Appendix A

Executive Summary
Flow Recommendations for the San Juan River

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

Flow Recommendations for the San Juan River

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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 °C at peak runoff for razorback sucker spawning and near 18 to 20 °C 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.