. Consequently, the Implementation Program cannot commit at this time to its reviewing the flow recommendations every five years. The frequency of review is an implementation issue for the Coordination Committee to consider. The subject paragraph should be modified accordingly. **RESPONSE:** *Included in the flow recommendation is a 5-year review and update based on adaptive management. The last sentence has been changed to reflect that the review is a recommendation.*

In addition, is there enough information to conclude or reliably predict that the goal of recovery of endangered fish populations cannot be achieved under a particular level of development given RiverWare modeling results as compared to the flow recommendations? If so, the report should discuss the incremental impacts on the endangered fish habitat and populations of not fully meeting the flow recommendations. The small amount of endangered fish collected during the 1992-1997 period did not show a significant natural increase in endangered fish populations in the San Juan River despite six years of reoperating Navajo Dam to provide a downstream flow regime that mimicked the natural hydrograph and produced flow statistics which exceed the criteria given by the flow recommendations. **RESPONSE:** *It is our best judgment, based on the available data, that the flows recommended will promote recovery. There is obvious uncertainty in this assessment but that has been considered in the recommendation. If future results show that recovery can be achieved with less water or more water, then, through the adaptive management process, the recommendation* *can be modified. We have recognized that other limiting factors besides flow exist in the San Juan River, including population size. The lack of measured response of the existing very small populations of endangered fish is no indication that the recommendation is not valid.*

Page 8-2, second paragraph, third sentence. The flow recommendations include criteria for the maximum number of years of non-occurrence of particular flow rate and duration combinations at Four Comers. For these criteria, the flow rate recommendations for fish habitat maintenance are reduced by 3 percent to account for side inflow between Four Comers and Bluff. However, the subject sentence states that this 3 percent reduction is to allow for both gage and modeling error in addition to side inflow. For actual gaged flows, the US Geological Survey rates the streamflow records at these gages as having the following degree of accuracy: 95 percent of the daily discharges are within 10 percent of their true value. The accuracy of modeled or otherwise estimated daily flows is less than the accuracy of gaged flows when all the data and modeling assumptions are taken into account. The report should discuss why the 3 percent effective reduction in recommended flow rates is not applied to all flow comparisons and is not a larger percentage reduction. **RESPONSE:** *A statement on error has been added to Chapter 7. Given the critical nature of the maximum interval, the reduction in the criteria for the gage difference was applied. It could have been applied to the other categories, but it would have made no difference. We have edited the language to indicate that it is a reflection of the gage difference, not gage error.*

Also, the draft report provides no data or information to support the recommendations regarding the maximum number of years that can be permitted to occur without meeting the specified combinations of flow and duration given as primary criteria. The report should explain the biologic, habitat or geomorphologic justifications for these specific recommendations. **RESPONSE:** *The statement on page 8-2 is the only justification that exists.*

Page 8-3, table 8.1. The frequency distribution values shown in table 8.1 represent both primary and secondary flow-duration criteria for the San Juan River. The sole support for the secondary flow duration criteria are the hydrologic modeling results for different water depletion scenarios given by the draft report at pages 8-16 through 8-19, figures 8.3 through 8.10, from which the numeric frequency values were selected based on modeled trends of flow-duration frequencies. Although the report at page 8-2, second paragraph, fifth and sixth sentences, recommends secondary criteria to mimic variation in the natural hydrograph, the secondary criteria were selected on the basis of modeled flow variability with some water development, which differs from natural hydrograph variability. The primary criteria shown in table 8.3 are to provide for the maintenance of geomorphologic conditions in the river channel for endangered fish habitat (for example, generating channel complexity and cobble, building and cleaning of cobble bars, and cleaning of backwaters and side channels). The report should explain the biologic, habitat or geomorphologic justifications for the secondary criteria. The report also should discuss fish habitat and flow needs on a reach-by-reach basis. **RESPONSE:** *The secondary criteria were not derived based on specific biological, habitat or geomorphological responses, but are based on mimicry. It is the only portion of the criteria that quantifies the stated need for variability. While the table was produced by examination* *of modeling results that approached the threshold primary values, providing the variability listed will provide variability that was judged adequate for the purposes of mimicry. Had the natural distribution been used (See Figures 8.3 through 8.10) these secondary criteria would have controlled the recommendation rather than the primary condition. Therefore, the variability requirements were described such that the primary criteria would always control. While many relationships were examined on a reach-by-reach basis, the flow recommendation has to address the entire river. Some discussion by reach is included, where appropriate, but the end result is one recommendation.*

Pages 8-6 through 8-12, section entitled "Recommended Reservoir Operating Rules." This section recommends operating rules for Navajo Dam which would provide water releases in support of meeting the flow recommendations for the San Juan River below Farmington. For the flow charts of the operating rules given in figures 8.1 and 8.2, the term "perturbation" needs to be defined with direction as to how to determine when it has occurred. Also, in explaining the term "available storage," the report should clarify that the carry-over storage needed to prevent future shortages reflects the total storage in Navajo Reservoir, which includes inactive storage that is not available for diversion or release. The report also should compare the recommended releases from Navajo Dam with the inflow rates for Navajo Reservoir to evaluate the volumes and frequencies with which stored water would be released to augment bypassed inflow. **RESPONSE:** *The paragraph on p. 8-7 describing the use of Figures 8.1 and 8.2 has been edited to include the information you request. No analysis has been made of bypass vs augmented flow releases. Such information did not and would not influence the flow recommendation.*

Page 8-12, last paragraph. The Navajo Dam operating rules presented in the draft report are not flow recommendations themselves; rather, the operating rules, shown as flow charts in figures 8.1 and 8.2, are scenarios by which the flow recommendations for the San Juan River below Farmington might be met. Other scenarios, including an alternative formulation of the Animas-La Plata Project, might be able to provide enhancements to spring flows in some years so as to take some of the burden from the Navajo Reservoir water supply in meeting the flow recommendations. The target is to meet the variability provided by the San Juan River flow recommendations, not the variability provided by recommended reservoir operating rules. The topic of Navajo Reservoir operations is a matter of implementing the flow recommendations. The report should be modified to make this matter clear. **RESPONSE:** *See last paragraph on Page 8-12.*

Page 8-13, last paragraph. The RiverWare model for the San Juan Basin was constructed with an intent to evaluate impacts of alternative depletion and operation scenarios on San Juan River flows. The report describes the use of the model to simulate the effects that alternative operations of Navajo Reservoir would have had on San Juan River flows both after 1961 and prior to 1962 had the dam been in place. It is not clear why the model could not be used to simulate also river flows for historical conditions but without Navajo Dam in place for years after 1961 as well as for years prior to 1962, especially when the report claims that any collection of projects can be simulated for their impacts on San Juan River flows (see page 8-24, last incomplete paragraph, third sentence). The report should discuss limitations to the use of the model, including the range of diversion and storage scenarios the model can simulate. The report also should explain how any limitations might have affected flow statistic values used to develop the flow recommendations. **RESPONSE:** *The model could have been used to extend the historic condition for this period of time. It was never configured to do so, which would have been a significant level of effort. The paragraph has been edited to reflect this possibility.*

Pages 8-16 through 8-21, figures 8.3 through 8.14. These figures need to be reviewed and corrected to reflect all modeling results. **RESPONSE:** *The corrections have been made.*

Page 8-24, third paragraph, last sentence. While Lake Powell might have flooded potential backwater habitat in the lower San Juan River, it also resulted in artificial backwater habitat due to sediment deposition at the head of the lake which lowered the stream gradient in the canyon. The report should either delete this sentence or provide data in support of the sentence indicating the net impact of Lake Powell on backwater habitat in the San Juan River. **RESPONSE:** *The net impact is not known, since the area was never mapped prior to being flooded. However, the loss of 77 miles of river, some of which was low gradient similar to reach 3, would have had much more backwater habitat than was gained in the 12-16 miles of river upstream of Lake Powell.*

Page 8-27, first complete paragraph, last sentence. Modeling tests with hypothetical scenarios were not only used to develop recommended operating rules for Navajo Dam, they also were used to derive secondary criteria for the flow recommendations as given in table 8.1. Again, the report should distinguish between the flow recommendations themselves and the possible implementation of alternative measures for addressing the flow recommendations. **RESPONSE:** *The model results were not used to derive the frequency distributions listed in Table 8.1, but to evaluate the impacts of various developments on the shape of the distributions to assure that the secondary criteria did not overrule the primary criteria. Table 8.1 is an integral part of the recommendations.*

Page 8-27, last two paragraphs. It is uncertain how the flow recommendations will be implemented in the field or in Section 7 consultations because there is no agreement in place between the Implementation Program participants and the Fish and Wildlife Service regarding Section 7 procedures. Therefore, it is uncertain what role, if any, Program participants or others will have in defining depletion baselines or in Section 7 consultations. These two paragraphs should be deleted from the report because they discuss possible future modeling in the context of implementing flow recommendations, not the development of the flow recommendations themselves. **RESPONSE:** *These paragraphs describe how the model may be used and the results interpreted for any purpose and include appropriate language to recognize that the depletion base used in the model runs is not the same as the environmental baseline. There is no requirement for the models to be used for any particular purpose. There is simply a description of how they could be used. The paragraphs will remain.*

I hope that the Biology Committee addresses these comments in the final report. I also hope that our concerns regarding the flow recommendations for the San Juan River can be dealt with effectively through future work of the Implementation Program and adaptive management.

Sincerely,
John Whipple
Staff Engineer

cc: Ren Lohoefener, Chair, Coordination Committee

MEMORANDUM

TO: Paul Holden - **VIA FACSIMILE AND U.S. MAIL**

FROM: Les Taylor and Jessica Aberly, Nordhaus Law Firm

DATE: July 26, 1999

RE: Comments on Behalf of the Jicarilla Apache Tribe Regarding the December 4, 1998, Draft Report: Flow Recommendations for the San Juan River

On behalf of the Jicarilla Apache Tribe, we submit the following comments regarding the draft flow recommendations report dated December 4, 1998.

- Tables 8.5 - 8.8, and Figures 8.3 - 8.18: References to "baseline" need to be revised to read "depletion base." **RESPONSE:** *This change has been made.*

- Page 7-17, 3rd paragraph: We request that the term "corrections" be put in quotation marks in the second sentence. We further suggest an additional qualification in that paragraph as follows: **RESPONSE:** *The changes you requested have been incorporated into the latest document.*

  > Those rights that the two states believed were likely to be developed were included in the depletion base.

- Tables 7.3 and 7.4: We request that a footnote be added to category entitled "current" which clarifies that this category includes existing Indian water rights depletions except for those otherwise specified in the table. Our concern is that a reader glancing at these tables will assume that the Jicarilla Apache Tribe has no current water rights or a right to only 25,500 afy of depletions. In fact, in addition to the 25,500 afy depletions, the Tribe has recently been adjudicated 2,194.58 afy (depletion) of historic and existing use federal reserved water rights. It appears that some of the Tribe's existing depletions are being "counted" in the non-Indian irrigation and non-irrigation figures.[1] Arguably, all of the Tribe's historic and existing use water rights should be "counted" as "current" since those rights are adjudicated federal reserved water rights which cannot be forfeited or abandoned.

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[1] The same may be true of the current water uses of the Navajo Nation, the Southern Ute Indian Tribe, and the Ute Mountain Ute Tribe.

Alternatively, those rights should be specifically included in the "depletion base" since the depletion base does not necessarily track the environmental baseline and includes water rights that may not be presently fully utilized but are likely to be developed without a section 7 consultation. **RESPONSE:** *We assume that all existing water uses, whether on Indian lands or non-Indian lands, that are not tied to a major irrigation project are included. For lands above Navajo Dam and those not irrigated from the mainstem San Juan River below the dam, Indian and non-Indian lands are combined and tabulated by location. The Jicarilla Apache, Southern Ute, and Ute Mountain Ute irrigated lands are all included in these categories. We are editing the table to reflect this condition.*

- Page 8-27, second and third paragraphs: These paragraphs, as presently drafted, are troubling, because they imply a consensus amongst the SJRRIP participants that the model outlined in the flow recommendations report is *the* tool, not *a* tool, to evaluate proposed water development projects. If that is the position of the Biology Committee, then other portions of the document appear to be misleading. See, e.g., December 4, 1998 Draft Report at 7-9 ("There are several best-science river basin simulation models available, any one of which would be appropriate for developing and analyzing San Juan River flow recommendations.") and 8-12 ("These operating rules are presented as recommendations . . . . Other operating rules may be employed to achieve the desired river conditions specified in this chapter, if that [sic] the natural variability provided by the rules presented is maintained."). Even if this is the position of the representatives on the Biology Committee, it is not necessarily the position of the Coordination Committee. Indeed, we reiterate our November 20, 1998, comments on the September 16, 1998, Draft Report:

  > The comments discussed herein should not be interpreted as approval of any of the hydrologic assumptions used to model the flow recommendations. The Jicarilla Apache Tribe is in the process of conducting an independent review of those assumptions. It is our view that the Coordination Committee (and the Tribe's representative on that committee) can allow the flow recommendations to go to the Bureau of Reclamation to begin the NEPA process without endorsing the entire document or all of the assumptions therein.

  Accordingly, we request that the last two paragraphs be modified or deleted. **RESPONSE:** *The last two paragraphs of Chapter 8 essentially discuss how the flow recommendations would most likely be implemented. If another model is used to model the* *basin, or if other operating rules are developed, they also would be used very similarly to the model and operating rules as described in these paragraphs. Therefore, if another river model is developed, or other operating rules are developed, the process that would be involved in assessing if proposed water projects meet the flow recommendations would be essentially the same as discussed in this section. Hence, we have not changed these paragraphs.*

We appreciate the opportunity to comment upon this latest draft report. We would be happy to discuss these comments further with you or with any member of the Biology Committee.

cc: Members of the San Juan River Recovery Implementation Program Biology Committee
Honorable Rodger Vicenti, Vice President, Jicarilla Apache Tribe
Honorable Joe Muniz, Council Member, Jicarilla Apache Tribe

From: "Errol Jensen" <EJensen@ibr4gw80.uc.usbr.gov>
To: BIOWEST.LOGAN(paul)
Date: 1/15/99 4:04pm
Subject: Comments on the Flow Recommendations for the San Juan River - Draft Report

Paul: Attached is a couple of comments on the Draft Report. If you have any questions, please give me a call (970-385-6589).

CC: BIOWEST.smtp("LCRIST@ibr4gw80.uc.usbr.gov","PSchum...

Comments on the "Flow Recommendations for the San Juan River" Draft Report dated December 1998

Page 7-13, 4th full paragraph, Paragraph starting with "The proposed Animas-La Plata Project....", last sentence - 56,610 af should be changed to 55,610 to match with the numbers on page 7-17 and tables 7-3 and 7-4. **RESPONSE:** *We have made this correction.*

Also, need to add a footnote to the end of the paragraph stating something to the effect:

The 1996 Section 7 consultation and resulting Reasonable and Prudent Alternative for the Animas-La Plata Project are based on an average annual depletion of 57,100 af and 149,200 af for Phase 1 of the Project and the full Project respectively. The difference between these numbers and numbers stated in the text can be contributed to different models and different modeling methods. **RESPONSE:** *We have added additional explanatory language on p. 7-13 and in Tables 7.3 and 7.4.*

COMMENTS ON

Flow Recommendations for the San Juan River

Draft Report

December 4, 1998

Submitted by

Tom Pitts

on behalf of

San Juan River Basin
Water Development Interests

January 18, 1998

Overall General Comments

1. The errors of estimation that are built into the model used to develop the flow recommendations need to be discussed in the report. For example, the gauges on which the flow analyses are based are only accurate within 10 percent. In addition, other errors have been added and compounded into the model, based on the fact that a) it is a model, b) numerous estimates had to be made, c) the model was based on less than a complete data base, and d) there are errors in the baseline (existing use) estimate, among others. **RESPONSE:** *Regression coefficients are presented for perturbation and habitat models. We have added language to discuss the impacts of model error in Chapter 7. The fact that there is not agreement as to the depletion base has been acknowledged repeatedly in Chapters 7 and 8.*

2. Flow-habitat relationships are mentioned but none could be found in the report. Only apparent associations of habitat with short-term flow changes are described. The descriptions of procedures and results of measurements and mapping of habitat during the study period also give the impression of having considerable latitude in interpretation, yet specific flows are prescribed almost entirely on the basis of an empirical associations between habitat and flow characteristics. No attempt was made to corroborate the empirical conclusions, but without corroborative analyses, any investigator's conclusions of cause-effect relationships in any data set are subject to different interpretations by other investigators. The occurrence of habitat under certain flow conditions does not prove a cause-effect relationship. **RESPONSE:** *See Chapter 7 for the flow/habitat model dealing with backwaters. We acknowledge throughout the report that the recommendations are based on the best information we have in hand and that they are not final, but are subject to adjustment through the adaptive management process as more is known. Further, the recommendations embody the collective interpretation of the researchers with oversight from the peer review panel.*

3. The report's conclusions appear to be based on a predisposition for reliance on and acceptance of short-term cause-effect relationships. The geomorphology of a stream this month is not necessarily formed, or even maintained, by this month's hydrology, yet the report makes numerous short-term associations of geomorphic/habitat conditions with immediately-preceding flow characteristics. Managing the fluvial habitat of a river this way might be intuitive or even possible, but is not consistent with geomorphologic principles. Flow regime changes should not be proposed without establishing how the river will respond and whether the response will be immediate or delayed, or temporary or permanent. **RESPONSE:** *The recommended flows are based on mimicry of the pre-regulation hydrograph, with all the variability that existed. There is no disagreement that the fluvial habitat is based not just on the present hydrology, but the hydrology for several previous years and possibly decades. Mimicry of the natural hydrograph preserves those very complex relationships that form the channel morphology and affect fluvial habitat. However, there are a few conditions that are shorter term in nature in the San Juan River, and probably other systems. The 7 years of data that we have along with an analysis of the geomorphological processes form the basis for backwater and low velocity habitat cleaning*

and for cobble transport necessary for cobble bar building. To understand and define all the relationships between hydrology and the geomorphological processes that form and maintain the features influencing fluvial habitat would be an impossibly difficult task for 200 miles of river. With seven years of data, a look at multiple year processes and the impact on habitat has been possible and the habitat response to a series of flows that represented mimicry of a natural hydrograph lead to the relationships developed.

4. A principal concern with the report's focus on mimicking flow hydrographs is that sediment transport and geomorphologic relationships, and the resultant impacts on riverine habitat, cannot be derived from hydrograph analysis alone. Inventories and analysis of sediment sources, characteristics, changes and transport relationships must be combined with flow analysis before reaching conclusions. Simple procedures, such as estimating effective flow values (dominant discharge) link the flow hydrograph with sediment-transport and channel-forming processes. By these or other similar methods, a much wider range of hydrograph regulation can be investigated to accomplish the same geomorphic and habitat results. **RESPONSE:** *Inventory and measurement of sediment sources were not possible in the San Juan River. The bulk of the sediment inflow occurs during short duration storm events distributed in over 100 major and 500 minor inflow points in 200 miles of river. While performing a sediment balance study would have been desirable, it was not practical. Mimicry of the natural hydrograph incorporates both biological and geomorphological response. Managing a stream based solely on the basis of sediment transport conditions is not wise, especially given the limitations of the data in the San Juan.*

5. Bank-full flow is offered as an index of channel maintenance, and a single value of 8,000 cfs is used for the entire river in setting flow recommendations. Using a single value for this much river length is unprecedented, and the bankfull flow rate is a weak and very subjective index, and is considered by most to be the weakest index for this purpose. Effective discharge or other measures are much more widely-accepted indices of the channel maintenance flow rate. **RESPONSE:** *See Chapter 4 for a discussion of how the 8,000 cfs recommendation is derived and what it means. The report clearly specifies that there is a range in bankfull conditions in the San Juan River and acknowledges that a range of flow magnitudes, durations and frequencies is important. The sole purpose of the 8,000 cfs in not channel maintenance.*

6. It has been assumed that 8,000 cfs is a channel maintenance flow because it equates to the bankfull flow. Equating channel maintenance flow with bankfull is subject to widespread disagreement in the scientific community. If channel forming flows are less than channel capacity, this could have significant effect on flow recommendations. The correlation between scour and peak discharge in the draft report is very weak. **RESPONSE:** *It is incorrect to speak of a flow magnitude without discussing duration and frequency, in terms of its utility for channel maintenance or any other purpose other than bankfull. We are mimicking a natural hydrograph, not specifying a flow condition only for channel maintenance. Read Chapter 4 for a more complete discussion of the derivation and utility of the 8,000 cfs recommendation.*

7. At the July 8, 1998 Biology Committee meeting, additional data were presented concerning 1) extension of the “without dam” hydrology to a period from 1929 to 1996 , including the very dry 1960’s; 2) channel capacity before and after the dam; and, 3) the statistical relationship of YOY catches versus 8,000 and 10,000 cfs flows. Although the Committee chose not to adjust the draft flow recommendations at that time based upon this new information, these data should be included within the appendices because they were mixed in support of the flow recommendations. For example, with the reduction in channel size, a flow of 10,000 cfs presently is equivalent to a flow of 13,000 cfs prior to the dam. The argument could be made that frequency and duration should be based upon those values for the 13,000 cfs event. Likewise, an analysis of the YOY data, if assumed to be statistically significant, showed a correlation to 8,000 cfs but not 10,000 cfs. To be considered as unbiased as possible, our draft report needs to include findings which support the flows being recommended as well as those that necessarily don’t. **RESPONSE:** *The material you refer to was not included because it was too speculative in nature. The comparable pre-dam conditions listed in the table were developed on an assumption in the reduction of channel capacity. No hard data exist to determine channel capacity before the dam was built. We only know that it was greater. We do know that statistically, the 10,000 cfs flow/duration/frequency relationship for the flow recommendation is about what the 13,000 cfs flow/duration/frequency relationship was pre-dam, indicating that the recommendation accounts for a smaller channel.*

8. In reading the report, a number of minor questions were raised that may have simple explanations upon further investigation, or may have affected the results. These include things such as:

    - How can the aerial survey of islands used in developing the channel complexity index distinguish an island from a lower-height bar or dune? **RESPONSE:** *The islands are identified by on-the-ground mapping using aerial videography as a base map.*
    - Why are some of the reaches described as "stable" when the same descriptions include discussion of bank protection? **RESPONSE:** *The bank protection and diking is partly responsible for the stability of the channel. When the lateral movement of the channel is confined by dikes and bank protection, the channel becomes less dynamic.*
    - If armoring has occurred, why doesn't the study examine means of protecting these zones as cobble bar habitat by reducing flows that would otherwise disturb or remove the armor layers? **RESPONSE:** *Armored reaches do not provide spawning habitat. Open interstitial space is required for spawning conditions and armored, stable bars have little, if any, open interstitial space.*

9. An important assumption underlying at least a portion of the draft recommendations is that the response of native, but non-endangered, fish is an acceptable surrogate for the response of the endangered species. The merits of this assumption need to be thoroughly explored and openly

discussed. As the draft now stands, the positive response of bluehead suckers to high flows serves as major justification for the 8,000 cfs recommendation. However, flannelmouth sucker showed no such response. Such conflicting results need to be presented and discussed in a less biased manner where undue significance is not given to one finding over another, thereby weakening the credibility of the report. **RESPONSE:** *We do not agree that because bluehead and flannelmouth sucker do not have the same response to flow, that the results are conflicting. Having two of the three common native fish (bluehead sucker and speckled dace) respond favorably in reproductive success to higher and longer flow periods would suggest these types of flows are important to the native fish community. Flannelmouth sucker reproductive success appears to be related to factors other than spring flow magnitude and duration.*

10. There is no scientific justification for the 10,000 cfs flow recommendation. **RESPONSE:** *Both Colorado pikeminnow and razorback sucker, and both juveniles and adults of both species, tended to select habitats in complex river reaches. Flows of 10,000 cfs and greater are the only flow levels that will maintain and potentially increase complexity in the river. See discussion on pp 4-11 to 4-12, 6-7, 8-3.*

11. Many of the definitions in the glossary are weak. The authors may want to check the American Fisheries Society List of Aquatic Terms being developed by Neil Armantrout. In addition, the authors may want to add "juvenile", "PAH", "GUI", "DMI", "acute toxicity", "habitats (run, riffle, shoal, slackwater)" to the glossary, as well as "endemic", "indigenous", "non-native", and "exotic". **RESPONSE:** *We appreciate your suggestions. Some of the abbreviations you note are on the chapter cover pages, and some of the words are in the Glossary. We have added some of the other terms to the Glossary.*

CHAPTER 1 - INTRODUCTION

Specific Comments

1. On the last paragraph of page 1-1, is it fair to say that "the Colorado squawfish and razorback sucker were widespread and apparently abundant...including the San Juan River?" Historic collections do not provide sufficient information to make this inference. The species were present, but historic abundance and distribution in the SJR are not well documented. **RESPONSE:** *The Biology Committee feels that the capture of adult and young fish with very little effort during pre-dam periods suggests more than just presence in the river. Population levels similar to present conditions would not have been detected pre-dam with the effort that was expended, hence, we have concluded that populations were widespread and relatively abundant.*

CHAPTER 2 - GEOMORPHOLOGY, HYDROLOGY, AND HABITAT OF THE SAN JUAN RIVER

General Comments

1. Discussion of historical occurrence of backwaters should be included. Because of the steep gradient and channel morphology, the predam river likely could not support an extensive backwater habitat. The San Juan does not nor ever did support flooded bottom lands required for razorback suckers. How can this species be recovered in a river that never had nor ever will provide for the fishes required habitats? **RESPONSE:** *There are no historically available data to accurately assess backwater habitat during pre-dam conditions. The pre-dam aerial photography was taken at a flow too high to accurately map backwaters. Therefore, no data are included. However, an examination of the photos indicate a very complex channel with ample opportunity for backwater formation. Studies with YOY Colorado pikeminnow indicate that nursery habitat for this age fish is not limiting in the system. You are correct that very little, if any, flooded bottom land exists in the San Juan floodplain. It will be unknown if YOY razorback suckers will use some other low velocity habitat in the San Juan River until millions of larvae are produced in the river, hopefully in the next few years. See page 4-52.*

2. The length of time that it takes for habitat degraded due to storm events to recover should be discussed with supporting data included. **RESPONSE:** *See the discussion on the flow/habitat model in Chapter 7. The model accounts for degradation based on the number of storm event days. Recovery depends on the flushing flow conditions being met.*

3. One weakness in the argument for flow recommendations is the lack of a geomorphic/hydrologic link to habitats, particularly backwaters. Since backwaters are the most important habitat for YOY Colorado squawfish, it is intuitive that understanding mechanisms for backwater formation are vital to flow recommendations. The draft report needs to emphasize the contribution of bedform to available habitat, not just current hydraulic conditions, and highlight the role of antecedent flow regimes in creating the habitat we observe at any instant in time. Along this same line, the draft report lacks a solid and defensible definition for a "backwater". For example, in Table 2.1, a backwater is "Typically an indentation of channel...", while the Glossary on page G-1 defines a backwater as "A pool type formed by an eddy along channel margins...". Neither definition provides a link to geomorphic processes that can be quantified in support of certain flow recommendations. For example, eddy return channels form in association with large recirculating eddies, chute channels form in association with low elevation channels, scour channels form on sand islands, etc. Knowing and understanding the type of backwater that the fish are using and relating type with geomorphic process and hydrology strengthens the argument for certain flows that create these habitats. **RESPONSE:** *The definition of Backwater has been edited. The bulk of the backwaters in the San Juan River, especially the more stable backwaters, occur at the mouths of seasonally dry secondary channels. Further, the correlation with flow conditions during the previous spring runoff is stronger for the secondary channel associated backwaters than other main channel backwaters, and since the secondary channel backwaters*

make up the bulk of the total, the correlations for total backwaters are similar to those for secondary channel backwaters. See pp. 4-30 to 4-32 and Table 4.12.

Specific Comments

1. Aerial videography was used extensively to analyze habitat availability and channel complexity (e.g., p. 2-21, p. 4-9). The efforts made to "ground truth" this information should be described and appropriate literature cited to support this relatively new technique. **RESPONSE:** *Aerial videography was used as the base map. Actual mapping was completed on-the-ground as noted on page 2-21.*

CHAPTER 3 - LIFE HISTORY OF THE FISHES OF THE SAN JUAN RIVER

Specific Comments

1. A discussion of productivity related to summer storm events is needed in the section of larval survival (Page 3-8). Bestgen's data concludes that food is a determining factor for survival and growth of larval squawfish. If summer storms affect food production in the San Juan at the critical stage for larvae, then survival of these larval fish will be greatly reduced. **RESPONSE:** *Productivity (biomass) is discussed at the end of Chapter 2. Any effect of late summer storms on larval pikeminnow would be pure speculation at this time. This issue will be studied in the future once sufficient larval pikeminnow are available in the system for study. Young-of-the-year pikeminnow stocked at less than 50 mm have grown exceptionally well in the San Juan River during years with extensive late summer storm events.*

2. Page 3-13; Some additional discussion of the effects of lacking flooded bottomlands in the San Juan for razorback staging is needed. This is a critical habitat requirement in the Green and Colorado rivers and if lacking in the San Juan may limit recovery. **RESPONSE:** *See the response to a similar question above and page 4-52.*

3. Page 3-23, paragraph 5, speculates that the roundtail chub is the most abundant carnivore in the Upper Basin. However, unpublished data from Valdez, Masslich and Leibfried for 60 fish collected from the Colorado River near Stateline indicates roundtail chub stomachs rarely contained fish. **RESPONSE:** *Carnivore means that the fish feeds on animal material as opposed to plant material. Insects are also eaten by carnivores. Piscivores feed primarily on fish.*

CHAPTER 4 - PHYSICAL AND BIOLOGICAL RESPONSE TO TEST FLOWS

General Comments

1. As the results in Chapter 4 and the recommendations in Chapter 8 are presented, it is apparent that 8,000 cfs is the channel maintenance flow and 2,500 cfs is the estimate of the flushing flow needed to maintain cobble quality for spawning. In a regulated river, it is possible for these two flow levels to be incompatible (Kondolf and Wilcock, 1996). If the channel maintenance flow moves spawning cobbles out of the system at a faster rate than they are replenished due to

upstream storage, these recommendations potentially could be setting a mechanism in place which in the long-term could result in loss of spawning habitat. While such a scenario may seem a bit farfetched given the sediment sources coming into the SJR below the dam, the question should at least be asked and the draft report should at least briefly attempt to answer it. What do we really know about cobble transport into and through the system? What do we know about the quantity, quality and location of cobbles stored within the floodplain environs that our 8,000 and 10,000 cfs flows are intended to erode and make available? Are there any possible adverse affects associated with this from the standpoint of habitat quality? The report needs to include mention of these possible concerns. **RESPONSE:** *See pp 2-1 to 2-2 for a discussion of the abundant cobble source in the flood plain. Examine Table 2.2 "eroding bank" which shows the abundance of unstable banks that contain cobble and gravel. Cobble supply is not a concern, as long as the channel stays active.*

2. The 1st draft of this document discussed the apparent positive effect the late 1980's drought had on speckled dace. Why was this deleted? As mentioned earlier, the report needs to remain as unbiased as possible in our presentation of results, especially in Chapters 4 & 6. **RESPONSE:** *The earlier draft of the document indicated that speckled dace did not disappear during the drought period, not that there was a positive effect. It is likely that speckled dace numbers declined during that period. This information was in reference to a statement that this short-lived species may be impacted by several consecutive drought years. These statements in slightly revised form are still on p. 4-17 of the December 4 draft.*

Specific Comments

1. Justification for the 10,000 cfs recommendation is based almost solely on the use of "island count" as an index of channel complexity (p. 4-11). The use of just this one surrogate parameter needs to be supported by appropriate citations from the geomorphologic literature and additional detail provided on how the measurement was actually done. Dr. Tom Wesche has attempted to use "island count" to quantify long term channel simplification in response to flow regulation on several large Wyoming rivers, his results have been mixed and difficult to explain. Also, Dr. Wesche has always used other parameters (e.g., change in width-depth ratio, variability in bankfull depth, change in meander geometry) in conjunction with island count. Assuming the literature supports the use of "island count", then the question becomes how has this index of complexity changed historically. Is there quantifiable evidence from historic aerial photographs that the count has changed substantially? Can a case then be made that such changes have lead to habitat simplification for the fish? Given the significance of this flow recommendation, the report needs to provide as much justification as possible. If such a case cannot be made, we need to carefully explain the reasons. **RESPONSE:** *The basis of the 10,000 cfs is first to mimic a portion of the natural hydrograph that has been most heavily modified with reservoir operation. The need for restoring these higher flow rates was first established by observation of the function of the flood plain and then verified with the island data analysis. Restoration of high flows in the more heavily vegetated flood plain had the possibility of degrading and simplifying the channel. When higher flows less than 10,000 cfs occurred (1992-1994) this appeared to be*

happening. The trend was reversed and channel complexity restored when the flow conditions above 10,000 cfs were met (See Figure 4.6 and discussion on pp 4-9 to 4-13). The long term change in island count deals with permanent islands under bankfull condition and does not directly relate to the analysis of channel complexity at low flow (1,000 cfs).

2. The assumption is made in Chapter 4 (e.g., p.4-13, 4-14) that bankfull flow is the same as the effective discharge for the SJR, the implication being that 8,000 cfs is the channel maintenance flow. Measurement difficulties aside, an unstated assumption underlying this is that the SJR is in a stable condition. Bankfull flow is meaningful as a measure of channel formative or maintenance flows only if it is first shown that the river has reached a state of dynamic equilibrium. Furthermore, equating channel maintenance flow with bankfull is subject to widespread disagreement in the scientific community. For example, after hearing extensive testimony by several experts (including Dr. Luna Leopold and Dr. Stanley Schumm), the Colorado Division 1 Water Court adopted as more compelling the definition that channel forming flows are less than channel capacity , and that channel forming flows are referenced more appropriately to the level at which the incipient floodplain is being formed rather than the present main channel capacity. Likewise, studies on the upper Colorado have revealed that effective discharge is less than the bankfull discharge (Pitlick and Streeter, 1998). Although the sediment transport rating curves needed to quantitatively determine effective discharge are not presently available, the report needs to bolster the justification for use of bankfull as the channel maintenance flow in order to avoid criticism. Along these same lines, it needs to be recognized in the report that flows other than bankfull or the annual peak can and do play a role in transporting sediment through the system. This could be why on p. 4-4 and Figure 4-1 the correlation between scour and peak discharge is weak. Perhaps Ellen Wohl can be of help on these matters. **RESPONSE:** *Bankfull is not equated to effective discharge in the report. 8,000 cfs for 8 days with an average frequency of 33% is discussed as necessary primarily to transport cobble and secondarily maintain channel capacity based on the recurrence frequency of this magnitude and duration post-dam and the loss of channel capacity that has resulted. Further, the 8,000 cfs is the flow considered necessary for cobble transport for bar building based on the four modeled reaches. If the pre-dam effective flow had been used as the target (computed to be about 7,000 cfs), the frequency and duration would have increased relative to 8,000 cfs, resulting in a similar overall flow recommendation. If the results of continued monitoring show this, or any other flow recommendation, to be too high or too low, there is opportunity to modify the recommendation.*

3. Page 4-29, 2nd paragraph: The basis for the 21-day duration of the 5,000 cfs flow is based on conditions in reach 3. However, few, if any, endangered fish were found in reach 3. Without the reach 3 data, the duration would be seven days. This could result in a significant difference in terms of water releases for endangered fish. **RESPONSE:** *Stocked YOY Colorado pikeminnow have been found in Reach 3. This reach has the highest abundance of backwater habitat when flushed and the greatest distance below the upstream spawning sites of the reaches that can be influenced by flow manipulation, an important consideration for larval drift.*

4. For razorback sucker telemetry data (Page 4-38) the number of individuals used to make habitat preference determination should be stated. Are there enough to make this analysis valid? **RESPONSE:** *On p. 4-49 it is noted that 57 razorback sucker were radio-tagged. These were the fish used in the analysis.*

5. Page 4-40: Previous sections discuss the fact that temperature may override flow effects. No mention of year to year temperature variation is found in the section on squawfish early life stages. This should be included as a non-flow limiting factor and discussed. Also, the effect of storm events on food availability should be discussed here. **RESPONSE:** *We are not sure what earlier sections you are referring to. The temperature/flow discussion was primarily related to Colorado pikeminnow spawning time, not reproductive success. Refer to our answer above related to food availability and storm events.*

6. Table 4-14, on p. 4-41, lists data regarding young-of-the-year and juvenile squawfish collected in the San Juan River. These data are scant and not related to catch per unit effort. These data do not support the inference "that high flow years with naturally shaped hydrographs like 1987, 1993, 1994, and 1995 are important for Colorado squawfish reproductive success." **RESPONSE:** *This section has undergone considerable change as the Biology Committee has investigated this information. It is the consensus of the Biology Committee that the way this information is presented is accurate. The fact that it fits with what has been learned in other Upper Basin rivers lends credence to the conclusions in the San Juan Basin.*

7. Page 4-42: For adult squawfish, are four fish one year and five fish another a valid sample size to make habitat preference determinations? Small sample size and the associated error for telemetry observations should be discussed. A table for habitat availability and use would be beneficial to the reader. **RESPONSE:** *As is always the case with biological information, more data would always be helpful. Since so much of the habitat information from these few fish indicated habitat use was very similar to other pikeminnow populations in the Upper Basin, it strengthened the validity of these data.*

8. Page 4-48, 2nd paragraph: Can the SJR temperature data that has been collected be used here to support the Upper Colorado data? At some point in the report, the SJR temperature data needs to be brought in and evaluated as a possible limiting factor. **RESPONSE:** *We suspect you are referring to recent work by Doug Osmundson on temperature. Temperature in the upper San Juan River will continue to be investigated as we repatriate the endangered fish to this area.*

9. Page 4-48, last paragraph: If there is a "question about the overall suitability of backwaters in the San Juan for squawfish," then recommending flows to maintain these questionable habitats is questionable. This may be an area of monitoring under the Adaptive Management Program. **RESPONSE:** *This question was answered in the ensuing section of the report. Nursery habitat for young Colorado pikeminnow in the San Juan River includes a variety of low velocity habitats, and backwaters were more common than some people thought. This information made*

the use of backwaters even more important in the flow recommendations, and not questionable at all.

10. For flannelmouth suckers, additional analyses should be considered to determine correlations with temperature, food availability, and turbidity. **RESPONSE:** *We agree that the changes observed in flannelmouth sucker populations needs additional study. We anticipate that the monitoring information will be useful in evaluating these changes.*

11. Pages 4-53 to 4-68: For both flannelmouth and bluehead sucker data a relationship between year class strength and other non-flow limiting factors should be analyzed. This would include temperature, food availability, storm event turbidity increases and potential competition with nonnative fishes. **RESPONSE:** *Information on these factors is not available for all the years, or in some cases for any of the years, studied to date. These non-flow factors will likely be investigated during the Synthesis Report analysis.*

12. Pages 4-68 to 4-72: In the first paragraph of the speckled dace discussion on page 4-68, the author dismisses the lack of correlation between September dace numbers and availability of high flows because of a shift in habitat usage. However, in the last paragraph beginning on 4-68, when September dace numbers appear to follow the author's preconceived flow-fish relationship, no mention is made of the previously discussed habitat shift. **RESPONSE:** *As noted in that section, the first paragraph refers to main channel collections by UDWR, the last paragraph refers to secondary channel collections made by NMGF. Riffles were not sampled by UDWR, but were by NMGF. Hence, two different sets of data were being discussed, which suggests the conclusions may also be different.*

13. The discussions of nonnative fishes beginning on Page 4-72 should explain that flow augmentation to date has probably benefitted the nonnative fishes as well. **RESPONSE:** *The conclusion drawn by the Biology Committee was that nonnative fish were not reduced by flow changes, but the data do not support a conclusion that they were benefitted. By and large, populations of nonnative fishes changed during the 7-year research period but did not increase or decrease markedly.*

CHAPTER 5 - CONTAMINANT CONSIDERATIONS IN THE FLOW RECOMMENDATION PROCESS

General Comments

1. In regard to Chapter 5, contaminants in the San Juan River have been a historical event and may have been a limiting factor for these fishes prior to construction of Navajo Dam. Since the decision was made to include this chapter in the report, why not discuss contaminants as a non-flow limiting factor? **RESPONSE:** *The extent of historical contamination (prior to the beginning of good data collection in the last 20-30 years) is not known, although the upstream mining activity in the Animas suggests that it could have been a problem. We have not identified*

any contaminant yet that would be a limiting factor. However, discussing the full range of contaminant effects is beyond the scope of the flow recommendation report.

CHAPTER 6 - SUMMARY OF FISH HABITAT/FLOW RELATIONSHIPS

None

CHAPTER 7 - FLOW RECOMMENDATION DEVELOPMENT PROCESS

Specific Comments

1. The inventory of the types of habitat reveals that the preferred habitats are very rare (usually less than 1 percent of the total wetted area) and the report implies that they cannot be increased by flow regulation. The authors state on p. 7-1 (second paragraph) that the "abundance [of the controlling habitats] is not as directly affected by flow…" It seems unreasonable and scientifically incredible to conclude that these infrequent, micro-features can be maintained by macro-regulation of flows. **RESPONSE:** *You have mis-read the statement. The paragraph and Table 7.1 comment that backwaters and cobble bars are the primary controlling habitats in the flow recommendation since they (1) respond to flow in abundance and quality, (2) are very important to the life history of the fish and (3) have been most heavily affected by the altered flow regime. The habitats you reference, while important, are not limiting to the life stage of the fish that are using them and either do not respond to changes in flow or maximize at high flows that are impossible to provide. Since they don't respond to flow, they were not diminished by dam regulation. The recommendations are based on habitats that matter to the fish and that can be substantially influenced by changes in the flow regime.*

2. Page 7-3, second paragraph: The perturbation (habitat/flow) model needs to be explained more clearly to the non-geomorphologist. What does this mean to the ability of the fish to feed under perturbations to the system? **RESPONSE:** *The perturbation model applies only to backwater habitats and is related primarily to their availability expressed as total area (see p 7-3). Associated with a reduction in area is a reduction in water depth due to increased sediment depth. Impact on food availability is not considered in the model. Food availability may be reduced, but growth of the stocked YOY Colorado pikeminnow has been high during the test period when perturbations occurred.*

3. Page 7-8: If squawfish spawning did occur during a period where the 8,000 cfs condition for 8 days was not met, then why should this criteria be implemented. This is a "biological-response" driven model and a biological response was observed with less than the required condition. **RESPONSE:** *8,000 cfs for 8 days is the condition required to build bars and is only required one year in three. Spawning area can be maintained on these bars between rebuilding flows by flows of 2,500 cfs for 10 days.*

4. On Figure 7.4, the areas shown as “key young-of-year” habitat do not correspond to the captures of YOY shown on Figure 4.13. Shouldn’t they? **RESPONSE:** *This notation was removed from the schematic in the December 4, 1998 draft.*

CHAPTER 8 - MODEL RESULTS

General Comments

1. The recommended “maximum periods” between recommended flows have significant impact on water releases for endangered fish. The “maximum periods were based on the collective judgement of the Biology Committee members of the maximum time possible between conditions before substantial or irreversible impacts to the fish or their habitat resulted, and in all cases, are at least as long as the historical pre-dam statistics indicate.” No substantive basis for these recommendations is provided. **RESPONSE:** *You are correct. The values resulted from long discussions and are judgments that are subject to revision through adaptive management.*

2. Sensitivity analyses need to be conducted with the model on the potential range of key parameters, including maximum periods, duration, and bankfull flow, to determine the effects of realistic variations on water releases. The results of these analyses should be incorporated into the report and reflected in the flow recommendations. **RESPONSE:** *The sensitivity analyses you suggest would only have impact on the amount of water development allowed for most of the parameters listed. Many of those analyses have been made and the results reviewed by the Biology Committee in arriving at the recommendations in the report. In fact, by examining the results in the tables and figures in Chapter 8, the impact on future development of many of these parameters can be seen. Only utilizing a different magnitude for the 8,000 cfs condition is not presented in the tables. Since duration and frequency would have to change if a lower value was used here, the end result would be minor.*

Specific Comments

1. On p.8-3, Table 8.1 “Frequency distribution table for flow/duration recommendations” includes a variety of frequencies and durations that go far beyond the primary flow recommendations. There is no basis whatsoever in the report for the frequency duration recommendations that are not primary criteria. There is no basis whatsoever in the report for stating that “natural variability maintained by meeting conditions in Table 8-1” is part of the flow recommendations. Table 8-1 needs to be deleted from the report. Only the appropriate primary criteria should be included, after modification based on the comments submitted herein and comments by others. **RESPONSE:** *Table 8-1 is critical to the condition of mimicry. The condition of maintaining variability similar to natural conditions is inherent in hydrograph mimicry and is specified as an underlying condition for mimicry in the San Juan (page S-1, S-5, 8-1).*

2. Page 8-4: Purpose of 8,000 cfs. One of the purposes is that 8,000 cfs had a positive response for bluehead sucker and speckled dace. Where is the data to support that what is good for these fish

is good for squawfish when these fish are not endangered? **RESPONSE:** *The native fish community is of interest and concern to the SJRIP. These species are part of that community. Healthy native fish communities supported healthy populations of the endangered species. Recovery of the endangered fishes without a healthy native fish community is likely not possible.*

3. The purpose and use of Table 8-4 on page 8-12 is not clear, nor the description directly above the table. Are the minimum carryover storage amounts just informational or are they to be used in the decision tree? Please clarify. **RESPONSE:** *The description of the use appears on page 8-7 under the fourth bullet describing the use of the operating rules in the model. This is a calibration parameter in the model that protects against water shortage in future dry years.*

January 15, 1999

Mr. Ron Bliesner
Chairman, SJRRIP Biology Committee
Keller- Bliesner Engineering
78 E. Center
Logan, Utah 84321

Dear Ron:

The following are the State of Colorado's comments for your consideration and inclusion in the Biology Committee's December 1998 "Draft Flow Recommendations for the San Juan River." These comments are limited in scope to the "technical and scientific" aspects of the report as agreed to the December 1998 Coordination Committee meeting. The comments previously provided concerning "administrative and implementation" issues will be addressed in other aspects of the San Juan RIP.

GENERAL COMMENTS

1. The San Juan River RiverWare model used to develop flow recommendations is a planning model that makes a number of assumptions on who will develop water and how they will do it. While it is clearly stated that the flow recommendations are subject to adjustment through the "Adaptive Management" process in the future, there does not appear to be clear language that anyone can develop a portion of the water identified as available for development at any time. As a result, there should be a mandate to adjust the modeling assumptions and flow recommendations on any regular basis.

   Major model assumptions include:

   a. The release rate from Navajo Dam. A discussion of the 6,000 c.f.s. versus 5,000 c.f.s. release rate at Navajo Dam is included and it appears either release rate will support the flow recommendations and the same level of water development. The U. S. Bureau of Reclamation ("Reclamation") might be able to make releases in the range of 5,200 to 5,500 c.f.s. from Navajo Dam and stay, for the most part, in the existing San Juan River channel. However, the 5,000 c.f.s release should not be exceeded at the present time based on information provided to the Coordinating Committee by Reclamation and the U.S. Army Corp of Engineers. The option to release additional water, up to 1,000 c.f.s., through the Navajo Indian Irrigation Project ("NIIP") canal should be mentioned as a possibility until the research clearly ruling it out is completed. **RESPONSE:** *This is not an option that would be available universally, and certainly not at nearly that capacity during the time of year it would be needed. It is beyond the purview of the SJRIP to access any NIIP features other than Navajo Dam.*

b. Where, when and how future water development occurs will impact the basin hydrology making it either easier or harder to achieve the flow recommendations at certain times. This will need to be evaluated on a regular basis. **RESPONSE:** *We agree. The tools are provided to do this.*

2. Not all flow recommendations appear to have a strong supporting biological basis, and therefore may ultimately not be critical for recovery. For example, the 10,000 cfs peak appears to have as many arguments against it as for it. For example, on page S-2 it is noted that an important feature for Colorado Pikeminnow (Squawfish) spawning is very clean cobble bars with very little fine sediments between individual cobbles. If this is the case, why interject sediment and debris into the river system with overbank flooding, especially when downstream property damage potential has not been identified as part of the research program. Furthermore, while backwaters are important for young Pikeminnow, it is noted on page S-3 that there are other low velocity habitats necessary for the survival and growth of the young Pikeminnow. Finally, it is also noted on page S-3 that high flows on the San Juan did not repress non-native fish populations. All these factors appear to argue against a 10,000 cfs peak flow at least at this time. The Biology Committee needs to provide better indication of the most important goals to try and achieve at present (more spawning bars, more low velocity habitat, or more adult habitat). This would help decide what to strive for when making Navajo releases to shaping a peak. **RESPONSE:** *Sediment and debris are not a major factor during high spring flows, but rather are a concern during late summer and fall storm events. High spring flows have sufficient hydraulic force to move cobble and thereby clean sediment from spawning cobbles. Low velocity habitats are often most abundant in complex river reaches which the 10,000 cfs flow creates and maintains. We do not understand why failure to depress nonnative fish would argue against a 10,000 cfs flow since this flow was not recommended to reduce nonnative fish. As noted throughout the document, spawning habitats and nursery habitats are the focus of the flow recommendations, but adult and juvenile habitat are also provided for by this level of flow.*

3. Each section under the "Recommended Hydrograph Conditions" should contain references to the work or section of the report that supports or is the basis for the recommendation. The reader needs to know and understand the strength of the research given the often competing results. **RESPONSE:** *The primary purpose of Chapter 6 is to provide this type of comparison and that information is summarized under each Recommended Hydrograph Condition.*

4. Peer Group. Peer Group review has indicated that: a) the number of fish collected are not adequate to develop sound conclusions; b) a discussion of the impact of non-native fish needs to be provided; and c) general support for the process and of the direction of the Biology Committee in making the best use of the little data available. We understand Peer Group comments will be

integrated into the next version of the flow recommendations. **RESPONSE:** *Peer Review Panel comments have been addressed in the final report.*

5. On page 1-5 it is noted that actual stocking was initiated in 1994 when it became clear that existing population levels in the San Juan River system were too low to measure responses. Has this stocking effort been adequately considered in all the studies supporting the flow recommendations? **RESPONSE:** *Yes it has.*

6. Develop a table of research needs such as those associated with the 10,000 cfs peak flow and as indicated at the top of page 6-7, on page 4-40 and on page 7-7. **RESPONSE:** *Nearly every aspect of the flow recommendation needs either future monitoring for verification or additional research. We believe it is beyond the scope of this document to identify future research needs in any comprehensive manner. The synthesis report will address the research needs while the monitoring plan will address the monitoring requirements, all of which will be used to verify and update flow recommendations.*

SPECIFIC COMMENTS

Page S-1, 2nd paragraph. Please explain why it is necessary to mimic the historic magnitude and duration of the natural hydrograph. We can understand the historic shape and timing aspects, but water development in the basin will limit the ability to attain all the statistical parameters. **RESPONSE:** *Mimicry does not mean replication. Mimicking just shape and timing does not fully address the range of issues involved. The shape of a natural hydrograph could be mimicked with 10% of the natural flow, yet that would not meet the conditions needed for mimicry. At issue is the definition of mimicry in terms of each parameter specified. The report attempts to do that for magnitude, duration, frequency, variability and timing.*

Page S-2,, 2nd paragraph. Please clarify this paragraph. The research suggests that Navajo Dam reduced the sediment load and cooled the water reducing the historic habitat. Also, diversion dams further reduced historic habitat by limiting historic migration. It is also clear that the introduction of non-natives has resulted in heavy predation on the young-of-the-year limiting if not preventing any recruitment to the reduced habitat. It needs to be clear that the reasons for the native fish becoming endangered are many and complex. **RESPONSE:** *We agree that reasons why native fish numbers have been reduced are many, and it is a complex issue. The paragraph referenced does not discuss reasons why fish numbers were reduced but rather how Navajo Dam changed the San Juan River.*

Table S-1 and 6.1. The first two sets of flow requirements do not fairly represent the research reported later given some of the arguments noted in #2 above. Also, Block 7 dealing with flows to cue spawning seems to contradict the requirements in Block 12 noting that releases from Navajo Dam are to cool. Clarification and noting some of the downsides or contradictions seems appropriate. **RESPONSE:** *We disagree with your first point concerning #2 above. Block 7 has been changed in response to your, and other, comments*

Page S-5, Recommendation for flows greater than 10,000 cfs. We remain concerned that this recommendation is not justified. Flows of this magnitude bring additional sediment into the river that may clog spawning bars. Inadequate research has been done to quantify both the property damage potential and impacts to spawning bars. **RESPONSE:** *The volume of fine sediment entering the system through overbank flow is not even measurable at high flow in relation to the sediment inflow into the system from the watershed. Erosion of new channels brings in about equal amounts of fine (silt/sand) and coarse (gravel/cobble) sediments, while high flows typically remove at least 10 times as much fines as coarse sediments. The flooding remains in the active flood plain as identified by the Corps of Engineers (estimated capacity at Shiprock of 14,000 cfs), so property damage is confined to areas that have historically flooded with some regularity. The impact to spawning bars is positive not negative.*

Page S-8, Flood Control Releases. Clarification needed, we fail to understand how flood control releases can be delayed until after September 1. Not sure this recommendation is achievable as a practical matter. **RESPONSE:** *The flood control releases are those that occur after those required during spring runoff. They are the result of maintaining the required target space in the reservoir at certain times of the year, according to the flood control requirements specified by the Corps of Engineers, to prevent reservoir spills. If, for example, the inflow during the late summer and fall raises the reservoir too high to meet the target space necessary to prevent overtopping during spring runoff, water would need to be evacuated before runoff began to prevent a spill. Historically the release is made by increasing the base release over a long period of time. The recommendation on page 8-12 modifies this procedure to release the same required volume in a spike. You will note in the recommendation, that if the release is needed before September 1, it is added to the release hydrograph.*

Page 1-2, first paragraph. Again seek a balanced description of all the factors associated with the decline of the endangered fish. Making reservoirs the primary factor is not supported by the research. The attempts to eradicate the native fish and replace them with a non-native sport fishery were significant factors as well. **RESPONSE:** *All of these factors are mentioned in this paragraph and the balance of the paragraph is correct. The native fish collapsed after the construction of the* *large dams, whereas nonnative fish, and all the other factors, have been around in the basin since the early 1900s. Many experts feel that nonnative fish and other nonflow limiting factors have been exacerbated by habitat degradation due to flow change since the advent of the large dams.*

Page 1-2, last complete paragraph, last three sentences. It would seem that all potential limiting factors affecting recovery of endangered fish in the San Juan River should be evaluated and addressed concurrently with the flow recommendations. Please explain why the adoption and implementation of flow recommendations prior to defining and implementing other measures necessary to recover the fish is appropriate and potentially more effective. Potential limiting factors and measures for dealing with these factors should be investigated and discussed concurrently with the flow recommendations. **RESPONSE:** *Flow recommendations where a major effort for the Biology Committee and trying to prepare a document on all the other factors at the same time was too large an effort. The other factors will be considered in the Synthesis Report being prepared in 1999. Some have already been addressed and activities have been started to overcome them (e.g. small populations requiring augmentation and limitation of range resulting in barrier removal). These factors have been considered in making the flow recommendation.*

Page 1-3, last sentence. The ALP Biological Opinion makes reference to achieving 300,000 AF 96% of the time in order for slightly more depletion to occur. Is this condition achieved as part of these flow recommendations? **RESPONSE:** *No. This discussion in the Biological Opinion is based on old hydrology that was completed to reflect the flexibility in the system to meet the needs of the fish. While our releases average more than 300,000 af, they do not occur 96% of the time. This would not result in mimicry of a natural hydrograph.*

Page 2-2. last incomplete paragraph. The flow recommendations assume that San Juan River flows alone can and should be used to maintain the river channel and channel complexity needed for endangered fish habitat. However, the draft report indicates significant changes in watershed conditions in the San Juan River Basin including; reduced suspended sediment loads, changes in river channel vegetation, and changes in the river flow regime. Is it realistic to assume the flow recommendations can overcome all these changes? The Biology Committee should highlight these changed conditions in the executive summary recommend further evaluation of the potential for maintaining the river channel and desired fish habitat conditions. Vegetative controls, watershed management measures such as sediment retention structures, and physical river channel modifications such as bank stabilization may be viable options and the Recovery Program requires that flow be considered in conjunction with non-flow actions. **RESPONSE:** *The flow recommendations are made in light of these changes that have occurred in the basin. For example, without the reduction in sediment load that has occurred in the system, more water may have been* *required to maintain habitat. The other watershed management actions you suggest may have an influence in the future if they could be accomplished, but until they are studied, found practical and effective and implemented, the flow recommendations have to be functional with the system as it presently exists. Bank stabilization is detrimental to the system, not beneficial. The other activities may well be considered under adaptive management in the future.*

Page 2-10, second paragraph, second sentence, and page 2-26, second paragraph. The flow recommendations include criteria based on the amount, duration and frequency of flow considered necessary to clean backwaters and maintain low velocity habitat in secondary channels in reach 3. However, it is not clear that using Navajo releases to meet these criteria is an effective use of water. The beneficial effect of the spring releases on fish habitat in reach 3 is often negated by runoff from summer and fall storms. The draft report at page 4-37 states that storm events, not spring runoff conditions, appear to be the dominant factor regulating backwater and other low velocity habitat quality and productivity. Given this, do releases that generate flows that contribute to backwater formation become a lower priority? The Biology Committee should indicate the more important goals of reservoir releases and suggest investigating other measures such as watershed management techniques to reduce sediment loads to the San Juan River instead of relying on large reservoir releases to help scour sediments. Also, construction of passages around barriers to fish movement between Cudei and Farmington would allow endangered fish access to potential spawning and rearing habitat further upstream in the San Juan River, which might lessen the need for lesser quality rearing habitat in reach 3. Creating more access to backwater and spawning habitats upstream could offset losses in backwater habitat in reach 3. Temperature control devises on Navajo Dam outlet works may also be useful. **RESPONSE:** *The beneficial effects of spring releases are not negated by storm flow. If no release is made and storms occur, even more habitat is lost. It is true, that the need for flushing this reach is related to the amount of perturbation that occurs due to storm flow, but the releases are not negated. Productivity of backwaters, not quantity, is more influenced by storm flow than runoff. Maintaining backwaters is a high priority goal of the flow recommendation. The priorities for the flow recommendations are listed in Chapter 7, pages 7-1 and 7-2. The recommendation for flushing of Reach 3 assumes that passage will be constructed. Since the potential spawning locations have been moved down river by 50 miles by the construction of Navajo Dam, assuming barrier removal (100 miles without), and the bottom 77 miles of historic nursery habitat has been lost, to suggest that Reach 3 is not needed would be irresponsible given on our present knowledge of the system.*

Page 3-27. first paragraph. The draft report at pages 3-31 through 3-35 indicates that channel catfish and common carp use the same habitats used by Colorado squawfish and other native fish. Therefore, flow management for native fish habitat could also benefit non-native fish. The draft report at page 4-8 1, last paragraph, indicates that non-native channel catfish and carp populations are not negatively affected by mimicry of the natural hydrograph. This suggests that implementing the flow recommendations might not be a very effective recovery action unless accompanied by actions to remove non-native fish from the river. The report should at least indicate that the amount of streamflow needed to conserve the endangered fish in the San Juan River might be reduced if actions taken to control non-native fish populations prove effective. **RESPONSE:** *Channel catfish and common carp have been in the Colorado Basin since the late 1800s. Their influence on native fish appears to be most problematic in areas with poor habitat. Hence, by improving habitat for native fishes, nonnatives become less of a concern. The flow recommendations were made to improve habitat for native fish. In the future, if specific flow features can be linked to reduction of nonnatives, they will be tested if they fit within the overall goal of mimicry of the natural hydrograph.*

Page 4-14, last incomplete paragraph. Again, language to help justify a flow recommendation of greater than 10,000 cfs is suggested to maintain channel complexity. Again, we note that flows greater than bankfull spread onto the floodplain and do not add substantial energy for transporting cobble or forming cobble bars. Furthermore, they may contribute debris and sediment to river that must then be flushed. Flows greater than bankfull may also cause property damage and this potential has not been fully investigated based on statements made at the last Coordination Committee meeting. Based on this information flow recommendations greater than 8,000 c.f.s should not be included at this time and we continue to urge there removal until the needs and risks for creating these flows are fully understood. **RESPONSE:** *See previous responses to this issue of out-of-bank flooding. The need is based on mimicry of the most modified portion of the hydrograph, supported by the findings reported on pages 4-11 to 4-12.*

Page 4-28, last full paragraph. Again, there is language suggesting flows above 10,000 cfs are helpful in maintaining channel complexity, providing new cobble sources for subsequent bar construction and maintaining floodplain integrity. Yet, on the top of page 4-29 it states, "Percent cobble substrate has increased with time, cobble is abundant in the system, the cobble bars surveyed do not appear to be degrading, and open interstitial space is consistently maintained. The first sentence of the next paragraph indicates that backwaters flush at 4,000 to 5,000 cfs thereby questioning the need for flows grater than this level. **RESPONSE:** *The observations include results where the 10,000 cfs condition has been met two of seven years, which is greater than recommended. Therefore, the observations of the channel condition include the response to these flows.*

Page 4-40, last incomplete paragraph, first sentence; page 4-41, first complete paragraph, first five sentences; and page 6- 1, first paragraph. There were so few YOY Colorado squawfish collected in the San Juan River during the 1987-1996 period that it is not fair to draw conclusions relating spawning success to spring runoff. Consequently, it is also difficult to conclude from these few fish and different sampling techniques that spawning success is significantly correlated to spring runoff volume. The report so indicates at page 4-41. This fact should be a major consideration and reason to limit the high flow recommendations at this time. **RESPONSE:** *This section has undergone considerable change as the Biology Committee has investigated this information. It is the consensus of the Biology Committee that the way this information is presented is accurate. The fact that it fits with what has been learned in other Upper Basin rivers lends credence to the conclusions in the San Juan Basin.*

Figure 6.1. Good idea but some information appears out of place. For example, under Bluehead Sucker the spawning should probably be under the "runoff" time slot rather than the "base flow" slot. Please review. **RESPONSE:** *Bluehead sucker are the last sucker to spawn, and hence they spawn after the peak flow period as flows are being reduced to base flow.*

Page 6.6. Red shiner abundance increased with the number of days flows were above 8,000 cfs. This is a downside to flows of 8,000 cfs or more for longer than 8 days and argues for a shorter duration of bankfull flows along with the bank erosion that occurs at this flow. **RESPONSE:** *We are not sure this is a downside, since this observed increase was only in secondary channels and the increased density of red shiner does not perpetuate itself beyond one year.*

Page 6.6 Summer flow spikes could negatively impact native YOY **RESPONSE:** *We agree as stated on page 6-6.*

Page 6-7. More high flow language to consider. **RESPONSE:** *See above responses to same comment.*

Page 7-1. If controlling habitats are either backwaters or cobble bars, why introduce more sediment into the system when it is not needed. **RESPONSE:** *See earlier responses to the high flow issue.*

Page 7-2. More high flow language to reconsider. **RESPONSE:** *See above responses to same comment.*

Page 7-6: If squawfish spawning did occur during a period where the 8,000 c.f.s condition for 8 days was not met, then why should this criteria be implemented. This is a "biological-response" driven model and a biological response was observed with less than the required condition. Backwater habitat is optimal at between 6,000 and 7,000 cfs. **RESPONSE:** *8,000 cfs is not required each year,* *but only 1 in 3 years to build bars, with periods as long as 6 years allowable between events. 2,500 cfs is adequate for maintaining spawning conditions on existing bars in between the years with bar building flows. Therefore, the "response" is consistent with the recommendation.*

Page 7-8 A frequency of 1 year in three does not appear to be ample consideration for an extended drought. **RESPONSE:** *Agreed. This is the average over a 65-year period of record. We allow 6 years without meeting the conditions during drought periods.*

Page 7-9 last sentence of third paragraph under "River Operations": the RiverWare model should be used for Section 7 consultations but it is very difficult to operate. At the present time only Keller-Bliesner Engineering with cooperation from USBR are able to run the model. It is probably not realistic to have an applicant operate the model. A recommendation for the Coordination Committee to develop a process for using the model in consultations and maintaining it would be appropriate. **RESPONSE:** *We have provided a description of how the tool may be used. The Coordination Committee may develop any procedure for use that they see appropriate. Any use in the Section 7 process would be with the approval of Fish and Wildlife Service.*

Page 7-9. It is noted that a fourth controller for water ownership and accounting is being developed. This means that water rights are not supported in the model at present, only depletions. As a result the advantages of lagging return flows is not fully supported and exchange type operations can not by implemented. Also, operations of Electra Lake and other smaller facilities were ignored. This controller when completed will help to significantly improve the identification of project impacts rather than limiting them to a strict examination of depletions. **RESPONSE:** *The model in its present form cannot consider the administration of water rights or accurately represent priority. The addition of the fourth controller would help that ability. The limitation was not significant to the flow recommendation process.*

Page 7-13. The report should explain why Phase I, Stage A of ALP is not shown as 57,100 but as 56,610 AF which is less than the Biological Opinion for the project currently provides. Also, depletions under the 57,100 AF scenario only occur to the Animas and San Juan. We need a full project at 146,000 AF to impact the La Plata. **RESPONSE:** *The results were modeled exactly as they were for the Section 7 Consultation for ALP. Language has been added to indicate the limitations of those model results and reflect the difference between the representation and the planned project depletion.*

Page 7-17. Language here highlights that the "depletion base" is not equivalent to the "environmental baseline." This issue needs to be resolved with the USFWS and is a good argument for review of the recommendations at the end of 1-year. **RESPONSE:** *We agree as noted on p. 8-27. This is a Coordination Committee issue.*

Pages 7-18 and 7-19. Table 7.3. The depletion estimates have changed for Colorado largely because we know have better information. This should be noted in the report. Furthermore, the added depletion levels even though selected projects were used for modeling purposes do not represent a right for that particular entity to claim a right to that depletion. New depletions are available to any entity on a first come first serve basis. **RESPONSE:** *We recognize your position. Due to the sensitivity of issues concerning the changes from the environmental baseline for ALP, we have elected to not discuss the reasons for the change, but simply state that "corrections" were made.*

Page 8-1, last paragraph. This paragraph suggests a few conditions under which flow recommendations for the San Juan River may be modified in the future. The Coordination Committee has not yet discussed the implementation of the flow recommendations, including criteria for modifying them. Again, these are good reasons for a review at the end of one year. **RESPONSE:** *This has been edited to reflect that it is a recommendation.*

Page 8- 3, table 8. 1. The frequency distribution values shown in table 8.1 represent both primary and secondary flow-duration criteria for the San Juan River. The sole support for the secondary flow duration criteria are the hydrologic modeling results for different water depletion scenarios given by the draft report at pages 8-13 and 8-14, figures 8.2 through 8.5, from which the numeric frequency values were selected based on modeled trends of flow-duration frequencies. The report should either present further evidence in the form of actual gage record to support the secondary flow criteria, or the secondary criteria (and table 8.1) should be deleted from the report. **RESPONSE:** *While the table was produced by examination of modeling results that approached the threshold primary values, providing the variability listed will provide variability that was judged adequate for the purposes of mimicry. Had the natural distribution (available from an analysis of the gage data) been used (See Figures 8.3 through 8.10) these secondary criteria would have controlled the recommendation rather than the primary condition. Therefore, the variability requirements were described such that the primary criteria would always control.*

Pages 8-2 through 8-7, section entitled "Recommended Hydrograph Conditions." The report needs to address comments above as appropriate in this section. Flow recommendations should be reconsidered after a year as suggested at the last Coordination Committee meeting. **RESPONSE:** *This section has been edited to improve description of the flow recommendations. Inadequate additional data will be available to reconsider these recommendations in one year.*

Pages 8-6. In the first paragraph under operating rules, revise the sentence, "**As noted in Chapter 7, the use of these hypothetical water development scenarios does not imply any right to develop, any priority of development, or any priority for consultation. Neither do these scenarios attempt to exclude others from developing.**" **RESPONSE:** *The suggested changes have been made.*

Page 8-7, first bullet. Please clarify that you anticipate always ramping up and down from and to 1,000 cfs and not some lesser flow rate like 500 cfs. Also include a definition for the term "perturbation" here. Finally, you need to recommend that the Coordination Committee establish who will be responsible for determining who operates and maintains the model for consultation and RIP purposes. **RESPONSE:** *The clarification is provided in Tables 8.2 and 8.3. The ramp rates never exceed 1,000 cfs per day but they may be less and they follow different timing, depending on the ramping duration. It would be difficult to explain narratively.*

Tables 8.11 to 8.14 are missing data. **RESPONSE:** *Do you mean Figures? The Figures have been corrected.*

In closing, the Coordination Committee must discuss how the flow recommendations will be implemented both in the field and in section 7 consultations. The impacts of the flow recommendations on water development in the San Juan Basin must be fully understood.

Thank you for the opportunity to comment on the latest draft, we look forward to your responses.

Sincerely

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