Research plan for developing flow recommendations in the Little Snake River, Colorado and Wyoming, for endangered fishes of the Colorado River Basin

FINAL REPORT

January 1997
Revised December 2001

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Report for the:
Recovery Implementation Program
for the Endangered Fish Species
in the Upper Colorado River Basin

Project 56-A

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PREFACE

This report was originally titled "*Management action plan for endangered fish recovery in the Little Snake River, Colorado and Wyoming*" and was approved by the Recovery Program Biology Committee in April, 1997 with minor revisions. The original objectives were to document the state of knowledge of the fishery and hydrology resources of the Little Snake River that are important for the conservation of endangered fishes in the Colorado River Basin. From this base, we were to identify data deficiencies and develop a research plan to resolve uncertainties. The information in this report was updated in 2001 to reflect new information and the title was changed to more accurately reflect the purpose and intent of this document. It is important to acknowledge that this report serves as a reference for other documents that will direct management activities in the Little Snake River and associated basins. The role of the Little Snake River in recovery of endangered fishes will be determined by the Management Plan for the Yampa River.

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ACKNOWLEDGMENTS

We thank Rick Patton, George Smith, and Ed Wick of the conceptual work group for help outlining the components of this report. We also thank Angela Kantola and Henry Maddux of the U.S. Fish and Wildlife Service (FWS) Recovery Program Director's Office for additional guidance. Earlier versions of this report were improved by comments from the following reviewers: Tom Annear (Wyoming Game and Fish Department), Henry Maddux (FWS), Tom Nesler (Colorado Division of Wildlife), and Paul Thompson (Utah Division of Wildlife Resources). This study was funded by the Recovery Implementation Program for the Endangered fish species in the Upper Colorado River Basin. The Recovery Program is a joint effort of the U. S. Fish and Wildlife Service, U. S. Bureau of Reclamation, Western Area Power Association, states of Colorado, Utah, and Wyoming, Upper Basin water users, environmental organizations, National Park Service, and the Colorado River Energy Distributors Association.

Disclaimer

EXECUTIVE SUMMARY

The Little Snake River is the largest tributary of the Yampa River which is a river of high priority for recovery of endangered fishes in the Upper Colorado River Basin. The four endangered fishes include: humpback chub (*Gila cypha*), bonytail (*G. elegans*), Colorado pikeminnow (*Ptychocheilus lucius*), and razorback sucker (*Xyrauchen texanus*). The purpose of this document is to describe the fishery and hydrology resources of the Little Snake River sub-basin that are important for the conservation of endangered fishes of the Colorado River Basin. We identify data deficiencies and outline a research plan to resolve uncertainties. The goal was to develop a plan that defines the information necessary to protect, recover, or restore the Little Snake River for endangered fishes following guidelines of the Recovery Implementation Program, Recovery Action Plan (RIPRAP) that directs recovery of endangered fishes in the Little Snake River in Colorado and Wyoming in the context of basin-wide recovery actions. The role of the Little Snake River in recovery of endangered fishes and necessary management actions will be determined by the Management Plan for the Yampa River Basin.

The objectives were to:

1. Review and summarize hydrology and geomorphology information of the Little Snake River.
2. Review and summarize fisheries information of the Little Snake River.
3. Identify missing information critical to managing the Little Snake River for recovery of endangered fishes.
4. Develop a hierarchy to obtain missing information so that priorities can be set.
5. Develop a step-down Instream Flow Work Plan that lists actions necessary to identify and protect Instream Flows for the recovery of endangered fishes in the Upper Basin.

The Little Snake River is significant to endangered Colorado River fishes for two primary reasons. First, it provides mainstream habitat for humpback chub and Colorado pikeminnow and second, it contributes flow and sediment that maintain nursery habitats in the alluvial reaches of the Green River. Since the closure of Flaming Gorge Dam beneficial sediment loads have decreased 50% in the downstream alluvial reaches of the Green River. Sediments from the Little Snake River are critical in maintaining the active channel in alluvial reaches of the Green River and partially ameliorate the loss of sediments in the Green River due to Flaming Gorge Dam. Currently a high percentage of the beneficial sediment load in the Yampa and Green rivers originates from the highly erosive soils in the Little Snake River Basin. Approximately 77% of the Yampa River sediment load is from the Little Snake River and downstream in the Green River, about 60% of the sediment load at the Jensen gage is from the Little Snake River. Seasonal runoff in the Little Snake River is early compared to the Yampa River and because flows are unregulated, the amplitude between peak and base flows is high. Depletions from the Little Snake River are about 11% of the historical yield and are low compared to most Upper Basin rivers. Additional depletions from the tributary Savery Creek at the new High Savery Dam, Wyoming will increase annual depletions to about 14% of the total yield of the Little Snake River.

In four years of sampling the Little Snake River between 1981 and 1995, seventeen species of fish were caught, including ten nonnative species. However, these nonnative species that are typically abundant and widespread in other Upper Colorado Basin rivers were few in number and limited in distribution in the Little Snake River; native species were more abundant and widespread than nonnatives in all years sampled. In 1981, 64% of all individuals captured were natives; in 1988, 96% were native; in 1994, 69% were native; and in 1995, 72% were native. The most abundant native species included flannelmouth sucker (*Catostomus latipinnis*), bluehead sucker (*C. discobolus*), and roundtail chub

(*G. robusta*) and the most abundant nonnative species included reside shiner (*Richardsonius balteatus*) and red shiner (*Cyprinella lutrensis*). Large bodied nonnative species including gamefish were extremely rare in the Little Snake River in all years. Reasons for the paucity of nonnative were not studied but might be related to the extreme habitat conditions in the Little Snake River. The high variability of discharge (high in spring and extremely low in fall) influences related physico-chemical characteristics of the river such as water temperature and sediment transport that directly and indirectly affect fish survival and growth. During baseflow, fish tend to concentrate in refugia pools where conditions are often less than ideal. Pools are subjected to extreme diel temperature fluctuations, loss of water quality, and storm spates that displace fish and carry and deposit large amounts of sediment. There may be other unobserved causal agents for the scarcity of nonnative species but the events related to the hydrograph probably play a significant role in structuring the fish community in the Little Snake River.

Based on captures and telemetry data, individuals of both Colorado pikeminnow and humpback chub from the Yampa River move into and occupy the lower 15 km of the Little Snake River between May and July. Colorado pikeminnow probably move into the Little Snake River from the Yampa River to increase their condition prior to their spawning migration and exploit abundant prey fishes and warmer water temperatures found in the Little Snake River. Most Colorado pikeminnow leave the Little Snake River and return to the Yampa River just before their spawning migration; however, some Colorado pikeminnow may remain in the Little Snake River year round, based on historical accounts and the reported capture of one in late August near the Colorado-Wyoming state line during baseflow.

Humpback chub may also use the Little Snake River for reasons similar to those of Colorado pikeminnow, but the following circumstantial evidence suggests that humpback chub might be attempting to spawn in the Little Snake River. Humpback chub were captured and telemetered in the Little Snake River between May and July during their spawning period. Two humpback chub were captured with secondary sexual characteristics such as spawning coloration and breeding tubercles. Water temperatures in the Little Snake River were adequate for spawning when humpback chub were present. Long-range movements of 32 and 39 km by two telemetered humpback chub in the Little Snake River were similar to distances moved by spawning humpback chub in the Grand Canyon. Despite considerable fidelity to local population centers, humpback chub are known to move relatively long distances between populations groups or for spawning. Although there is circumstantial evidence that support potential spawning of humpback chub in the Little Snake River, currently there is no proof. No humpback chub have been collected in ripe, spawning condition in the Little Snake River and all juveniles collected there have been identified as congeneric roundtail chub. In addition, confirmation through larval collections was not possible because there were not adequate morphometric characteristics to distinguish small larvae of *Gila* species. Differentiation of small *Gila* species larvae may require genetic evaluation.

Our recommendations for the Instream Flow Work Plan focus on research necessary to develop scientifically defensible flow recommendations. We recommend:

1. Develop interim flow recommendations based on present knowledge.
2. Estimate Little Snake River flows and sediment loads necessary for creation and maintenance of Colorado pikeminnow and razorback sucker nursery habitats in the Green River.

3. Determine if humpback chub spawn or attempt to spawn in the Little Snake River and if so, then estimate the flows necessary to create and maintain spawning habitats.
4. Investigate if flows or flow patterns influence the distribution or abundance of nonnative fishes in the Little Snake River.

Keywords: channel morphology, Colorado pikeminnow, depletions, endangered fishes, fish composition, instream flow recommendations, Green River, humpback chub, Little Snake River, native fishes, nonnative fishes, recovery actions, sediment yield, spawning, tributaries, Yampa River.

INTRODUCTION

The Recovery Implementation Program for the Endangered Fishes of the Upper Colorado River Basin (Recovery Program) was established in 1988 with a cooperative agreement to recover and delist endangered fishes while providing the potential for existing and new water development to proceed in the Upper Basin (USFWS 1987; Hamill 1993). The four endangered fishes; humpback chub (*Gila cypha*), bonytail (*Gila elegans*), Colorado pikeminnow (*Ptychocheilus lucius*), and razorback sucker (*Xyrauchen texanus*); will be considered recovered once self-sustaining populations and habitat are established.

The process of recovery within the Upper Basin is guided by a management plan known as the Recovery Implementation Program, Recovery Action Plan (RIPRAP, USFWS 1995). The RIPRAP outlines actions necessary to achieve recovery of the endangered fishes based on the best available biological information and the recovery goals for each species. It guides future planning, research, and recovery efforts including the annual work plan and budgeting. Annual review allows modification of the plan as knowledge increases about the fish or the ecosystem, as priorities change, or as states develop their entitlement.

The RIPRAP applies recovery actions to each of seven sub-basins of the Upper Colorado River Basin, including the Green, Yampa and Little Snake, Duchesne, White, Colorado, Gunnison, and Dolores rivers. The Little Snake River is the largest tributary of the Yampa River which has been identified as a river of high priority for recovery of endangered fishes in the Upper Basin. The purposes of this document are to describe the fishery and hydrology resources of the Little Snake River sub-basin that are important for the conservation of endangered fishes of the Colorado River Basin, identify data deficiencies, and outline a research plan to resolve uncertainties. The plan will follow the guidelines and format of the RIPRAP to direct recovery of endangered fishes in the Little Snake River in

Colorado and Wyoming and in the context of basin-wide recovery actions. The goal was to develop a plan that defines the information necessary to protect, recover or restore the Little Snake River for endangered fishes. The role of the Little Snake River in recovery of endangered fishes and necessary management actions will be determined by the Management Plan for the Yampa River Basin.

An important component of this report is the work plan that focuses on actions necessary to identify and protect Instream Flows necessary for the recovery of the endangered fishes. The work plan follows recommendations of Stanford (1994) for an ecosystem approach. The process identifies goals and objectives for fish recovery through an overview (umbrella proposal) that sets priorities and clear directives. The objectives of the are to:

1. Review and summarize hydrology and geomorphology information of the Little Snake River.
2. Review and summarize fisheries information of the Little Snake River.
3. Identify missing information critical to managing the Little Snake River for recovery of endangered fishes.
4. Develop a hierarchy to obtain missing information so that priorities can be set.
5. Develop a step-down Instream Flow Work Plan that lists actions necessary to identify and protect Instream Flows for the recovery of endangered fishes in the Upper Basin.

METHODS

Information in this report came from reviews of the fisheries literature (by J. Hawkins) and the hydrology and geomorphology literature (by J. O'Brien) of the Little Snake River. These reviews provide an overview of the river ecosystem. The hydrology and fisheries information is summarized in context of each of the five RIPRAP actions (program elements). For each program element we identify existing knowledge (*What do we already know?*) and missing information that is necessary to support future management decisions (*What do we need to know?*). These deficiencies identify key questions that must be answered to recover the endangered fishes. As directed by the Recovery Program, we conclude with a step-down outline for a work plan for determining instream flow recommendations.

The hydrology review was a compilation of available water resources information and data. No new data or analyses were developed in this study. Included in this synthesis of information is a discussion of historic streamflow, sediment loads and channel morphology of the Little Snake River in Colorado. The literature was divided into two categories: the water and related land resources of the river basin and physical processes which effect channel morphology and habitat. A brief discussion of the Little Snake River Basin water and related land resources is presented and physical processes shaping the river morphology and fish habitat are discussed.

In addition to the review of available information, two hydrology field trips were conducted to the Little Snake River. The first trip in the spring of 1994 was a reconnaissance trip. The second trip was a channel monitoring trip establishing cross sections in two reaches of the river. The first reach was located upstream of the Lily Gage where six cross sections were established. The second reach was upstream of the Powder Wash road where eight cross sections were monitored (FLO 1996). A reconnaissance of the entire Little Snake River basin was not conducted for this study.

Information for the fisheries review was obtained from a literature search of professional journals, agency reports, and Recovery Program reports. Most information came from unpublished agency reports and U.S. Fish and Wildlife Service capture records from the Recovery Program database manager (C. McAda, *personal communication*). The fisheries review identified the location, effort, and dates of earlier studies. Generalized fish species composition and abundance is presented along with details about endangered fish captures.

Locations on the Little Snake River are kilometers upstream from the confluence of the Yampa River. Locations on the Yampa River are kilometers upstream from the Green River confluence. Units of measure are reported in metric units except for some hydrological data that are reported with either English or both metric and English units. Hydrologic data are reported in English units because these units are commonly used and widely accepted by the US Geological Survey and by States when defining Instream Flow needs.

STUDY AREA

The Little Snake River is an unregulated tributary of the Yampa River in the Green River drainage. It drains the Southern Rocky Mountains and the Wyoming Basin of Colorado and Wyoming (Figure 1). The river flows past two small communities: Dixon, population 82; and Baggs, population 433 (Bureau of Census 1992). Lower elevation tributaries upstream of Baggs, Wyoming (elevation 1903 m) include Battle, Slater, Savery, Willow, and Muddy creeks. Downstream of Baggs, intermittent tributaries Red Wash, Sand Creek, Sand Wash, and Powder Wash drain the Washakie Basin to the north in Wyoming and Sand Wash Basin to the south, in Colorado. After meandering between the two states, the river enters Colorado and flows approximately 160 km southwest to its confluence with the Yampa River.

The specific area of interest was the lower 180 km of the Little Snake River, downstream of Baggs, Wyoming. This area represents the warmer-water reaches of the river that contain potential habitat for endangered fishes. We partitioned this area into five reaches based on geomorphology and longitudinal location. Geomorphology influences riverine characteristics such as channel morphology, water velocity, water depth, suspended sediment, and substrate and these characteristics influence distribution and abundance of aquatic invertebrates and fishes. The reaches provided a convenient method of classifying areas that may be important to the endangered fishes.

Reach V: The uppermost reach extends downstream from Baggs, Wyoming at river kilometer (RK) 180 to about RK 80. Elevation changes 1 m/km from 1902 to 1798 m through the reach. The confined channel contains gravel and cobble substrates that form a riffle-pool habitat sequence. The reach contains diverse habitats year round that are apparently suitable for all life stages of fish. Riffles provide spawning habitat at runoff and maintain refugia pools at low discharge. An adult Colorado pikeminnow was captured in this reach in 1990 (Marsh et al. 1991).

Reach IV This reach extends from about RK 80 to RK 15. Elevation changes about 1 m/km from 1798 to 1731 m in this unconfined sand-bed reach that is often very wide (250 m). There is a lack of diverse habitat except for some sharp bends and islands that create eddies or backwaters at high runoff flows. Substrate is predominately sand that is contributed by several ephemeral washes which supply the bulk of fine sediments carried by the Little Snake River. At extremely low discharge, interstitial flow provides little suitable fish habitat and creates a barrier to large fish movement. Scour holes at higher flows become isolated pools at low flows that provide refugia for mostly smaller-sized fish.

Reach III This reach extends from RK 15 to 9.5. Elevation is 1731 m. At RK 15 the channel narrows at a hydrologic control that is the location of Moffat County Road 10 bridge and the U.S. Geological Survey (USGS) "Little Snake River near Lily, Colorado Gage" # 09260000 (Lily Gage). The river quickly enters a narrow bedrock canyon about one kilometer long and continues through a less confined canyon reach about 4.5 km. Higher gradient (3 m/km) in this reach and boulder debris from canyon walls and adjacent washes create fast and deep eddy habitats at higher discharge. These eddies become pools at extremely low discharge and provide refugia for fish. Colorado pikeminnow and humpback chub adults were captured in this reach in 1988 and 1995 (Wick et al. 1991; Hawkins et al. 2001).

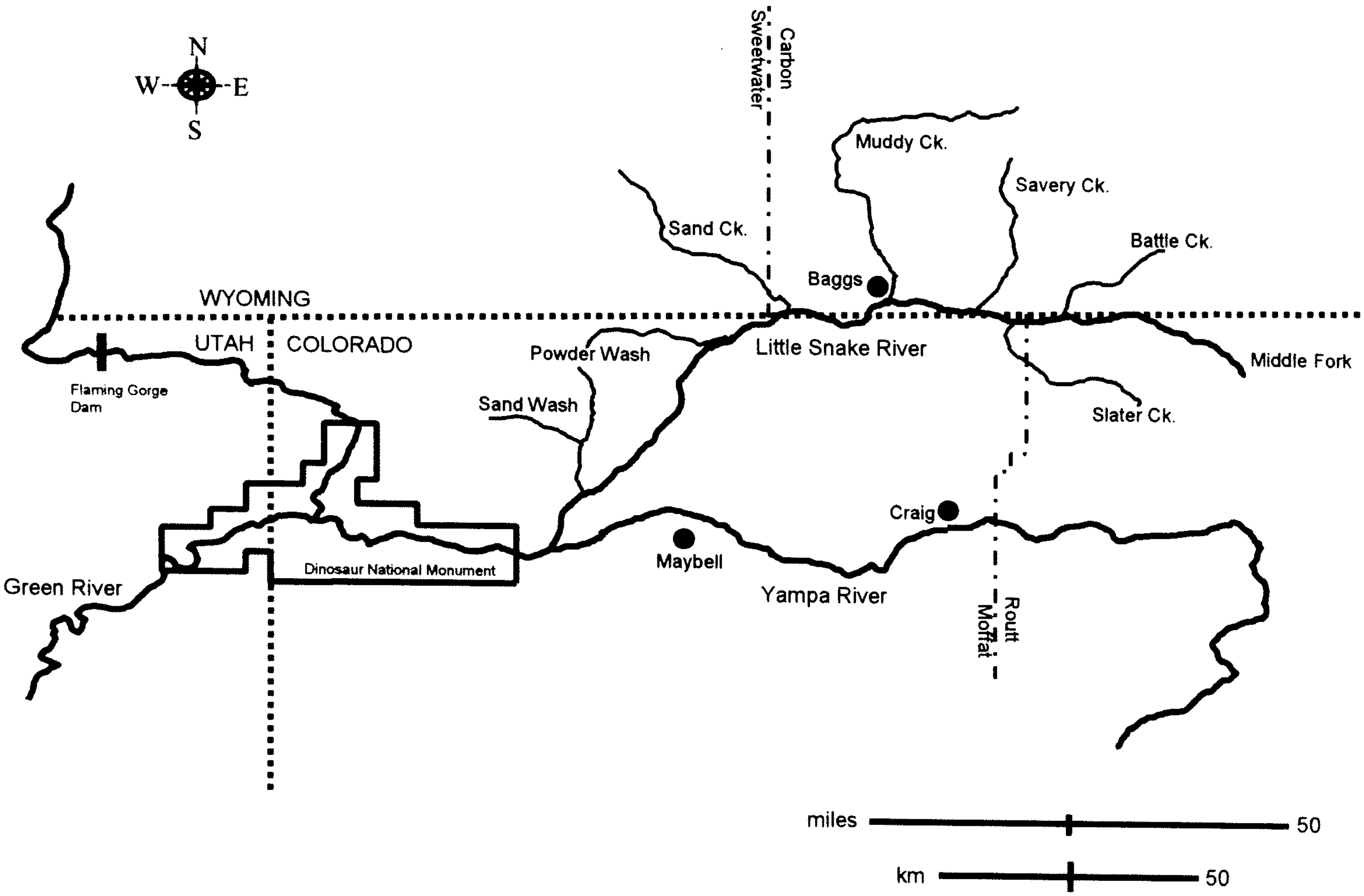

Figure 1. Little Snake River drainage basin, Colorado and Wyoming

Reach II The reach from RK 9.5 to RK 5 is less confined and gradient is 1 m/km. The major substrate materials are cobble, gravel, and sand probably input from local ephemeral tributaries. Cobble debris fans at tributaries form eddy habitat at higher flows. These eddies become refugia pools for fish at base-flow. Habitat in this reach is diverse at all flow levels. Several vegetated islands increase habitat diversity by providing velocity breaks at higher flows and side-channel backwaters at lower flows. At extremely low base-flow, pools provide refugia for all sizes of fish. Colorado pikeminnow and humpback chub adults were captured in this reach in 1988 and 1995 (Wick et al. 1991; Hawkins et al. 2001).

Reach I The final reach is 5 km long from the confluence with the Yampa River and is greatly influenced by Yampa River stage height. Flow is uninterrupted through the unconfined channel and the reach contains very little fish habitat at higher flows. As discharge recedes, backwaters are formed at islands and provide habitat for smaller fish but the reach becomes a barrier for fish movement at extremely low discharge because of the unconfined, wide, sand bed. During runoff, Colorado pikeminnow and humpback chub adults must move through this area on their way to Reach II (Wick et al. 1991; Hawkins et al. 2001). The confluence of the Little Snake River to the Yampa River is located 80.8 km upstream from the Green River.

HYDROLOGY RESOURCES REVIEW

One of the most important resources of the Little Snake River to the habitat and recovery of endangered fish is the highly variable water discharge and sediment supply to the Green River system. Water and sediment yield in the Little Snake River basin are influenced by a number of factors including geology, topography, soils, vegetation, climate and land use. Soil conditions are related to geology and climate. Clearly these factors are interrelated and combined with man's activity can result in highly variable sediment yield.

Geology

The Little Snake River contains two different geological regions, the headwaters region within the Southern Rocky Mountains and a lower watershed region within the Wyoming Basin. The geology of the Little Snake River basin was discussed by the Army Corps of Engineers (COE) in the Draft Environmental Impact Statement on the Sandstone Project (COE, 1988) and by Resource Consultants, Inc (RCI, 1991). The delineated geologic regions are: 1) the Tertiary and Cretaceous age sedimentary formations of the lower and western Little Snake River basin; and 2) the pre-Cambrian igneous and meta-sedimentary rock of the Sierra Madre range on the eastern portion of the basin. Upstream of Dixon, Wyoming the highest parts of the basin are underlain by Precambrian granites and mafic intrusives. These bedrock units are relatively erosion resistant. The sedimentary formations are dominated by Cretaceous age Steel Shale and Mesaverde Group sandstones. The Steele Shale formation is an erosive older formation consisting primarily of siltstones and claystone shales. The Mesaverde Group is predominantly sandstones and shales. The Browns Park formation which caps this sedimentary network consists of loosely cemented sandstones, siltstones and mudstones.

Other sedimentary formations in the basin include: Wasatch and Green River Formations which consist of loosely cemented, interbedded sandstones, siltstones and mudstones; the Washakie Formation, an interbedded sandstone, siltstone, mudstone and conglomerate; and the Bridger Formation, with shale, mudstone, claystone, siltstone and sandstone. All these formations are relatively young and very erodible in the far western part of the basin where the Paleozoic sedimentary rocks, primarily limestone, sandstone and siltstone are exposed on the surface. Shales are more common in the Cretaceous formations and mudstones are more common in the Tertiary units. These formations are widely exposed due to sparse vegetation and are relatively erodible resulting in high sediment yield from the tributaries.

The four major tributaries in the lower Little Snake Basin include: Muddy Creek, Sand Creek, Powder Wash and Sand Wash (Figure 1). The geology of these tributaries are described by Gregory (RCI 1991). Of these four streams, Sand Wash and Muddy Creek are the most prodigious producers of sediment. Muddy Creek drains the Green River and Wasatch Formations and the Sand Wash basin is underlain almost entirely by the Bridger Formation. Sand Creek delivers sediments primarily from the Washakie Formation, the youngest formation (Eocene Epoch) in the Little Snake Basin. Powder Wash drains the Wasatch and Green River Formations. Many of the small streams in these formations are incised. Muddy Creek provides relatively fine sediments while Sand Wash contains high concentrations of sand-sized sediments. There are no quantitative estimates of sediment yield from these tributary systems.

River-basin geology also effects channel morphology, river valley slope, sediment contribution and river substrate at local scales. For example, the Little Snake River Canyon beginning at RK 14 creates a bedrock control which results in a mild sand-bed slope for several kilometers upstream. The geology thus creates markedly different habitats abruptly, from a sand-bed alluvial river to canyon confined bedrock river.

Vegetation and Precipitation

A variety of vegetative communities occur in the basin including: desert shrub, sagebrush grasslands, aspen woodland, montane forests, some wetland areas, riparian communities along the river and tributaries, and some subalpine vegetation along the far eastern border. Much of the erosive topography is covered with the sparse vegetation of the desert shrubs and sagebrush grasslands. This vegetation occurs on gentle to moderate slopes and is characterized by sagebrush, rabbitbrush, serviceberry, and snowberry and various grasses including wheatgrasses, bluegrasses, prairie junegrass, Indian ricegrass, needle grass, cheatgrass and fescue.

The distribution of vegetation in the Little Snake basin can be explained by the combination of soil conditions, topography and precipitation. Langbein and Schumm (1958) developed a relationship between mean annual sediment yield and mean annual precipitation. It showed that in areas where the mean annual precipitation was greater than 35 cm per year, the vegetative cover is more dense and more diverse. Soil erosion decreases for areas of higher precipitation because the vegetation protects the soil from raindrop impact and the soil particles are bound together with root systems. For areas with a mean annual precipitation of less than 25 cm, sediment yield is limited by the low rainfall/runoff.

A mean annual rainfall of 23 to 30 cm occurs in the lower elevations of the Little Snake watershed (Andrews 1978). This rainfall supports desert shrub and lower grassland vegetation community. The combination of limited rainfall, sparse vegetation and erosive geology in the lower Little Snake basin generates a high sediment yield in the tributary system.

Land Use

Based on BLM land ownership maps, most of the Little Snake River basin is federal land. There are five small communities along the mainstem river (Baggs, Dixon, Savery, Slater and Battlecreek) whose combined population is less than 1,000. Rangeland and grazing constitute the primary land use. While the number of ranches have increased in the basin, the average size of the ranches and the total acreage being ranched and farmed has decreased. Some gas and oil production occurs in the basin. The potential impacts of gas, oil and coal mining, and coal-bed methane on the water and related land resources are unknown, but could be extensive.

Historic grazing which resulted in vegetation removal and soil surface disruption has contributed to the high sediment yield in the Little Snake basin. Cattle grazing reached its zenith in this region in 1889 (USFS 1936). During the ensuing 35 years, the Colorado River at the Grand Canyon experienced the period of highest annual flows in its recorded gage history. Following 1942, a 62% decline in annual sediment load was observed at the Grand Canyon gage (Schumm and Gellis 1989). Less runoff, soil and water conservation practices and improved grazing practices have all contributed to a reduction in the sediment yield in the upper Colorado River basin. Overgrazing in the Little Snake basin effected riparian and wetland areas as well as the desert shrub and grassland vegetative communities. In some riparian areas, where livestock tended to concentrate, reproduction of cottonwoods has been eliminated (COE 1988). However, photographic evidence suggests that a decrease in grazing acreage and improved soil conservation practices have reduced channel incision in the tributary basins.

Hydrology

More than half of the drainage basin of the Little Snake River is in Wyoming. The major tributaries include Battle Creek, Slater Creek, Savery Creek, Willow

Creek and Muddy Creek (Figure 1). Elevations in the watershed range from 1,676 m at the confluence with the Yampa River to above 3050 m in Sierra Madre mountains along the Continental Divide. The Little Snake water allocations and distribution between the states falls under the provisions of the Upper Colorado River Basin Compact (October 11, 1948).

Although the Yampa River and Little Snake River basins are approximately equal in size, the Little Snake River contributes only 27% of the average annual water yield to the Yampa River in Deerlodge Park. The average annual water yield from the Little Snake River is 428,000 af whereas the Yampa River flows average 1,120,000 af (O'Brien 1987). The Little Snake is a very seasonal river, high flows related to snowpack melt occur in the spring months from mid-April through early June and low base flows extend from August through February. On an average year, the peak discharge in the Little Snake River will approach 3,000 cubic feet per second (cfs; 85 m^3/s) whereas the Yampa River average peak discharge exceeds 8,000 cfs (227 m^3/s) at Maybell. The historical mean base flow from September 1 to February 28 is 98 cfs (2.7 m^3/s). For long periods during the low flow months, particularly in dry years, the Little Snake River flow at Lily Gage will approach zero cfs. On average, annual peak flows in the Little Snake River precede the peak flows in the Yampa River by approximately six days, therefore Little Snake River discharge can contribute to earlier opening of backwater and side channel habitat in the Yampa and Green rivers.

Comparing the average annual sediment load on the basis of suspended load data, the Little Snake transports an average of 2,020,000 tons per year at Lily while the Yampa averages only 389,000 tons per year. This disparity in runoff and sediment load for relatively equal drainage areas that are contiguous illustrates the combined effects of elevation, geology and precipitation on sediment yield. Depletions from the Little Snake River have a greater impact on sediment load and channel morphology in the Green River than depletions from the Yampa River because of the high sediment load associated with the smaller runoff.

Streamflow Records

A total of five USGS gaging stations have been operated historically in the Little Snake basin (Table 1). Currently only one USGS gaging station is still in operation, the Lily Gage (RK 15) on the Little Snake near Lily, Colorado which has been in continuous operation since 1922. The other important gages on the main stem Little Snake were the gage near Slater, Colorado and the gage near Dixon, Wyoming. The flow measured at the Dixon gage is influenced by two diversions upstream of the gage. Two tributary gages were historically operated on Savery Creek and Slater Fork. The Lily Gage is located near the confluence of the Yampa River with no intervening major tributaries and therefore provides a good measure of the water yield from the basin. The streamflow records at the other gages have been intermittent (Table 1). The Dixon Gage has had no winter records since 1971.

Table 1. Summary of the Daily Streamflow Gaging Stations in the Little Snake Basin [a]

USGS Station No.	Station Name	Period of Streamflow Record (water years)	Period of Sediment Record (month/year)
09260000	Little Snake River near Lily, CO	1922-94	1952-1953 1957-1958 5/58-9/64 10/75-9/77
09257000	Little Snake River near Dixon, WY	1911-23 1939-92	10/72-9/76
09259650 09259700	Little Snake River near Baggs, WY	infreq [b] 1962-68	
09256000	Savery Creek near Savery, WY	1942-46 1948-71	4/53-8/53 10/75-7/77
09255000	Slater Fork near Slater, CO	1932-77	4/52-8/53 10/75-9/77
09253000	Little Snake River near Slater, CO	1943-47 1951-1977	4/52-5/52 10/75-9/77

[a] Source: Andrews (1978).

[b] Collected with water quality samples.

The Colorado Water Conservation Board (CWCB 1994) estimates that approximately 50% of the flow in the Little Snake as measured at the Lily gage originates in Wyoming. Based on the period of record at the Lily Gage the mean daily streamflow is approximately 590 cfs (17 m^3/s) with the driest year (1977) averaging only 143 cfs (4 m^3/s) and the wettest year (1984) on record averaging 1252 cfs (35.5 m^3/s). RCI (1991) presented a peak flow frequency analysis using the USGS WATSTOR system for the data base through 1988 (Table 2). The flow duration and flow frequency analysis should be updated for recent years.

Current Depletions

Current annual water depletion of the Little Snake River within Wyoming is estimated to be 39,900 af (CWCB 1994). This depletion, approximately 9.1% of the historical water yield, is broken down as follows: 23,300 af for irrigation, 16,500 af for transmountain diversions and 100 af for municipal use. In-basin municipal diversion is estimated at 200 af with a net result of 100 af of consumptive use. Irrigation depletions were estimated by assuming 20 inches of water application over 14,000 acres. Monthly depletion estimates are shown in Table 3 and include Cheyenne Stage II depletions (CWCB 1994). Stanford (1994) estimates that the average annual flow depletion is 48,800 af from the Little Snake or approximately 11% of mean annual flow (428,000 af) in the river. This estimated depletion is greater than the CWCB estimate and a detailed analysis would be required to refine the actual amount. For comparison, the average depletion from the Yampa River is about 109,770 af (Stanford 1994) or approximately 10% of the mean annual flow.

In Colorado, actual depletions from the mainstem Little Snake River are unknown at this time. The irrigation water rights which constitute all the potential depletion from the river in Colorado total approximately 142 cfs (4 m^3/s). An additional 36 cfs (1 m^3/s) in conditional rights remain to be perfected. The total potential depletion by Colorado diversion is 178 cfs (5 m^3/s) from the mainstem Little Snake River.

The CWCB estimates that the average yearly Little Snake River flows at the Lily Gage adjusted for depletions is approximately 422,700 af. This compares with 428,000 af based on the historical record 1921 to 1984 (O'Brien 1987). Water depletion simulation conducted by Western Water Consultants for the Wyoming Water Development Commission in 1990 used a data base through water year 1982.

Table 2. Little Snake River Peak Flow Frequency at Lily Gage for Selected Return Periods

Station	2	5	10	100	500
Lily [a]	4,830 cfs (137 m^3/s)	7,300 cfs (207 m^3/s)	9,060 cfs (257 m^3/s)	15,110 cfs (428 m^3/s)	19,810 cfs (561 m^3/s)
Maybell [b]	9,670 cfs (274 m^3/s)	12,370 cfs (350 m^3/s)	14,550 cfs (412 m^3/s)	20,070 cfs (568 m^3/s)	23,700 cfs (671 m^3/s)

[a] Using Log Normal Distribution and the period of record 1923 to 1994

[b] Adapted from RCI (1991)

Table 3. Wyoming Monthly Depletions from the Little Snake River [a] (af)

Depletion	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Irrigation	216	0	0	0	0	0	0	1,224	4969	7,202	5,977	3,745	23,333
Municipal	3	3	3	3	3	3	8	8	8	8	8	8	66
Transbasin	286	258	245	226	191	199	507	4,257	6749	2,718	528	296	16,460
Total	505	261	248	229	194	202	515	5,489	11,726	9,928	6,513	4,049	39,895

[a] Adapted from CWCB draft report (1994)

Future Depletions

The CWCB draft report (1994) relied on the proposed Sandstone Reservoir Feasibility Report to estimate future depletions of the Little Snake River which included Sandstone Reservoir, additional irrigation acreage and increased in-basin municipal and industrial use. The additional annual depletion was estimated at 51,300 af which would increase the annual depletion to 91,200 af. This projected depletion represented approximately 21% of the average annual flow in the river. About 31% of the projected depletion would be diverted from the river during the peak flow month in May and 58% of the total projected annual depletion would occur during the May-June period. No other future depletions were identified at that time.

Sandstone Reservoir was the original water storage project for the Little Snake River basin sought by the Wyoming Water Development Commission. The project went through several iterations until it was finally approved in 2000. A brief history of the iterations follows. The planned location for Sandstone Dam was in the lower portion of Savery Creek, 16 km upstream from the Little Snake River. The original Sandstone Reservoir project was reviewed in a Draft Environmental Impact Statement (COE 1988), but in 1990, the Army Corp of Engineers (COE) recommended that a 404 permit not be issued because there was no identified specific use for 20,000 af of the project yield. The denial of the 404 permit was upheld again after review by the Corp in 1991. In 1992, the Wyoming Water Development Commission evaluated a smaller Sandstone Reservoir that would deplete 12,000 af per year, but in 1995, the COE indicated that they would not issue a 404 permit unless the project was the "least environmentally damaging alternative" and only if the project need was narrowly defined for a "supplemental late season irrigation water supply". The project was redefined to meet the requirements of COE, the name was changed to "Little Snake Water Supply Project", and High Savery Dam and Reservoir on upper Savery Creek was selected as the preferred alternative in 1997. The Final EIS for Little Snake Supplemental Irrigation Water Supply was completed in 1999 and a 404 permit for the preferred alternative was issued in 2000 (WWDC 2001).

High Savery Dam will be located about 68 km upstream from the Little Snake River confluence and the reservoir will have a total capacity of 23,443 af. Water will be stored during spring runoff and 12, 000 af of late-season irrigation water will be released from July 15 until September 15 in 8 out of 10 years. Minimum flow releases are planned to equal the lesser of natural inflow or 12 cfs (0.34 m^3/s) for aquatic habitat protection in Savery Creek. Average monthly discharge in Savery Creek will be reduced up to 89% as the reservoir fills in the spring and in late summer average monthly discharge will increase up to 1300%.

Average annual peak flow in Savery Creek will be delayed by 3 days on average and 25 days maximum and reduced by 165 cfs (4.7 m^3/s). Water diverted for irrigation will be lost because of evapotranspiration. This will result in a maximum reduction in average monthly discharge of 10% in April and a maximum increase of 23% in October in the Little Snake River at the "near Lily" gage. Average annual depletion in the Little Snake River will be 10,836 af. Salts in the Little Snake River are predicted to increase about 25% during base flow (Burns and McDonnell 1999).

Sediment Yield

The Little Snake River sediment load constitutes approximately 77% of the Yampa River sediment load in Deerlodge Park (O'Brien 1987). Roughly 60% of the total sediment load in the Yampa River is derived from the Little Snake River between Dixon and Lily (Andrews 1978). Andrews (1978) arrived at this conclusion by examining the difference in the computed average annual sediment loads based on the available data at the Dixon and Lily gages. This portion of the basin is underlain by relatively young, high erosion sedimentary formations. Very little information is available to quantify the sediment yield of the various tributaries of the Little Snake River basin. The four major tributaries draining this area were ranked by RCI (1991) in terms of sediment contribution as follows: 1) Sand Wash, 2) Muddy Creek, 3) Sand Creek, and 4) Powder Wash. Sand Wash and Muddy Creek were given relatively equal rankings. As was previously discussed, the poorly cemented sandstones, siltstones and mudstones combined with the effective rainfall and sparse vegetation generate a high sediment yield from these tributary basins.

Most of the available data base for determining sediment yield in the Little Snake River basin was collected at the Lily Gage between 1959 and 1964 when suspended load measurements were made on a daily basis (Table 1). This core sediment load data base is supplemented with sediment samples collected in the early 1950s and again sporadically throughout the 1970s and into the 1980s. The more recent sediment load measurements have been collected only once a month or a few times a year. Incidental sediment load measurements were also made in 1983 by the USGS (Elliott, et al. 1984) and in 1989 by RCI (1991).

Several analyses of the Little Snake River sediment load have been attempted including Andrews (1978 and 1986), O'Brien (1984 and 1987), Elliott, et al. (1984a and 1984b), Koch and Smillie (1984) and RCI (1991). All these analyses have included use of sediment rating curves (sediment discharge expressed as function of water discharge). Only Andrews (1978) and O'Brien (1987) analyzed the original Lily Gage sediment load data to derive sediment rating curves. These two analyses were not consistent in the use of the data base nor was the same functional relationship derived between sediment discharge and water discharge. All the other studies applied the rating curves derived by Andrews (1978) and O'Brien (1987) in some form. In addition, none of the studies examined all the available data for sediment load at Lily which now covers a 40 year period. Missing from these analyses is a consistent application of the sediment rating curve, projection of trends in the stream flow data, an investigation of sediment load variation by size fraction, and projection of trends in the sediment rating curves.

The Lily Gage sediment load analyses are summarized in Table 4. Andrews (1978) computed a mean annual suspended sediment load for the Lily Gage of 1.3 million tons. A total sediment load of 1.4 million tons per year was based on the sum of the suspended load and a computed bed load of 70,000 tons per year based on the Meyer-Peter and Müller bedload equation. Andrews (1978) did not provide the Lily Gage sediment rating curve in his publication. O'Brien (1984, 1987) computed the mean annual sediment load on the basis of the measured load and application of the sediment rating curve to the historic record. Elliott et al. (1984) and Butler (1988a and b) computed annual loads at Deerlodge Park which included the Yampa River sediment load; a separate analysis involving the Little Snake River was not conducted.

Table 4. Little Snake Sediment Load at the Lily Gage.

Source	Mean Annual Discharge	Suspended Load (tons/year)	Bedload (tons/year)	Total Load (tons/year)
Andrews (1978)[a]	575 cfs (575 m^3/s)	1,300,000	70,000	1,400,000
O'Brien (1984)[b]	-	1,341,300	-	1,340,000
O'Brien (1987)[c]	591 cfs (16.7 m^3/s)	2,020,000	-	2,020,000
Koch and Smillie (1984)[d]	-	1,901,000	-	1,901,000
Butler (1988a)[e]	547 cfs (15 m^3/s)	1,172,000	60,000	1,232,000
Butler (1988b)[f]	-	-	-	2,062,000

[a] Based on a load-duration analysis. Also reported in RCI (1991).

[b] Average annual measured load.

[c] Based on a regression analysis for 64 years of flow record (1921-1984) with a bias correction factor applied.

[d] Based on a normal distribution using a bias correction factor.

[e] Applied Andrews (1980) analysis.

[f] Computed by subtracting Andrews (1978) Yampa River total load from Butler's (1988) Deerlodge Park total load estimate.

Channel Equilibrium Concepts

The concepts of channel stability and equilibrium are important to the alluvial reaches of the Little Snake, Yampa and Green rivers. When the river channel morphology as governed by a variable sediment load is relatively constant over a long period, the river reach is considered to be in a state of dynamic equilibrium. A river system in dynamic equilibrium will experience small, local and relatively short-lived variations in the channel geometry that do not effect the overall channel morphology. When the sediment transport balance of an alluvial river reach is disrupted, long term sediment deposition or scour may induce widespread changes in the channel morphology (e.g. width-to-depth ratio). Andrews (1986), Butler (1988b), RCI (1991) and Lyons et a l.(1992) have all addressed the concept of channel equilibrium.

The concepts of alluvial channel equilibrium, channel stability and adjustment need to be defined in relation to appropriate time scales. Alluvial channels have a bed and bank composed of the sediment that is being transported by the river. According to Schumm (1977) stable alluvial channels are defined as river channels experiencing no progressive adjustment during the last ten years. The concept of an alluvial channel being in equilibrium as related by Schumm (1977) and alluded to by RCI (1991) refers to a channel that has attained a balance between its ability to transport sediment (sediment transport capacity) and the sediment being supplied to it over the long term. An alluvial channel in equilibrium is neither aggrading nor degrading although the channel itself may be incised. RCI (1991) also makes the distinction between alluvial sand-bed channels and alluvial cobble-bed streams.

River evolution can be viewed with different time scales. The geologist or geomorphologist may be interested in changes related to paleoclimate variation or tectonic uplift during a cyclic time span covering millions of years. These processes may induce dynamic equilibrium changes in the channel gradient over a very long time. On the other hand, the engineer often views the river in terms of the downstream effects of a dam on the order of tens or hundreds of years. A final, but important time scale is that of a steady-state, relatively short time span encompassing only several months or years. During a steady-state time span, the relationship between water and sediment transport and channel morphology and river habitat may appear to be more or less constant.

A river system over time is undergoing continual transition related to changes in climate, geology, topography, basin vegetation, and river management activities. Predicting a river's response to both short term perturbations in the system (e.g., dam construction) and long term gradual changes (climate variation or geologic evolution) is difficult at best and impossible if the changes in hydrology (discharge of water and sediment) and channel morphology can not be recognized or monitored. Analysis of a river's dynamic equilibrium is further complicated by the inability to separate the effects of water resource management and geologic or climatic controls. Furthermore, the complex response of a river system to short term influences (i.e., flow depletions) may mask other more important responses in the river system to environmental variables (e.g., rejuvenation of tributary headcutting during a wet climatic period). For these reasons, the dynamic relationship between river hydrology, river hydraulics, channel morphology and riverine habitat must be monitored over a long period of time to be able to discern definitive adjustments to water management activities in a basin.

The primary effect of upstream water development on channel morphology is to alter the relationship between water discharge and sediment transport in the river. Disruption of the dynamic equilibrium by a dam or water diversion can result in dramatic channel morphology and aquatic habitat changes which are then followed by a long period of adjustment to a new equilibrium condition. During the period of adjustment the river may appear to be in a state of dynamic equilibrium, but in reality the river is changing slowly and progressively in the downstream direction.

Throughout the Green River system, including the Little Snake River, the response of a given alluvial reach to water management is constrained by the geologic controls of canyon reaches. The Little Snake, Yampa and Green rivers are a blend of alluvial reaches and bedrock controlled reaches. The bedrock controlled reaches (of which there are several in the lower Little Snake basin) are confined by outcrops or have bedrock exposed at the river level which establishes the average stream gradient. The Little Snake River enters a narrow bedrock canyon at the Lily Gage and upstream of the gage the river channel is a wide, rather shallow sand-bed stream. The gradient of the sand-bed reach is partly controlled by the canyon entrance base elevation and therefore, this relatively short sand-bed reach has a limited range of potential slope and channel geometry adjustment to changes in upstream sediment supply.

Little Snake River Flows and Channel Morphology

The Little Snake River has a wide range of discharges and sediment loads typical of tributaries to the Colorado River. Peak flows have ranged from a low of 934 cfs (26 m^3/s) in 1934 to 16,700 cfs (473 m^3/s) in 1984 with a mean annual peak of 5,420 cfs (153 m^3/s) for the period of record 1923 to 1994. The mean annual sediment load varies from 440,000 tons to in excess of 3,000,000 tons. The Little Snake River is capable of delivering huge quantities of sediment in a relatively short period. In 1962, the sediment load during a four day period was 1,156,000 tons (O'Brien 1984).

The alluvial reach (Reach IV) of the Little Snake River extends approximately 65 km upstream from the Lily Gage. This is a predominately sand-bed reach which meanders through pasture and cropland valley bottomland and at low flow is a wide, anastomosing sand-bar channel. Large macroform bars appear which shift back and forth across the channel. Cottonwood and tamarisk seedlings grow in vast numbers on the exposed sand bars. During high flows the channel is active bank to bank and vegetation encroachment on the bars is minimal (FLO, 1994). The sand-bed channel is confined in some reaches by valley bedrock or alluvial hills.

Yampa River Flows and Channel Morphology

The Yampa River is the only major tributary in the Upper Basin whose flows have not been substantially altered by water resource development involving mainstem channel impoundment or significant water diversion. As such, the Yampa River still exhibits the basic diversity and integrity of habitat associated with highly variable flow conditions and sediment loads.

Downstream of the Yampa River and Little Snake River confluence is an 8-km long, sand-bed reach in Deerlodge Park. When the river enters Yampa Canyon, it begins a steep and tortuous descent of 72 km to a confluence with the Green River in Echo Park. The canyon channel morphology is dictated by geology and there are few areas of canyon bottomland floodplain. Much of the Yampa River in Yampa Canyon has boulder or bedrock substrate. The sand load from the Little Snake River and upstream Yampa River passes through the canyon with minimal opportunities for storage within the active channel.

Yampa Canyon provides a diverse variety of fish habitat ranging from runs in cobble riffles, boulder rapids, eddies, sand-bed pools, deep boulder holes and backwater habitat. In the lower half of Yampa Canyon, the river follows ancient meanders incised in soft Weber sandstone. Reaches of cobble substrate have evolved into a riffle-pool sequence related to river bend constrictions and canyon expansions. The cobble bars are energy dissipating structures that promote overall channel stability (O'Brien 1984). The cobble riffles around the bars are relatively free of sand despite the large sand load supplied by the Little Snake River. The peak sediment load lags the water discharge peak by several days in the lower canyon reaches because the sediment supply originates from the Deerlodge Park reach. Sand deposition occurs in the pools upstream of the cobble riffles during low flow and is scoured during the high spring flows. Some sand deposition occurs on the cobble bars and riffles during the peak flows (O'Brien 1984).

It was observed during the 1983 peak flow that portions of the cobble bars and riffles were covered by 0.15 m or more of sand. At low flow, this sand deposition affected the discharge distribution around bars. High flows on the recessional limb were required to flush sand from the interstices of cobbles (O'Brien 1984). The dynamics of removing the sand from the cobbles involving the incipient motion of the cobbles is discussed in Harvey et al.(1993). Generally, the flushing of sand from the cobbles without cobble mobilization is limited to a depth equivalent to the median coarse particle diameter (O'Brien 1984; Berry 1985). The cobble bars in Yampa Canyon in the vicinity of RK 26-29 were used as spawning habitat by Colorado pikeminnow (Tyus 1990).

The 8 km Deerlodge Park sand-bed reach is an important indicator of the dynamic relationship between the sediment load in the Little Snake River and dominant discharge of the Yampa River (Table 5). Upstream of the confluence of the two rivers, the Yampa River has cobble substrate. Immediately downstream of the confluence, the river is primarily sand-bed with a few exposed cobble and gravel bars. The sediment transport capacity of the Deerlodge Park reach controls the sediment load to Yampa Canyon. Deerlodge Park serves as a sediment storage reach. Sediment may build-up in this reach over several years then a large slug of sand enters the canyon during high flows.

Elliott et al. (1984) concluded that the Deerlodge Park reach was in sediment transport equilibrium, i.e., that neither aggradation or degradation were occurring over the long term because on an average basis the amount of sediment transport through the reach was equal to the amount of the sediment supplied to it. Based on the comparison of a survey of the area in 1922 and aerial photos in 1970, Elliott et al. (1984) determined that no significant changes in river planform or channel morphology had occurred beyond those typical of rivers transporting large sediment loads which results in bend migration and bar formation. In addition, it was observed by Elliott et al. (1984) that the river had not developed strath terraces which would suggest progressive down cutting, nor were there any overbank deposits that would indicate aggradation.

The Deerlodge Park reach is very active and monitoring channel morphology response to variations in the Little Snake River sediment load would greatly enhance the understanding of relationships between sediment transport and discharge for the two rivers. Over 12 m of lateral channel migration occurred at Deerlodge campground during the 1983 and 1984 high flows and new floodplain development occurred on the north side of the river across from the campground. Sometime between 1976 and 1982, the Little Snake river confluence moved approximately 0.8 km downstream. In 1983, during a fairly high flow year, 21 Yampa Canyon cross sections monitored in the spring and fall, indicated a net storage of sand in the canyon (O'Brien 1984).

To summarize, the Little Snake River contributes a large sediment supply to the Yampa River which eventually is delivered to the Green River. Storage of sediment can occur in Deerlodge Park and the dynamics of sediment transport through this reach determines the sediment load to Yampa Canyon. There is limited opportunity for sand storage in Yampa Canyon, but sand deposition on the lower cobble reach can affect habitat used by endangered and native fishes (O'Brien 1984).

Table 5. Measured Historical Sediment and Discharge Data[a]				
Water Year	Yampa River @ Maybell		Little Snake River @ Lily	
	Discharge af x 10^6	Sediment Load (tons/yr) x 10^6	Discharge af x 10^6	Sediment Load (tons/yr) x 10^6
1952	1.447	0.548	0.728	
1953	0.829	0.248	0.269	
1954	0.522	0.125	0.178	
1955	0.773	0.402	0.233	
1956	1.033	0.398	0.411	
1957	1.781	0.607	0.507	
1958	0.883	0.512	0.425	
1959				
1960	1.010		0.300	0.932
1961	0.629		0.163	0.438
1962	1.492		0.569	3.157
1963	0.630		0.204	0.958
1964	0.865		0.318	1.222

[a] From O'Brien (1987)

Green River Flows and Channel Morphology

The Little Snake and Yampa rivers combine to give the Green River its seasonal discharge variability at the Yampa River and Green River confluence. The release from Flaming Gorge Dam has not exceeded 4,600 cfs (113 m^3/s) in most years since 1963, therefore spring nursery habitats (e.g. backwaters and flooded bottomlands) are primarily created as a function of Yampa River peak flows. Endangered fish life stages and behavior such as spawning and utilization of nursery habitat in the Green River are related to spring runoff timing and flow duration which are highly dependent on Yampa River and Little Snake River flows (Nesler et al. 1988).

The sediment load in the Green River downstream of Jensen maintains the active channel in the alluvial reaches. The quantity of sand in this system in the form of active sand bars enables more frequent inundation of the floodplain. Without a consistent supply of sand to the reach of the Green River from Jensen to Ouray, Utah, channel degradation would ensue, bars would become stabilized by vegetation and attach to the bank, active channel width would be reduced, and flooding of bottomland and backwater habitat would be diminished. During the period since 1963, the Green River sediment load at Jensen has decreased by approximately 50% (Andrews 1986). The Little Snake sediment load constitutes approximately 60% of the sediment load at Jensen since the closure of Flaming Gorge Dam.

Once the sediment load from the Yampa River enters the Green River, the sediment is quickly transported downstream through Echo Park and Whirlpool Canyon. The next potential sand storage reach is Island Park/Rainbow Park just upstream of Split Mountain. At the upstream extent of this reach are several cobble and gravel riffles, the rest of the reach is a sand-bed channel whose sediment transport capacity determines the sediment load passing through Split Mountain and the Jensen gage. RCI (1991) referred to this reach as a sediment reservoir which may buffer the large sediment loads moving through the reach.

Downstream of the Jensen gage, the Green River enters a wide valley of relatively mild slope. This reach has bottomland nursery habitat for endangered larval fish drifting downstream. High sediment loads help keep the channel active with pulses of sand moving through the system in large macroform bars. With loss of the sand being transported through the system, the channel geometry has changed and the width to depth ratio has been reduced (FLO 1996). The Little Snake River sediment load is important to the Green River channel morphology downstream of the Jensen Gage.

Effects of Flow Regulation on Channel Morphology

Stanford (1994) posed a question of whether lost flooded bottomlands and nursery habitat in the Green River was caused by reduced sediment supply or lack of extreme flow events that would move large quantities of sediment. The answer is that both factors have contributed to the loss of flooded bottomlands. The 100-year period flood at Jensen was computed to be 51,200 cfs (1450 m^3/s) using pre-1963 peak flow data and 44,700 cfs (1266 m^3/s) using post-1963 data, indicating a decline in frequency of the higher peak flows. Similarly, 5-year return period flows declined from 30,000 cfs to 23,000 cfs (850-650 m^3/s). Data from the Green River, Jensen gage indicates a 50% decrease in sediment load from pre- to post-1963 (Andrews 1986).

Most large reservoirs in the West were constructed in the last 50 or 60 years and alluvial river channels downstream of these reservoirs may require several decades to adjust to the reduction in flow and sediment load. Williams and Wolman (1984) related observed changes in alluvial rivers downstream of reservoirs in the semiarid western United States and noted that channel degradation below the reservoirs was completed within the first twenty years after dam closure and that decreases in suspended load extended downstream for many kilometers. Generally, an alluvial river's geomorphic response approaches a condition of quasi-equilibrium relatively quickly after a disruption in the system, depending on the location of significant sources of sand in the system. Andrews (1986) stated that a century or more will be required for the Green River to adjust to the effects of Flaming Gorge Reservoir.

In addition to mainstem dams, small off-channel flow depletion projects can have cumulative impacts which may be superimposed on the mainstem response to upstream reservoirs. Butler (1988a) indicated that both large water projects and cumulative impacts of smaller projects in the upper basins have the potential to alter the sediment supply to downstream river reaches through streamflow regulation.

A number of reports discuss the potential impacts related to water resource development in the Little Snake River, Yampa River and Green River basins. Andrews (1978) projected an increase in sediment yield due to a potential increase in coal surface mining but confined his analysis to the Yampa River basin. He analyzed suspended sediment measurements collected at the Maybell and Lily Gages as well as the sediment records for 16 other gages in the Yampa River basin. Andrews concluded that the impact of increased sediment load will depend on where in the basin it enters the river channel.

In 1980, Andrews published an important paper on effective and bankfull discharge in the Yampa River basin which used his 1978 data base (Andrews 1978). This study addressed the concept of effective discharge and it's significance to the river channels in the Yampa River basin. The premise of the paper, as introduced by Wolman and Miller (1960), was that channel morphology characteristics, particularly meander length and channel width, were formed by relatively frequent flows and not by rare catastrophic events. Recurrence intervals for the effective discharges ranged from 1.18 to 3.26 years for 15 selected gaging stations.

Based on a Little Snake River cross section surveyed near Dixon, WY, Andrews (1980) determined that the effective and bankfull discharges were in close agreement and concluded that the stream channels were adjusted to the effective discharge. He further concluded that the channels appeared to be in quasi-equilibrium (dynamic equilibrium). Data from 15 gaging stations supported the correlation between effective discharge and bankfull discharge. Most of the stations were located in coarse bed cobble and gravel streams. For 65 km upstream of the Lily gage, the Little Snake River is a sand-bed river which is subject to potential channel adjustment from upstream water depletions.

Yampa River hydraulic and sediment transport data were collected during the period from 1982 to 1983 and the sediment load of the Little Snake River analyzed (Elliott et al. 1984; O'Brien 1984). O'Brien indicated that the most sensitive reach of the Yampa River to changes in the Little Snake River sediment load would be the Deerlodge Park reach. It was emphasized that channel response to reduced flows would be dependent on the revised shape of the seasonal hydrograph and the altered relationship between water and sediment discharge.

O'Brien (1984) used a mathematical model to simulate the potential effects of streamflow reduction on cobble substrate reaches in the lower Yampa Canyon. Based on the simulation and aggradation/degradation analysis for the Yampa River for 1983, a high water and sediment load year, there was approximately 288,000 af of water available that year that could be depleted without significantly impacting the relatively sand-free cobble substrate conditions in Yampa Canyon (O'Brien 1984). This analysis used the combined historical streamflow records at the upstream Little Snake River and Yampa River gages. There was no analysis of the potential impacts of flow reduction in either the Little Snake and Yampa rivers.

Elliott et al. (1984) collected suspended sediment, bedload and stream discharge measurements of the Yampa River at Deerlodge Park and reported that the river appeared to be in equilibrium in this reach. Mean daily discharge measured at Deerlodge Park was shown to be highly correlated with daily discharges recorded at the Lily and Maybell gages.

A sediment budget analysis was conducted by the USGS (Elliott et al. 1984) for the Deerlodge Park reach which was presented as a planning tool to determine combinations of discharge and sediment supply that would minimize channel adjustments. A matrix of flow and sediment reduction scenarios were analyzed by reducing the sediment supply by a prescribed percentage. Comparing the sediment supply and sediment transport capacity determined by the sediment rating curves resulted in a sediment budget for the Deerlodge Park reach. The results were intuitive; a large reduction in the assumed sediment load would promote channel bed degradation and a large percent reduction in streamflow would initiate bed aggradation.

There are two concerns regarding this type of analysis. First, the relationship between streamflow and sediment load are more complicated than presumed in the analysis because of the diverse areal distribution of sediment yield and water between the Yampa River and Little Snake River watersheds and second, because a reduction in stream flow may also be accompanied by a shift in the rating curve. One flow scenario analyzed the potential effects of altering the flows through Deerlodge Park by adjusting the historic flow duration curve to reflect the percent changes in flow duration of the Green River computed at the Jensen, Utah gage on the Green River following the construction of Flaming Gorge Dam. The analysis indicated that the alteration in the flow duration curve with no loss of annual flow volume would correspond to a surplus of sediment in the Deerlodge Park sediment budget. At least a 10% reduction in the sediment load would have to occur to create a deficit of sediment. This indicates that some reduction in the sediment supply to the Deerlodge Park reach must have occurred in the last thirty years as upstream flow depletions increased to 10%. The USGS report (Elliott et al. 1984) did not address the potential effects of flow or sediment reductions in the individual rivers.

Andrews (1986) reviewed the historical sediment load data in the Green and Yampa rivers to determine the effects of Flaming Gorge Reservoir on the Green River downstream of the Yampa River confluence. He noted that the reservoir did not significantly affect the mean annual runoff but that the duration of large discharges that transported most of the sediment had been severely curtailed. At the Jensen and Green River, Utah gages the sediment load had decreased by 54% and 48% respectively. Andrews stated that the channel morphology quasi-equilibrium that was apparent prior to Flaming Gorge construction no longer existed. He concluded that although a balance between the sediment supply and sediment transport capacity had been attained in the reach from the mouth of the Yampa River to the Duchesne River confluence, an adjustment of the channel morphology downstream of the Jensen gage was incomplete in 1978. He indicated that perhaps 30 years would be required to attain an expected value of the channel width based on post-reservoir effective discharges. The channel width was estimated to have decreased by 13% in his study reaches.

Andrews' analysis of the Jensen and Ouray gage sediment loads indicated that an average of 2.4 million tons/yr have been deposited and he concluded that substantial aggradation had occurred in this reach since the construction of Flaming Gorge Dam. He surmised that the aggradation may be concentrated within a short distance upstream of the Ouray gage. Based on recent channel surveys; however, it appears that the Ouray Wildlife Refuge reach has been subjected to some channel degradation related to changes in the width to depth ratio (FLO 1986; FLO 1996). This was verified through review of 1963 aerial photos.

The reduction in sediment load at Jensen from 6.21 to 3.21 million tons/yr following the construction of Flaming Gorge Dam is attributed to a decrease in effective discharge from 20,500 cfs (580 m^3/s) pre-1963 to 11,500 cfs (325 m^3/s) post-1963. (Andrews 1986). The Yampa River has a comparable effective discharge of 11,500 cfs (325 m^3/s, O'Brien 1984). An analysis should be conducted to determine if there has been a decrease in sediment supply from the Yampa River, post-Flaming Gorge, because the Little Snake River contributes approximately 60% of the sediment load at Jensen.

O'Brien (1987) analyzed historical sediment data to assess potential impacts of flow reductions in the Yampa River downstream of the Little Snake River confluence. This study analyzed the sediment supply from the Little Snake and Yampa rivers and compared them to sediment loads predicted by sediment rating curves derived by O'Brien (1984) and Elliott et al. (1984). The rating curves were represented by a power regression relationship between sediment discharge Q_s and water discharge Q:

$$Q_s = a\,Q^b$$

where a is a regressed coefficient and b is the regressed exponent. This power function was based on a log-log transformation using a least squares fit to the data. This regression method under-predicts sediment loads and the inaccuracy increases with rating curve data scatter and it therefore is necessary to apply a bias correction factor to the regression coefficient (Ferguson 1986; Koch and Smillie 1986). O'Brien (1987) re-computed annual sediment loads at the Lily and Maybell gages for the entire period of record 1921 to 1984 with this correction and predicted Little Snake River mean annual sediment load increased from approximately 1.3 million tons per year to 2.0 million tons per year (Table 4). The Yampa River predicted mean annual sediment load remained essentially unchanged (407,000 tons per year measured to 389,000 tons per year based on the corrected regression analysis). Whereas Elliott et al. (1984) and Andrews (1978) did not apply a bias correction factor, O'Brien (1987) and Koch and Smillie (1986) did apply the bias correction factor to the Lily Gage data base and computed comparable sediment loads.

Based on the sediment rating curve derived for Mathers Hole, O'Brien (1987) showed that the sediment moving through Yampa Canyon was approximately equal to the upstream supply. This was confirmed by applying the sediment rating curves for the Lily and Maybell gages to the daily discharge for the period from 1921 to 1984 to compute an annual sediment load and then comparing it to the Mathers Hole predicted sediment load. The difference in average annual upstream sediment supply and the sediment load predicted by the Mathers Hole regressed rated curve was only 5%. The sediment load in Yampa Canyon is therefore supply limited and depends on the sediment transport capacity of the Deerlodge Park reach.

O'Brien (1987) attempted to determine the effects of water depletions from the Yampa and Little Snake rivers by reducing the annual hydrographs in each river and computing a sediment budget based on the mean daily sediment loads calculated with the sediment rating curves. The drawback of this analysis is that the Mathers Hole sediment rating curve data is limited to two years of data and the rating curve data at the gages may have been shifting over the period of record. O'Brien (1987) concluded that some sediment storage should be expected if the Yampa River was depleted by 100,000 af per year or more while Little Snake River flows were undiminished.

Two reports were prepared by Butler (1988a and 1988b) which address the Little Snake River flows and effects of reduced stream flows. The first report addressed the potential impacts of the proposed Sandstone Reservoir on the sediment transport characteristics of the Little Snake, Yampa and Green rivers. The proposed Sandstone Reservoir would not trap significant quantities of sediment because of its relatively small reservoir storage pool (52,000 af) and its location upstream of major sediment producing tributaries. But Sandstone Reservoir would decrease river discharge approximately 32,000 af per year (about 8% of the annual flow). High Savery Dam is predicted to trap about 1.5% of the sediment previously delivered to the Yampa River and the reservoir will deplete an estimated 12,000 af per year or about 3% of the annual yield of the Little Snake River (Burns and Mc Donnell 1999).

Butler (1988a) applied previously derived, uncorrected sediment rating curves from Andrews (1980) and Elliott et al. (1984) to assess changes in Little Snake sediment load. Historical baseline data (with existing depletions) and project operation data were analyzed for 1930 through 1982. A decrease in sediment load in the Little Snake River of 32% (157,900 tons/yr) was predicted using the proposed Sandstone project flow duration curves and monthly project operation schedules. He also estimated a decrease of 18% in the effective discharge. Wyoming's Biological Assessment estimated a 14.7% potential decrease in suspended sediment load at the Lily Gage based on mean monthly flows for the same project period (Butler 1988a). Without the bias correction factor for the sediment rating curves the sediment load at the Lily Gage is underestimated by 40%. The potential effects of water depletion on the sediment load may be understated in Butler's analysis.

The prediction by Butler (1988a) that the proposed Sandstone project would reduce the sand load of the Little Snake River by one-third of the historic yield requires some clarification, especially with its implication for the effects of the High Savery project. High Savery Reservoir would not affect sediment delivery to the Little Snake River from the four high sediment yielding tributaries because it would be located upstream of the tributary confluences with the mainstem river. Water depletion attributed to the High Savery project would however decrease the sediment transport capacity in the reach from Dixon to Lily. This would result in aggradation of this reach until a balance was struck between tributary sediment loading and sediment transported out of the reach to the Yampa River. Once a new equilibrium condition is reached, the mean annual sediment load to the Yampa River should approach pre-project levels. Butler assumed that the Little Snake River is currently adjusting to existing depletions by aggrading the channel. Recent channel cross section surveys do not show evidence of an aggrading stream bed (FLO Engineering 1994b).

Based on the analysis of sediment sizes transported at the Jensen and Lily gages, Butler (1988a) estimated that the Little Snake River has averaged 548,000 tons/yr of sand-sized sediment (53% of the Green River Jensen gage sand load). This estimate would be much greater if the bias correction factor for the rating curve is applied. He concluded that the depletions from the Sandstone project would impact the Green River over the long term and that combined with depletions from the Yampa River would adversely impact habitats utilized by endangered fish.

Butler (1988b) attempted to 'pull together' a number of basin wide and site specific investigations of the Yampa River involving sediment transport measurements and sediment budget analyses. He indicated that various mathematical modeling efforts should be viewed in terms of trends, not in terms of absolutes. It was emphasized that if any of the physical processes of the prevailing river system were stressed too greatly then the sediment rating curves which define the sediment budget may become invalid. This is a valuable observation and it should be noted that the sediment rating curves for the important gages in the Green River system have not been analyzed for trends in the relationship between sediment load and discharge.

Butler (1988b) used existing data of USGS, Elliott et al. (1984), and O'Brien (1984) from Deerlodge Park and Mathers Hole to prepare a sediment budget to predict flow hydrographs for sediment transport equilibrium conditions in this reach of the Yampa River. This effort was an extension of the work performed by USGS (1984) and used the total sediment load to evaluate potential impacts of reduced streamflows. He assumed that the difference between predicted daily sediment loads at Deerlodge Park and Mathers Hole represented a surplus or deficit in this reach. The sediment budget program applied a synthesized record derived from the Maybell and Lily gages daily discharges for the period from 1941 to 1986. A Yampa River water project flow depletion analysis was developed for the Nature Conservancy by Wheeler (1987). Butler applied this analysis as a possible worst case scenario for Yampa River flow depletions.

Butler (1988b) used the results of this study to indicate that if the timing or magnitude of the peak flows at Deerlodge Park are significantly altered then the sediment distribution in the system would be effected. He showed that regulating flows of the Yampa River upstream of the Little Snake River without diminishing the Little Snake River sediment load would cause aggradation in the Deerlodge Park reach. He also used the analysis to demonstrate that a sediment transport balance can be achieved at various combinations of annual water yield and sediment load, but qualified his conclusion stating that the new sediment balance would be accompanied by channel adjustments.

There are several important aspects of Butler's study that should be highlighted. First, he established a basis for identifying low, average and high flow years. These flow delineations were computed using a log-Pearson Type III probability distribution for the period from 1921 to 1986 to assign a return period to the mean annual flow as follows:

Low flow year = 1.25 year return period = 1,530 cfs (43 m^3/s)
Average flow year = 2 year return period = 2,140 cfs (61 m^3/s)
High flow year = 5 year return period = 2,750 cfs (78 m^3/s)

Butler (1988b) used the period 1941 to 1986 to conduct his sediment budget analysis because of missing records. It should be noted that these records were missing from the computer data base WATSTOR but were not missing from the USGS Water Resource published records. Future analyses should use the entire record.

Another valuable contribution in this work was Butler's discussion and use of the bias correction factor to adjust the sediment loads predicted with regressed power functions as previously discussed for the Lily and Maybell gage data. Butler (1988b) estimated a mean annual sediment load of 2.6 million tons per year at Deerlodge Park. O'Brien (1987) estimated the average annual suspended load of 2.02 million tons per year at the Lily gage. Adding an average annual Yampa River suspended sediment load of 389,000 tons and a 5% bedload, the total sediment load for the combined rivers will be in excess of 2.5 million tons per year. It should be noted that the application of the bias correction is not valid for all data bases if the data are not normally distributed, if the log-transformed rating curve is not linear, or if the scatter does not have the same residual variance at all discharges (Ferguson 1986).

Butler (1988b) recognized that the sediment budget analyses are only as accurate as the rating curves on which they are based. The rating curves produced by O'Brien (1987) and Elliott et al. (1984), for example, were based on just two years of data and one of those years was an extremely high flow year. Butler also inferred that a minimum streamflow hydrograph cannot be characterized by volume or peak discharge alone, both the frequency and duration of the peak flows are also important. He concluded that the effects of changing sediment loads are not limited to Yampa Canyon, and that "...changes in the total sediment yield will affect the Green River."

Rivers in disequilibrium between channel geometry and sediment transport are the norm rather than the exception according to Andrews and Nelson (1989). Such disequilibrium can be persistent over a period of decades. Andrews and Nelson (1989) reported that the mean annual sand-sized sediment load decreased from 2.3 million tons/yr pre-reservoir to 0.84 million tons/yr post-reservoir at the Jensen gage (a 64% decline). Despite this decrease, they concluded that an approximate equilibrium had now been attained between the sediment supplied and sediment transported out of the Green River reach from the confluence with the Yampa River to the confluence with the Duchesne River. Their reason for the decrease in the mean annual sediment load at the Jensen gage for the period 1962 to 1982 when compared to the pre-reservoir period was the decrease in the magnitude of flows equal to or exceeded less than 30% of the time. They inferred that there was no change in the overall sediment supply to the Green River. They further claimed that the bankfull channel has adjusted slowly to the decrease in peak flows.

Schumm and Gellis (1989) reported that sediment loads in the Colorado River system have been declining since the late 19th century and early 20th century when arroyo development (incision) resulted in a high sediment load in the Colorado River. The annual sediment load in Grand Canyon has displayed a marked decrease since 1942. Some of the decrease may be attributed to soil conservation efforts and flood control, but Schumm and Gellis (1989) indicate that the sediment load reduction was a progressive trend that is masked by major flood events and drought years. They conclude that over the course of river basin evolution, sediment yield is high for periods of channel incision and then sediment loads decrease logarithmically as the channel approaches a new period of stability.

RCI (1991) undertook a comprehensive study to establish baseline hydrologic and sediment transport information for the Little Snake, Yampa and Green rivers. The focus of the study was to analyze the potential adverse effect on endangered fish habitat as a result of channel morphological changes. The report concluded that climatically, temperatures throughout the study area have increased during the period 1895 to 1989. It also stated that there has been a general decline in sediment loads in the rivers draining the Colorado plateau.

RCI (1991) suggested that the reduction in sediment load in the Green River attributed to the closure of Flaming Gorge Dam (Andrews 1986) was partly due to other factors such as climatically induced sediment storage within the tributaries to the Green River. RCI (1991) inferred that this decline in sediment loads throughout the Colorado basin casts doubt on the equilibrium status of the Green River prior to Flaming Gorge Dam construction reported by Andrews (1986). RCI (1991) also concluded that the cause and effect relationship between Flaming Gorge flow regulation and channel narrowing (and the loss of backwater habitat) was the result of reduced peak flows and reduced transport capacity and was not the result of a change in sediment supply.

RCI (1991) proposed that the response of the Little Snake River to potential projects in the upper watershed may be similar to the Green River response to Flaming Gorge. The primary sediment source areas in the Little Snake River Basin; however, are downstream of proposed water projects such as High Savery Reservoir. Therefore, the impact would be a reduction in transport capacity resulting in aggradation in the lower Little Snake River channel. This portends a decrease in sediment yield to the Yampa River. RCI quotes Butler (1989) as stating that Sandstone would reduce sand loads to the Yampa River by about 12% over baseline conditions and 32% over historic conditions. This reduction in sediment load may impact the Green River, but RCI states that it is inappropriate to assume that the impacts on the Green River resulting from water development on the Little Snake River will be similar to the impacts of Flaming Gorge on the Green River.

RCI (1991) also reported on the application of a bias correction factor to the rated curves. The bias correction for the log transformation of the regressed sediment load and discharge data tended to over predict the mean annual sediment load whereas the uncorrected rating curves underestimated the mean annual sediment load. As a result RCI (1991) only applied the bias correction to discharge data greater than 2,000 cfs (57 m^3/s). This was justified on the basis that the sediment load for discharges less than 2,000 cfs (57 m^3/s) is minimal. It should be noted that O'Brien (1987) adjusted the bias correction factor to reproduce the measured mean annual sediment load for the 5 years of data collected at the Lily gage.

Lyons et al. (1992) investigated the Green River sediment transport data, aerial photography, channel width surveys, and previous studies analyzing the post-reservoir Green River morphology from about Jensen to Ouray for the period 1952 to 1987. This included an extensive analysis of Andrews' 1986 data on channel width changes. Bed material load mass balance and effective discharge was also evaluated. A review of the aerial photos from 1952 to 1964 confirmed that the active channels were more or less constant during this period (Lyons, et al. 1992). Andrews (1986) had concluded that a quasi-equilibrium existed between sediment load and channel morphology pre-Flaming Gorge. RCI (1991) had suggested that over the long term the river may not have been in equilibrium pre-Flaming Gorge. From his analysis of post-reservoir aerial photos, Lyons et al. (1992) concluded that channel narrowing was essentially complete by 1974. This statement conflicted with Andrews conclusions that adjustment of the channel width downstream of the Jensen gage was incomplete in 1978. The overall conclusion drawn by Lyons et al. (1992) was that channel changes initiated by the construction of Flaming Gorge Dam occurred soon after operation of the reservoir began. Recent work indicates that channel narrowing is continuing in this reach (FLO 1996).

Stanford (1994) introduced a few concepts to guide instream flow studies. He indicated that the relationship between channel flows and flooded bottomlands should be assessed through the response of the system to a range of discharges and sediment loads. Flooded bottomlands should not be evaluated with a simple stage-area relationship. Flushing flows are needed to scour sediment and vegetation from low velocity habitats. Conversely, flushing flows may actually degrade the channel and further reduce flood frequency owing to reduced sediment loads in the system. If peak flows are unsuccessful in creating diverse habitat and complex channel features that passively retain drifting larvae, then the larvae can be swept out of the nursery habitat by the high flows. Occasional flows approaching the flood of record are required to reform and integrate the full suite of channel and floodplain features. Stanford stated that peak flows should approximate the range and frequency of pre-reservoir events. Another recommendation by Stanford was that no further depletion of flows delivering water to the Yampa Canyon should occur suggesting no future depletion of Little Snake River flows would be acceptable.

Hydrologic Data Deficiencies

One of the main conclusions of the Stanford (1994) report was that resolution of flow regime uncertainties requires a greater understanding of the coupling of flow processes and riverine bioproduction involving the flooding of bottomlands. He recommended that several specific reaches be selected that include a full range of channel morphology components and their responses to variable flow conditions be monitored in detail. He also suggested that alluvial reaches be selected over canyon reaches because they support a greater diversity of the habitat associated with flooded bottomlands.

It is unfortunate that some of the important USGS gaging stations have been discontinued or have had sediment data collection terminated. Sediment data would have quantified the sediment movement in the Green River system post Flaming Gorge. Specifically, the Ouray, Utah gage on the Green River, the Deerlodge Park gage on the Yampa River and the Dixon gage on the Little Snake River were terminated and daily sediment load measurements were curtailed at the Green River Jensen gage and the Little Snake River, Lily gage. Reestablishment of these gages as well as resumption of sediment load measurements at Lily and Jensen gages during the high flow periods is important. Bi-monthly measurements would suffice during the low flow season. Sediment data collection should also be done at Ouray and Deerlodge Park gages.

Little Snake River peak flow duration, frequency and timing should be analyzed. Flow duration curves derived by Butler (1988a) should be updated and analyzed for various periods to reveal the effects of flow depletion from the upper basin. The flood frequency return periods and peak flow timing should be compared with Yampa River and Green River hydrographs.

Future water use trends in the Green River system should be documented. The Bureau of Reclamation and the various conservancy districts should be contacted to compile this information. It is suggested that the cumulative depletion from the Little Snake, Yampa and Green rivers be plotted to illustrate when depletions have had the greatest impact. Tributary depletions should be analyzed to realize the greatest benefit from Flaming Gorge releases in the Lower Green river. To further investigate the effects of depletion, double mass curves should be plotted for the important gages: Lily, Maybell, Jensen, Ouray and Green River. The double mass curves will assist in visualizing trends in the flow record. Five year running averages are also an effective tool to investigate long term trends in the flow record.

Reports by Andrews (1978, 1986), O'Brien (1984), Elliott et al. (1984), and Butler (1988a) all provide estimates of the mean annual sediment load at various gages in the Green River system. The gage with the greatest variability in the sediment load estimates is the Lily gage on the Little Snake River. The variation in the prediction of the sediment load is associated with the large scatter in the data. Recent attempts by O'Brien (1984), Koch and Smillie (1986), and Butler (1988a) to apply bias correction factors to the sediment rating curves have resulted in much higher estimates of the mean annual sediment loads.

The relationship between the sediment loads in the Green, Yampa and Little Snake rivers and the response of the channel morphology in the Green River downstream of the Jensen gage should be investigated. Andrews (1986), RCI (1991) and Lyons, et al. (1992) have analyzed the historic data and reached conflicting conclusions regarding whether the Green River channel downstream of Jensen is narrowing, aggrading, has reached equilibrium or will require decades to complete adjustment to the flow regulation of Flaming Gorge Dam. Complete analysis of the historic sediment load and discharge relationships at the gage stations is required. The original sediment load measurements will have to be reviewed to determine sediment load by size fraction. The rating curves should be analyzed and updated to remove bias related to data scatter or low-flow data. An analysis of trends in the sediment load data is also required to assess the changes in channel morphology due to water development.

Various studies have indicated that the sediment load reduction at the Green River Jensen gage is the result of a decrease in the effective discharge and a reduction in the large infrequent discharges that move the greatest quantities of sediment. It was reported by Andrews (1986) that the sediment supply from the Yampa River had not diminished, however, both the Little Snake and Yampa rivers have experienced flow depletions of about 10% which has affected the sediment supply of the Green River.

The sediment yield in the Little Snake River basin constitutes 60% of the sediment load at the Green River Jensen gage. The Little Snake River sediment load should be defined by size fraction and the sediment rating curve data should be analyzed for trends. The tributaries should be analyzed for sediment yield, bed material size fractions and the condition of the drainage in terms of erosion potential. The Little Snake River sediment load based on Sandstone Dam depletions by Butler (1988a) should be revisited based on High Savery Dam depletions. Since the High Savery Dam is upstream of the major sediment sources, the response of the Little Snake River mainstem should be analyzed for potential aggradation or degradation.

Socioeconomic issues and land use practices such as grazing history of the basin, irrigation practice and water diversion should be investigated. Extensive grazing near the turn of the century throughout the West may have contributed to arroyo incision, upland erosion and sediment yield (Schumm and Gellis 1989).

Changing grazing and land use practices should be documented and related to sediment yield trends at the Lily gage.

Summer thunderstorm intensity and the effects on runoff and sediment loading in the Little Snake River Basin needs to be investigated. In the 72 years of record a total of four annual peak flows are the result of summer thunderstorms (one storm occurring as late as September 27, 1959). In addition, there have been two annual peak flows that have occurred in March. The size of the lower ephemeral tributary drainages are sufficient to contribute significant quantities of sediment during infrequent large convective storms centered on some of the tributary basins. The potential for sediment loading during thunderstorms should be evaluated in terms of sediment volumes, timing and potential storage in the mainstem Little Snake River.

Channel Monitoring

A channel monitoring program was initiated in the Little Snake River in 1994. Two sets of cross sections were established, one set of six cross sections in the sand-bed reach upstream of the Lily Gage (RK 15) and one set of eight cross sections in the cobble-gravel bed reach (RK 102) upstream of Powder Wash road (FLO 1994b). Until the establishment of these cross sections there was no existing data base with which to assess channel response to changing flow regimes and sediment loads. Some of this sand-bed reach is punctuated by exposed bedrock, cobble and gravel substrate. The various reaches of the Little Snake River should be documented with some detail. Additional cross sections in areas of importance to endangered fishes should be added to establish a baseline channel monitoring system.

In 1983, 21 cross sections were established and monitored at three different flow events throughout Yampa Canyon (O'Brien 1983). Some of the cross sections would be useful in determining the relationship between Little Snake River sediment loads and Yampa Canyon channel morphology. The cross sections can be used to evaluate channel aggradation or degradation, narrowing or widening patterns during the last 12 years. None of these cross sections were established with permanent markers but they could be still replicated and permanently marked because the crew establishing the cross sections is still available. The Colorado pikeminnow spawning bar cross sections in Yampa Canyon have now been permanently established. These 13 cross sections were concentrated in a limited 5 km reach in the lower canyon.

Six cross sections were established in the Deerlodge Park reach of the Yampa River in 1984. The sediment transport capacity in the Deerlodge Park reach determines the sediment supply to Yampa Canyon. A resurvey of these six cross sections would answer questions regarding the channel equilibrium and morphology response of this reach. The cross sections should be permanently established and perhaps supplemented with several more cross sections.

Channel monitoring sites in the Green River include four cross sections at Echo Park, 23 cross sections near the razorback sucker bar near the Dinosaur Quarry and Escalante Wetland (FLO 1993 and 1994a), 31 cross sections in the vicinity of the Ouray Wildlife Refuge, and 21 cross sections in Canyonlands National Park. Other researchers have established cross sections in Desolation Canyon and Lodore Canyon whose data should be compiled into a common data base. Additional bottomland areas have been considered for cross section monitoring and will be surveyed in the future. Within a year or two, a channel monitoring program should be firmly established throughout the Little Snake, Yampa and Green rivers.

As the channel monitoring program is expanded, channel morphology response to varying sediment loads can be documented. The Corps of Engineers HEC-2 water surface profile program can be applied to each reach of cross sections to compute water surface elevations associated with bankfull discharges. Bottomlands flooding can be evaluated through the application of curves relating the area of inundation as a function of discharge. Cross sections should be monitored three times: pre-spring runoff, just after the peak flow, and at low flow in the late summer. Cross sections should be re-surveyed during above average and below average years.

The hydraulic program should correlate variation in sediment load with channel morphology response. Water surface simulation with the HEC-2 model can be supplemented by water and sediment routing. The HEC-2 model can also be used to predict average velocity, flow depth, water surface gradients, and other hydraulic parameters to assess channel habitat. Stanford (1994) cautioned researchers that regime analyses too often rely on untested assumptions that some discharge is assigned as the dominant or channel-forming flow. By analyzing a series of cross sections and monitoring those cross sections through several seasons of high flows, channel morphology changes can be evaluated for their effect on bankfull discharges and flood stages.

Channel Morphology

Channel geometry (width/depth ratio) is strongly affected by the type of sediment load. Bedload dominated channels tend to be very active, wide, and shallow. In a stream where the suspended load is dominant, the channel tends to be deep and narrow. A reduction in sediment load can significantly affect channel morphology and fish habitat depending on the dominant type of transport. The channel geometry effects can be complicated by vegetative encroachment and water resource development. The consequences of a reduction in sediment load are more emergent sand bars, deeper thalwegs, an incised channel, a more sinuous channel, increased channel conveyance, reduced flood stage, and reduced flooding frequency.

Suspended load has decreased by approximately 50% or more at Jensen (Andrews 1986). Reviewing the historical Jensen gage, suspended load data will help to identify the nature of sediment load decrease. The relationship between the Little Snake River sediment size distribution at the Lily gage and the Green River Jensen gage sediment size data can be established to further evaluate the decrease in sediment load on channel morphology. Understanding sediment load patterns and shifts will assist in the analysis of instream flow requirements.

This analysis of sediment load should be accomplished on a system-wide level. It is important to relate the characteristics of the Little Snake River sediment load to the sediment load in the Green River at Jensen assessing trends of sediment movement through the system and its potential impact on fish habitat.

FISHERIES REVIEW

Fishery Collections

Eight references were found that contained Little Snake River fishery information for the warm-water reaches mainly in Colorado. In the 1950s, the Colorado Division of Wildlife (CDOW) electrofished the Little Snake River and several tributaries in the upper reaches to evaluate trout and other gamefish habitat (Baily and Alberti 1952; Klein 1957). Holden (1973) sampled most rivers of the Upper Colorado River Basin including the Little Snake River in 1971. He seined several, sandy bottomed sites in the summer but did not report sample locations or number of fish collected (Holden 1973; Holden and Stalnaker 1975). In 1981, the lower 14 km (Reaches I-III) were sampled between April and October with opportunistic boat electrofishing and seining (Miller et al. 1982). In 1988, from May through July, the lower 56 km (Reaches I-IV) were sampled with trammel net, seine, and angling (Wick and Hawkins 1989b). Most of their effort was concentrated in the Canyon (Reach III) and all seine collections were from one trip in June. Also in 1988, telemetered Colorado pikeminnow were monitored after they moved from the Yampa River into the Little Snake River (Wick et al. 1991). On August 20, 1990, Marsh et al. (1991) sampled RK 135 with experimental gillnets. In 1994 and 1995, the lower 121 km (Reaches I-V) were sampled from May through October with trammel net, cast net, angling, electrofishing, seine, and dipnet (Hawkins et al. 1997; Hawkins et al. 2001). In 1995, two humpback chub were caught in the Little Snake River, implanted with transmitters, and monitored from June through September (Hawkins et al. 2001).

Species Composition and Abundance

Seventeen fish species and four putative hybrids were caught in the lower 150 km of the Little Snake River, in the five years when data were reported (Table 6). Seven species were native to the basin, including two endangered fishes: Colorado pikeminnow and humpback chub (Table 6). Ten species were nonnative to the Little Snake River, including only two gamefish: channel catfish (*Ictalurus punctatus*) and black bullhead (*Ameiurus melas*). Based on number of fish collected, the Little Snake River fish community was composed predominately of native species. In 1981, 64% of all individuals captured were natives; in 1988, 96% were native; in 1994, 69% were native; and in 1995, 72% were native (Table 7). Number of fish was not reported for 1972 collections (Holden and Stalnaker 1975).

Large-bodied species were those that attain adult size at ≥200-mm total length and small-bodied species were those that attain adult size before 200-mm total length (Hawkins et al. 2001). Large-bodied species captured in the Little Snake River included native Colorado pikeminnow, humpback chub, bluehead sucker (*Catostomus discobolus*), flannelmouth sucker (*C. latipinnis*), and roundtail chub (*G. robusta*) and nonnative white sucker (*C. commersoni*), common carp (*Cyprinus carpio*), and channel catfish. Five Colorado pikeminnow were collected in 1981, 1988, and 1995 and eleven humpback chub were collected in 1988 and 1995 (Table 7). Details of endangered fish captures will be discussed later. Few large juveniles or adults of large-bodied species were collected in 1981 because the sampling gear (seine) targeted smaller fish (Table 8). In 1988, 1994, and 1995, additional types of sampling gear (e.g. trammel net, electrofishing, and angling) targeted juveniles and adults of large-bodied species and in each of those three years, native bluehead sucker, flannelmouth sucker, and roundtail chub were the most abundant large-bodied species collected (Table 7). These three large-bodied native species consistently outnumbered large-bodied nonnative species in each year (Table 7). Large-bodied nonnative species such as common carp, channel catfish, and white sucker were few in number most years and young fish of these species were seldom, if ever, collected. Larvae of bluehead and flannelmouth sucker matched these trends and were generally very abundant each year while larvae of large-bodied nonnative species were few or absent in collections (Tables 8-11).

Small-bodied species (adults <200 mm total length) captured in the Little Snake River included native mottled sculpin (*Cottus bairdi*) and speckled dace (*Rhinichthys osculus*) and nonnative fathead minnow (*Pimephales promelas*), red shiner (*Cyprinella lutrensis*), redside shiner (*Richardsonius balteatus*), sand shiner (*Notropis stramineus*), and creek chub (*Semotilus atromaculatus*). Mottled sculpin were captured only in 1994 and 1995, but their low abundance was probably because they live in riffles that were infrequently sampled (Hawkins et al. 2001). Speckled dace comprised over 10% of the fish captured in all years except 1988 when they comprised only 1% of the fish collected. Small-bodied nonnative species were often extremely low in number and in many years small-bodied larvae were not collected (Tables 8-11). Only two nonnative species, redside shiner and red shiner, comprised more than 10% of the fish captured in any given year; all other nonnative species comprised a much smaller portion of the fish community (Table 7). Larvae of small-bodied species were also relatively rare. Only in 1981 did larval small-bodied nonnative species comprise over 10% of the larvae collected, when red shiner and sand shiner each comprised 15% of the larvae collected (Tables 8-11). In other all years (1988, 1994, and 1995), larval small-bodied nonnative species comprised 1% or less of the larvae collected, except in 1995 when larval sand shiner comprised 9%.

Table 6. Fish species in the Little Snake River, Colorado.

Common Name	Scientific name	Status
Family: Cottidae (sculpins)		
mottled sculpin	*Cottus bairdi*	native
Family: Catostomidae (suckers)		
bluehead sucker	*Catostomus discobolus*	native
flannelmouth sucker	*Catostomus latipinnis*	native
white sucker	*Catostomus commersoni*	nonnative
flannelmouth sucker x bluehead sucker	*C. latipinnis* x *C. discobolus*	native x native, hybrid
flannelmouth sucker x white sucker	*C. latipinnis* x *C. commersoni*	native x nonnative, hybrid
bluehead sucker x white sucker	*C. discobolus* x *C. commersoni*	native x nonnative, hybrid
Family: Cyprinidae (minnows)		
common carp	*Cyprinus carpio*	nonnative
Colorado pikeminnow	*Ptychocheilus lucius*	native, endangered
fathead minnow	*Pimephales promelas*	nonnative
humpback chub	*Gila cypha*	native, endangered
roundtail chub	*Gila robusta*	native
humpback chub x roundtail chub	*G. cypha x G. robusta*	native x native, hybrid
red shiner	*Cyprinella lutrensis*	nonnative
redside shiner	*Richardsonius balteatus*	nonnative
speckled dace	*Rhinichthys osculus*	native
sand shiner	*Notropis stramineus*	nonnative
creek chub	*Semotilus atromaculatus*	nonnative
Family: Ictaluridae (catfishes)		
black bullhead	*Ameiurus melas*	nonnative gamefish
channel catfish	*Ictalurus punctatus*	nonnative gamefish
Family: Cyprinodontidae (killifishes)		
plains killifish	*Fundulus zebrinus*	nonnative

Table 7. Percent composition of fishes collected between 1972 and 1995 in the Little Snake River, Colorado. Percentages <1 were marked by an asterisk and those ≥10 were underlined.

Common Name	**1972[a]**	**1981[b]**	**1988[c]**	**1994[d]**	**1995[e]**
Native species:					
mottled sculpin	-	-	-	*	*
bluehead sucker	C	4	14	31	43
flannelmouth sucker	A	6	70	23	10
Colorado pikeminnow	-	*	*	-	*
humpback chub	-	-	*	-	*
roundtail chub	A	21	10	5	3
speckled dace	A	33	1	10	16
humpback chub x roundtail chub	-	-	*	-	-
flannelmouth sucker x bluehead sucker	-	-	-	-	*
Nonnative species:					
white sucker	-	*	*	1	1
common carp	-	*	2	3	*
fathead minnow	C	4	-	*	1
red shiner	-	8	-	*	2
redside shiner	A	14	-	20	5
sand shiner	-	9	*	9	18
creek chub	-	-	-	-	*
channel catfish	R	*	2	1	*
black bullhead	-	-	*	-	-
plains killifish	-	-	-	-	*
bluehead sucker x white sucker	-	-	-	-	*
flannelmouth sucker x white sucker	-	-	-	-	*
Number of fish		1798	1567	4451	11370

[a] Holden and Stalnaker (1975) collected by seine, number of fish was not reported, but abundance reported as A=Abundant, C=Common, and R=Rare.

[b] Miller et al. (1982) collected by seine and electrofishing boat.

[c] Wick and Hawkins (1989b) collected by seine and trammel net.

[d] Hawkins et al. (1997) collected by seine, cast net, angling, and boat and bank electrofishing.

[e] Hawkins et al. (2001) collected by seine, cast net, angling, and boat and bank electrofishing.

Table 8. Percent composition of fish collected in the Little Snake River, Colorado, 1981. Percentages <1 were marked by an asterisk. Data from Miller et al. (1982)

Species	Larvae	Juvenile	Adult	Total
Native species				
bluehead sucker	4	13	2	4
flannelmouth sucker	82	43	1	6
roundtail chub	42	42	1	21
speckled dace	9	--	58	33
Nonnative species				
white sucker	*	1	--	*
common carp	--	--	*	*
fathead minnow	4	--	4	4
red shiner	15	*	6	8
redside shiner	9	--	21	14
sand shiner	15	--	8	9
channel catfish	--	--	*	*
Number of fish	671	210	917	1798

Table 9. Percent composition of fish collected in the Little Snake River, Colorado, 1988. Percentages <1 were marked by an asterisk. Data from Wick and Hawkins (1989b)

Species	Larvae[a]	Juvenile/Adult	Total
Native species			
bluehead sucker	17	3	14
flannelmouth sucker	2	20	70
Colorado pikeminnow	--	*	*
humpback chub	--	2	*
roundtail chub	*	53	10
humpback chub x roundtail chub	--	1	*
speckled dace	1	--	1
Nonnative species			
white sucker	--	*	*
common carp	--	11	2
sand shiner	*	--	*
channel catfish	--	9	2
black bullhead	--	*	*
Number of fish	1260	308	1568

[a] All fish < 30 mm total length were considered larvae.

Table 10. Percent composition of fish collected in the Little Snake River, Colorado, 1994. Percentages <1 were marked by an asterisk. Data from Hawkins et al. (1997)

Species	Larvae	Juvenile	Adult	Total
Native species				
mottled sculpin	*	*	1	*
bluehead sucker	50	7	18	31
flannelmouth sucker	30	15	16	23
roundtail chub	*	11	9	5
speckled dace	9	12	14	10
Nonnative species				
white sucker	1	1	1	1
common carp	--	*	3	3
fathead minnow	*		*	*
red shiner	*	--	3	*
redside shiner	1	46	23	20
sand shiner	9	9	7	9
channel catfish	--	--	5	1
Number of fish	2367	1579	505	4451

Table 11. Percent composition of fish collected in the Little Snake River, Colorado, 1995. Percentages <1 were marked by an asterisk. Data from Hawkins et al. (2001)

Species	Larvae	Juvenile	Adult	Total
Native species				
mottled sculpin	--	*	1	*
bluehead sucker	76	6	22	43
flannelmouth sucker	9	9	22	10
flannelmouth sucker x bluehead sucker	--	--	*	*
Colorado pikeminnow	--	--	*	*
humpback chub	--	--	*	*
roundtail chub	--	6	6	3
unidentified chub [a]	*	-	-	*
speckled dace	11	21	17	16
Nonnative species				
white sucker	2	*	1	1
flannelmouth sucker x white sucker	--	*	*	*
common carp	--	*	2	*
fathead minnow	*	2	1	1
red shiner	*	4	5	2
redside shiner	*	12	4	5
sand shiner	1	40	14	18
creek chub	--	*	--	*
channel catfish	--	--	5	*
plains killifish	--	*	*	*
Number of fish	5842	4708	820	11370

[a] Unidentified chub were *Gila* species larvae identified to genus.

Reasons for the paucity of nonnative fishes in the Little Snake River were not studied but Hawkins et al. (2001) attributed it to the extreme habitat conditions in the Little Snake River. The extreme variability of seasonal discharge in the Little Snake River (high in spring and low in fall) was probably detrimental to both native and nonnative fishes, but may be more harmful to nonnative species as reflected in their low abundance and inability to produce abundant larvae. Most of the Little Snake River contains very little fish habitat at low discharge, but several reaches contain clear pools that provide refugia that congregate from hundreds to thousands of fish (Hawkins et al. 1997). Most of these pools are subjected to potential flash floods caused by summer and autumn rains. Short-term flood events are more detrimental to nonnative than native species in southwestern streams (Minckley and Meffe 1987). Low-flow refugia pools also undergo extreme diel temperature fluctuations which nonnative species may not tolerate(Hawkins et al. 1997 and 2001). Even with these extreme conditions, sampling in 1994 and 1995 consistently showed that the fish community within these pools were predominately native species and nonnative species extremely rare (Hawkins et al. 1997 and 2001). Environmental conditions have a strong influence on the composition of the fish community and refugia pools in the Little Snake river may provide research opportunities to determine if and how these conditions differentially affect native and nonnative fish growth, reproduction, and survival.

Fish Reproduction

Most native, non-endangered species that occurred in the Little Snake River also reproduced there based on capture of adult fish in spawning condition and capture of larvae (Miller et al. 1982; Wick and Hawkins 1989b; Hawkins et al. 1997 and 2001). Native species collected in spawning condition included: roundtail chub, flannelmouth sucker, and bluehead sucker and larvae were collected for native roundtail chub, flannelmouth sucker, bluehead sucker, speckled dace, and mottled sculpin (Tables 8-11). There was no proof of spawning by humpback chub or Colorado pikeminnow within the Little Snake River, although Wick et al. (1991) caught humpback chub with tubercles and in spawning coloration. Nonnative species also reproduced in the Little Snake River, but only red shiner and sand shiner were collected in spawning condition (Hawkins et al. 1997). Larvae were collected for nonnative redside shiner, red shiner, sand shiner, fathead minnow, and white sucker but not for channel catfish, common carp, creek chub, or plains killifish (Tables 8-11).

Colorado Pikeminnow

Colorado pikeminnow occupy the Yampa River, up and downstream of the Little Snake River confluence, but their occurrence in the Little Snake River was confirmed only recently (Marsh et al. 1991; Wick et al. 1991). Anecdotal accounts suggested that Colorado pikeminnow and humpback chub historically occupied the Little Snake River (Seethaler 1978; Wick and Hawkins 1989b; Quartarone 1993). In the 1980s, Bill Wiltzius of the Colorado Division of Wildlife, researched and compiled references to fish in turn-of-the-century Colorado newspapers. One reference was a letter from A. G. Wallenhan of Lay, Colorado in a Denver paper in August, 1897 (Sports Afield, Volume 19(2) page 134) where Mr. Wallenhan described catching many Colorado pikeminnow in the Lily Park area of the Yampa River and gave the range of the fish upstream to, but not above Baggs, Wyoming. Local residents and fishermen have also reported Colorado pikeminnow in the Little Snake River. Kathryn Rinker of Lily Park caught Colorado pikeminnow in the Little Snake River as a child in the 1920s and 1930s (Quartarone 1993). Seethaler (1978) reported that a ranch foreman of Cross Mountain Ranch at Lily Park, Dean Burman, had found Colorado pikeminnow in pools 5-km and 26-km upstream of the Yampa River confluence in the winter of 1974-1975. T. M. Lynch, CDOW fish manager reported seining young-of-year Colorado pikeminnow from the Little Snake River in 1963 (Seethaler 1978).

Carlson et al. (1979) cautioned that these young-of-year fish were probably roundtail chub, a common species not reported in Lynch's collections and a species often confused with Colorado pikeminnow (Quartarone 1993).

Based on observations of fish implanted with radiotransmitters and recaptures of previously marked fish, Colorado pikeminnow move into the Little Snake River from the Yampa River during runoff in May and June (Miller et al. 1982; Wick et al. 1991). In 1981, Miller et al. (1982) implanted three Colorado pikeminnow from the Yampa River, upstream of the Little Snake River and all three fish occupied the Little Snake River near the Yampa River confluence between June 17 and 30. One of the fish tagged by Miller et al. (1982) moved about one km up the Little Snake River (H. M. Tyus, personal communication in Wick and Hawkins (1989b). These fish were present when spring discharge was receding, but left the Little Snake River just before baseflow, migrated to the Yampa Canyon spawning area in early July, and returned to the Lily Park area by early August.

Another radiotelemetry study had similar results. In the fall of 1987, five Colorado pikeminnow were caught in the Yampa River 3-km upstream of the Little Snake River confluence and implanted with transmitters to study their winter movements (Wick and Hawkins 1989a). In May and June of 1988, two of these adult fish (824-mm and 486-mm long) moved into the Little Snake River (Wick et al. 1991). One fish moved about 11-km upstream and the other fish moved about 2-km upstream. Water temperatures were 19^{0}C in the Little Snake River and 16^{0}C in the Yampa River when the Colorado pikeminnow occupied the Little Snake River. Discharge was declining and both Colorado pikeminnow left the Little Snake River in mid-June, about a month before base-flow and migrated to the spawning area in Yampa Canyon. After spawning, one of the Colorado pikeminnow migrated back to near its original capture site in the Yampa River and contact with the other fish was lost, possibly due to transmitter failure (Wick et al. 1991).

In 1995, three Colorado pikeminnow were caught in the Little Snake River between early-June and mid-July during runoff and when daily water temperatures were 1-2° C warmer than those in the Yampa River. All Colorado pikeminnow were adults between 510-830 mm and were caught between RK 9.2 and 14 in eddy or shoreline habitat (Hawkins et al. 2001). In the spring, Colorado pikeminnow apparently use the Little Snake River much the same way they use flooded backwaters and tributaries in the Upper Yampa River as described by Wick et al. (1991). As discharge increases in spring, Colorado pikeminnow move into flooded tributary or backwater habitats in search of food, warmer temperature, and lower velocity (Wick et al. 1983). In many ways the Little Snake River is similar to backwater habitat because it has warmer temperatures than the mainstream Yampa River and an abundance of appropriately sized prey between 100 to 200 mm. An important difference in the two habitats is that the Little Snake River contains few if any potential competitors or predators such as northern pike (*Esox lucius*) that are often abundant in backwater habitat in the Yampa River (Nesler 1996).

Although most Colorado pikeminnow occupy the Little Snake River during spring runoff, evidence suggests that some Colorado pikeminnow may remain in the Little Snake River during other seasons and flow levels. First, there was an anecdotal account previously mentioned of a rancher who saw Colorado pikeminnow in pools in the Little Snake River in winter, although it is likely that he actually saw roundtail chub. Second, a Colorado pikeminnow was collected in the Little Snake River at RK 14.0 in July 1995 (Hawkins et al. 2001) while other Colorado pikeminnow were spawning in Yampa Canyon (K. R. Bestgen, *personal communication*). One of the most interesting observations was a 685-mm long adult Colorado pikeminnow caught on August 20, 1990 at about RK 135 (Marsh et al. 1991). Discharge was low (60 cfs, 1.7 m^3/sec) when this fish was captured and the fish was probably stranded in this upper reach until the following spring. Colorado pikeminnow of this size in the upper Yampa River usually remain at the same over-winter site from August through March (Wick and Hawkins 1989a) suggesting that this fish could be a Little Snake River resident; but, no other documented pikeminnow have been captured in the Little Snake River, in Wyoming, leading to the likely conclusion that this fish was a wandering visitor. Occasional sampling by the Wyoming Game and Fish Department in this area in June and August in an attempt to capture Colorado pikeminnow, has resulted in no pikeminnow seen or captured (Johnson and Oberholtzer 1987; WGFD 1993).

Humpback Chub

Compared to Colorado pikeminnow, less is known about the life history of humpback chub in the Upper Colorado River Basin, especially the population that resides in the Yampa River. Karp and Tyus (1990) described distribution, habitat use, spawning period, and species associations of humpback chub in Yampa Canyon, but few details are known about their spawning sites or nursery areas. Humpback chub are believed to live and spawn within very restricted river reaches such as Yampa Canyon or Black Rocks (Karp and Tyus 1990, Kaeding et al. 1990), but they also occur upstream of Yampa Canyon in Cross Mountain Canyon (Haynes 1980) and in the Little Snake River (Wick et al. 1991; Hawkins et al. 2001). The first indication of humpback chub in the Little Snake River area was in June 1987 when fishermen accurately described humpback chub they caught while fishing for catfish in pools at RK 15 (Wick and Hawkins 1989b).

Based on two years of capture data and radiotelemetry observations, humpback chub probably move from the Yampa River into the Little Snake River during runoff and return to the Yampa River just before baseflow (Wick et al.

1991; Hawkins et al. 2001). In 1988, seven humpback chub were collected in the Little Snake River in late May and early June during runoff as discharge was declining toward baseflow (Wick et al. 1991). In 1995, four humpback chub were collected in late June and mid-July also during runoff as flows were receding and when average daily temperatures were 1-2 ^{0}C warmer than those in the Yampa River. (Hawkins et al. 2001). Two of the four were implanted with transmitters and monitored bi-weekly. Both humpback chub maintained fidelity to specific eddies in the Little Snake River until just before baseflow and when daily temperatures declined lower than those in the Yampa River, then in late July, both fish migrated out of the Little Snake River into the Yampa River and then moved downstream into Yampa Canyon for total distances of 32 and 39 km. Both humpback chub were located within 2 km of each other in Yampa Canyon until transmitters failed in September.

All humpback chub in the Little Snake River were caught or monitored in or near a short, narrow canyon in the lower 15 km of the river. All humpback chub used fast, eddy habitats with depths of 1 to 3 m. The depth and velocity of these eddies were unlike many other shallow, low-velocity eddies in the Little Snake River, but were similar to eddies in nearby Yampa Canyon (Wick et al. 1991; Hawkins et al. 2001). Telemetered humpback chub showed strong site fidelity with either minimal local movement or apparently directed movement between similar eddy habitats. One telemetered humpback chub remained within the same eddy for 26 days, but another humpback chub occupied the Little Snake River for 20 days and moved several times between two large eddies, 1-km apart (Hawkins et al. 2001).

The reason humpback chub use the Little Snake River is unclear, but based on circumstantial evidence it may be related to spawning. Humpback chub were captured and telemetered in the Little Snake River between May and July during their spawning period and temperatures in the Little Snake River in May and June were suitable for spawning (Wick et al. 1991; Hawkins et al. 2001). Humpback chub collected in the Little Snake River were large enough (216-320 mm) to be sexually mature (Wick et al. 1991; Hawkins et al. 2001) and two had breeding tubercles (Wick et al. 1991). Long-range movements by two telemetered humpback chub from the Little Snake River were similar to distances moved by spawning humpback chub in the Grand Canyon (Valdez and Ryel 1995). Despite considerable fidelity to local population centers, humpback chub are known to move relatively long distances between populations groups, such as the 23 km between Westwater Canyon and Black Rocks in the Colorado River (Kaeding et al. 1990) or long distances in the Grand Canyon where they move an average 7.2 km (range 0.08 - 34.1 km) for spawning in the Little Colorado River (Valdez and Ryel 1995).

There is no proof of humpback chub spawning in the Little Snake River. No adult humpback chub have been collected in ripe, spawning condition and neither juveniles nor larvae have been collected in the Little Snake River. In addition, confirmation through larval collections was not possible because there were not adequate morphometric characteristics to distinguish small larvae of *Gila* species (Hawkins et al. 2001). Differentiation of small congeneric *Gila* larvae may require genetic evaluation.

There is some question about the genetic purity of humpback chub in the Little Snake River and whether these fish were hybrids with other *Gila* species. Humpback chub collected in the Little Snake River were not as large or distinctive in appearance as those caught in the Little Colorado River or Blackrocks, but humpback chub collected in 1988 were similar in appearance to those collected in Cross Mountain Canyon on the Yampa River (Haynes (1980) and Debeque Canyon on the Colorado River (Valdez and Clemmer 1982). Wick et al. (1991) noticed some humpback chub from the Little Snake River did not have the abrupt nuchal hump and fleshy snout found on larger specimens of typical humpback chub from areas like Blackrocks or Westwater Canyon on the Colorado River. These differences were attributed to phenotypic variation, the relatively small size of fish, or possible hybridization with other *Gila* species (Wick et al. 1991). Morphological and genetic studies may provide insight into the *Gila* complex; however, it will also be necessary to continue field studies of life history to distinguish different populations or stocks.

RECOVERY PROGRAM ELEMENTS

Program elements from the RIPRAP were used as a framework for our discussions about the state of knowledge of the Little Snake River (USFWS 1995). For each program element, we provide an overview of the element, identify the importance of the Little Snake River to that element, and end with a list of questions that remain regarding the role of the Little Snake River to endangered fish conservation. These questions expose information gaps and are hierarchical, with the most useful and important questions listed first. Management actions should proceed in the Little Snake River given the current state of knowledge, but answers to the listed questions will inform and focus future actions. The role of the Little Snake River in recovery of endangered fishes will be determined by the Management Plan for the Yampa River. Program elements that describe recovery actions for endangered fishes include:

1. protect instream flows,
2. restore habitat,
3. reduce impacts of nonnative fishes and sportfish management activities,
4. conserve genetic integrity and augment or restore populations, and
5. monitor populations and habitat and conduct research to support recovery actions (USFWS 1995).

Instream Flows

Program Element 1: *Protect instream flows*

Instream flow protection is crucial to protecting sufficient habitat for the recovery of endangered fishes. Flow protection starts by identifying the seasonal habitat components needed by the fish and understanding how flow affects these parameters to ultimately lead to survival, growth, and reproduction by individuals.

Components of flow that influence fish survival include habitat, channel morphology, velocity distribution, sediment transport, substrate characteristics, vegetative encroachment, and water temperature (USFWS 1995). Initial flow recommendations are typically based on the best available information and should be refined through additional field research using an ecosystem approach and adaptive management (Stanford 1994).

The focus of Little Snake River instream flow recommendations should be to sustain the existing variability of flows and to maintain sediment delivery to the Yampa River and eventually the Green River. Additionally, adequate flow recommendations for the Little Snake River will require an understanding of the significance of the Little Snake River to the life history of Colorado pikeminnow and especially the humpback chub. This is especially important if humpback chub are shown to spawn in the Little Snake River.

To provide for endangered fish recovery, instream flow requirements should address not only fish biology but also channel morphology. Little Snake River runoff flows carry a large sediment load that is important in the formation and maintenance of nursery habitats for endangered fishes in the middle Green River around Jensen and Ouray, Utah. The variability of the discharge and sediment load in the Green River is dependent on Little Snake River flows. Naturally functioning backwaters in the Green River which seasonally flood and are continuously connected to the channel during runoff are critical nursery sites for endangered fish (Stanford 1994). The importance of the Little Snake River flows to flooding the Green River bottomlands should be determined by estimating the discharge required to inundate prescribed habitat areas and then calculating the contribution from each river (Little Snake, Yampa and Green rivers).

Previous efforts to recover endangered fish have emphasized flow recommendations that re-regulate flows to maintain spring peak flows, reduce baseflow fluctuations, and reduce perceived shortages. Because the Little Snake River has no major flow regulation projects, the recommendations cannot re-regulate flows, but recommendations should maintain peak flows required to move large amounts of sediment into the Green River and maintain variability that enhances endangered fish habitat.

Questions related to Instream Flow in the Little Snake River:

1. Is the Little Snake River an annual or intermittent spawning area for humpback chub? If so, where do they spawn?
2. If humpback chub spawn in the Little Snake River, what flow patterns create and maintain spawning and nursery habitat?
3. Do endangered fishes typically leave all reaches of the Little Snake River before extreme low flows? What influences their movements (time, flow, water quality)?
4. Will changes in flow cause a change in the fish species composition or abundance of native or nonnative fishes?
5. Do native and nonnative fish respond the same to flow changes?
6. Is extreme high flow (runoff) in the Little Snake River a benefit or detriment to native or nonnative fishes?
7. Is extreme low flow (baseflow) a benefit or detriment to native or nonnative fishes? Do low-flow conditions create a water quality problem for native or nonnative fish?
8. Does extreme short-term variability of flow influence native or nonnative fish abundance?
9. What runoff flows are necessary to create and maintain endangered fish habitat in the Little Snake River, especially within the canyon (Reach III)?

10. What runoff flows are necessary to provide access to habitats in the Little Snake River?
11. How do extreme high or low flows influence food (periphyton or macroinvertebrates)? Is food a limited resource at any time of the year?
12. What affect do Little Snake River flows (discharge amount and periodicity) and sediment transport (or loss of transport) have on Green River nursery habitats?
13. How will depletions of High Savery Dam affect flows and sediment transport in the Yampa and Green rivers?
14. What is the impact of land use, water use, and east-slope diversion on Little Snake River flows?

Habitat

Program Element 2: *Restore habitat*

Components identified as important to habitat protection include restoring and managing in-channel habitats, flooded bottomland areas, restoring passage to historically-occupied reaches, enhancing water temperatures, and reducing or eliminating contaminant impacts (USFWS 1995). Flooded bottomlands have been disconnected from the mainstem river channel because of reduced spring peak flows, changes in channel morphology, and floodplain isolation by levees. Efforts are being made in the Upper Basin to restore flooded bottomlands by increasing flood frequency and duration.

Mainstem dams and water-diversion structures often present passage barriers to migrating fish and fish passageways may restore fish movement over some of these obstacles. Water quality including temperature and contaminants are another possible reason for decline of endangered fishes. Most contaminant issues are not directly researched or funded by the Recovery Program, but the program supports other agencies that are working on contaminant issues.

It is unknown if there was a significant change to historical in-channel habitat, but depletions in the Little Snake River are about 9% of historical flows and any habitat changes might be more related to land use practices that have caused changes to river morphology. Before initiating habitat restoration, we need to better understand why and when humpback chub and Colorado pikeminnow use the Little Snake River and identify the habitat necessary for those activities.

There are no known barriers to endangered fish movements in the Little Snake River during the runoff period. The only known barriers to fish movement in the Little Snake River are Reaches I and IV that create natural barriers at low flow due to their wide, unconfined river channel. Other man-made barriers might include temporary diversion dams, but it is unlikely these create additional problems beyond those caused by natural controls during the low-flow period. Sandbag berms placed near some irrigation pumps at baseflow to pool water may block some movements of small, non-endangered fishes but many reaches are already impassible during extremely low flows. There may even be positive effects of these berms by pooling water for smaller fish refugia. As long as adequate refugia pools exist, we do not recommend supplementing low-flows because these temporary low-flows may be important in preventing nonnative fish exploitation of the Little Snake River.

There are a few remnant oxbows within the lower reaches of the Little Snake River. One oxbow lake retains water year round and is on State Land Board property just downstream of Highway 318 bridge. It may have been created by a rancher who diverted the river with a dike in the early- to mid-1900s (personal communication with local rancher Monty Sheridan). Most flooded depressions or terraces are in the lower Little Snake River (Reaches I and II) and occur for a very short period during runoff. There are also large cottonwood stands near the confluence that may provide floodplain benefits during extremely high discharge.

Questions related to Habitat:

1. What habitat and flow characteristics of the Little Snake River cause a scarcity of nonnative fishes and could this knowledge be used to control nonnative fishes elsewhere in the Upper Basin?
2. How have the trends in historical sediment load affected habitat in the Little Snake River?
3. What is the importance of the Little Snake River flows and sediments to the flooded bottomland habitats in the Green River?
4. Has there been a significant change to historical in-channel habitat, and if so, then what were the natural conditions and what are the current trends?

Nonnative Fishes

Program Element 3: *Reduce impacts of nonnative fishes and sportfish management activities*

Nonnative fish species (about 39 species) have been suspected for a wide variety of problems for the native species in the Upper Basin (Hawkins and Nesler 1991). Competition and predation were the problems most often cited. Recovery Program focus on nonnative fish includes:

1. assess the impacts of nonnative fishes,
2. identify potential conflicts with reservoir sport fisheries management and develop and implement alternative management plans,
3. identify, implement, and evaluate viable options to selectively remove or reduce nonnative fish from certain areas, and

4. prevent nonnative fish escapement from reservoirs and assess sportfish regulations and angling mortality on native fishes and implement viable options to reduce negative impacts.

Overall abundance of nonnative fishes in the Little Snake River is low compared to other Upper Basin rivers and nonnative gamefish species were rare in the Little Snake River. Present environmental conditions in the Little Snake River apparently inhibit invasion, reproduction or survival of nonnative fishes. Large-bodied nonnative species that live in the Little Snake River included channel catfish, common carp, and white sucker and small-bodied nonnative species included redside shiner, red shiner, fathead minnow and sand shiner. There were reports of incidental catch of humpback chub by anglers fishing for catfish in the lower Little Snake River (Wick et al. 1991). Fishing in the warm-water reaches of the Little Snake River is directed mostly at channel catfish but this fishing pressure is probably minimal. There are a few small standing waters in Colorado that connect with the Little Snake River, but we did not investigate the number, location, or nonnative fish species that might escape from these waters.

Questions related to Nonnative Control:

1. What physical processes (e.g., hydrological, structural, water quality) influence the composition of native and nonnative fishes in the Little Snake River?
2. Could the processes that inhibit recruitment, growth, or survival of nonnatives in the Little Snake River be applied to other rivers in the Colorado River System to effect control of problematic nonnatives there?
3. What are the sources for nonnative gamefish species in the upper reaches of the Little Snake River?

Genetics and Augmentation

Program Element 4: *Conserve genetic integrity and augment or restore populations*

The genetic resources of each of the four species are important for recovery. The Recovery Program has determined that the genetic stocks of each endangered fish should be identified and protected within refugia. Additional plans call for developing propagation facilities for research, education, augmentation, and restoration. Genetic and field studies that separate genetic stocks are considered vital for appropriate genetics management.

Of the four endangered fishes, only Colorado pikeminnow and humpback chub occur in the Little Snake River. Colorado pikeminnow that move into the Little Snake River have been tracked to the Yampa River spawning area and probably belong to the Yampa River spawning population. There is reasonable circumstantial evidence that humpback chub were attempting to spawn in the Little Snake River. If humpback chub do spawn in the Little Snake River, this is a potentially significant phenomenon because spawning sites for humpback chub in the Upper Basin have not been identified. Humpback chub from the Little Snake River should also be included in future genetic and morphological studies.

Questions related to Genetics or Augmentation:

1. Do humpback chub successfully spawn in the Little Snake River? Are larvae produced and do they survive?
2. Are humpback chub in the Little Snake River of the same genetic stock as the Yampa River population?
3. Do humpback chub spawn annually in the Little Snake River or do individuals spawn in either the Little Snake River or Yampa River depending on conditions?

4. Because the Little Snake River is relatively predator free and contains essentially unchanged, historic habitat conditions, might it provide a good place to stock endangered species?

Monitoring and Research

Program Element 5: *Monitor populations and habitat and conduct research to support recovery actions*

Monitoring the population of endangered fishes and assessing changes in populations or habitat is important for documenting additional declines or recovery. Identifying and conducting research to fill data gaps in life history information is of primary importance. This includes improving scientific research and sampling techniques to make field efforts as effective and useful as possible.

There is currently no monitoring of endangered fishes in the Little Snake River, but there are implications for the Recovery Program's population estimates for Colorado pikeminnow and humpback chub in the Yampa River. Sampling for abundance estimates in the Lily Park reach in the Yampa River should consider the implication of Colorado pikeminnow moving from the Yampa River into the Little Snake River during sampling in the spring. Population estimates of humpback chub in Yampa Canyon, should also consider the effects of movements of the species into the Little Snake River and possibly include individuals in the Little Snake River in these estimates.

Supporting research can be broad in scope yet important for other recovery elements. It can include research that clarifies data gaps in life history of the endangered species, or it may include research in related areas, such as hydrology and geomorphology that elaborate the connections of the endangered fishes with the rest of the ecosystem.

Life history information is critical but lacking for humpback chub, especially their reproductive life history. Circumstantial evidence of spawning in the Little Snake River has important implications for other Recovery Elements, especially Instream Flow. We need to evaluate humpback chub life history, specifically potential spawning and larval production in the Little Snake River and define this relative to humpback chub populations in Yampa Canyon.

Questions related to Monitoring and Research:

1. Where do humpback chub from the Yampa River and Little Snake River ecosystem spawn and where are their nursery areas?
2. Are there reaches in the Little Snake River that should be included in the present adult Colorado pikeminnow and humpback chub population monitoring?
3. Could the Little Snake River be a surrogate study site to the Yampa River to understand the effects of extreme low flows on native and nonnative fishes?
4. Could removal sampling as conducted at base flow in isolated pools in the Little Snake River be useful in other rivers as a quantitative sampling method for evaluating the abundance of species and monitoring changes over time?
5. What additional geomorphology and hydrology information is needed to understand the relationship of the Little Snake River to habitat in the Yampa and Green rivers?

INSTREAM FLOW WORK PLAN

This work plan was written to guide work necessary to develop instream flow recommendations that will protect and recover endangered fishes in the Upper Basin. It synthesized a review of the hydrology and fisheries literature of the Little Snake River and the recommendations of a work group. In this work plan we describe physical and biological components of the Little Snake River that influence endangered fish habitat and require protection by instream flows. We identify other components that need additional understanding before flow recommendations will be meaningful. We conclude with four recommendations and their associated tasks that must be completed to scientifically defend flow recommendations for the Little Snake River.

Flow recommendations should focus on the needs of endangered fishes in the Little Snake River. It is critical to confirm if humpback chub are spawning in the Little Snake River, and if they are, then flow recommendations should enhance and protect spawning and nursery habitat. Flow recommendations that protect Colorado pikeminnow in upstream reaches will require quantitative data about Colorado pikeminnow use during baseflow. Research should distinguish the unique characteristics that inhibit the colonization, growth, survival, or reproduction of undesirable nonnative species in the Little Snake River and flow recommendations should maintain these characteristics

Instream flow recommendations should also focus on maintaining flow variability and sediment delivery necessary for endangered fish habitat in downstream reaches especially in the Green River. Understanding the relationship of flow and sediment load is critical for accurate flow recommendations. Flows in the Yampa and Green rivers also influence sediment load; therefore, flow and sediment load relationships need to be evaluated simultaneously for all three rivers to understand how flows or flow patterns from each river influence sediment load. If the impending Biological Opinion for Flaming Gorge recommends significant flow pattern changes then it will be critical to understand how new release patterns will influence transport or storage of sediment in the Green River. Flow recommendations must identify the effects of future depletions and flow pattern changes on sediment load and if possible define the limits at which sediments will no longer be supplied or transported into or through critical habitat reaches.

Our recommendations for the Instream Flow Work Plan focus on research necessary to determine: 1) the contribution of Little Snake River flows and sediments to Green River nursery habitats, 2) increased understanding of endangered fish use of the Little Snake River, and 3) the relationship of flow and flow patterns to these endangered fish habitats. This work plan will require a holistic, ecosystem approach to understand interactions of physical and biological processes in the Little Snake River and in the associated Yampa and Green rivers. The following recommendations identify the most critical information necessary to develop scientifically defensible flow recommendations for the Little Snake River, are ranked according to priority, and each contains a series of step-down tasks.

Goal: Identify year-round flows from the Little Snake River necessary to maintain the natural physical processes and habitat for endangered fishes.

Recommendations :

1. Develop interim flow recommendations based on present knowledge.
2. Estimate Little Snake River flows and sediment loads necessary for creation and maintenance of Colorado pikeminnow and razorback sucker nursery habitats in the Green River.

3. Determine if humpback chub spawn or attempt to spawn in the Little Snake River and if so, then estimate the flows necessary to create and maintain spawning habitats.
4. Investigate if flows or flow patterns influence the distribution or abundance of nonnative fishes in the Little Snake River.

Work Plan Approach:

Recommendation 1: *Develop interim flow recommendations based on present knowledge.*

Tasks:

1. Review current information and update based on recent depletions.
2. Review flow-sediment relationships of the Little Snake River, Yampa River, and Green River.
3. Develop interim flow recommendations for the runoff period (March - July) in the lower Little Snake River for Colorado pikeminnow and humpback chub.
4. Use adaptive management and refine flow recommendations as new biological and hydrological information become available.

Recommendation 2: *Estimate Little Snake River flows and sediment loads necessary for creation and maintenance of Colorado pikeminnow and razorback sucker nursery habitats in the Green River.*

Tasks:

1. Identify and quantify endangered fish nursery habitat in the Green River and define physical processes that create and maintain these habitats by implementing the following tasks.
2. Determine the contribution and relationship of flows from the Little Snake, Yampa, and Green rivers to maintenance of nursery habitats in the Green River.

    a. Plot mean monthly hydrographs for wet, average, and dry years.
    b. Update flow duration and peak flow frequency analyses.
    c. Define relationship of peak flow timing for each gage.
    d. Compare mean annual flow volumes monthly between gages.
    e. Define impact of flow depletions on historical peak flows for each river.
    f. Calculate and compare peak flow to base flow ratio for pre- and post-Flaming Gorge flows.

3. Establish sediment discharge relationships for the gaging stations on the Little Snake, Yampa, and Green rivers to determine if channel equilibrium is maintained in the Green River nursery habitats or in habitat restoration areas.
    a. Re-establish sediment data collection on the Little Snake, Yampa, and Green rivers concurrently to collect suspended load, bedload, and occasional bed material samples.
    b. Estimate the historic suspended load by size fraction at each gage.
    c. Determine long term sediment rating curve trends based on size fractions.
    d. Determine if sediment supply has decreased from the Yampa and Little Snake Rivers.
    e. Estimate the bedload and bedload size fraction.
    f. Compare sediment size data from the Jensen gage with bed material data from the razorback sucker spawning bar.
    g. Compare sediment data at Green River (Jensen gage) and Little Snake River (Lily gage) for pre- and post-Flaming Gorge periods with emphasis on sand-sized sediments.
    h. Investigate other sources to expand the sediment data base.

4. Determine how future flow depletions or changing flow patterns will affect formation and maintenance of Green River nursery habitats by evaluating potential changes in sediment rating curves.
    a. Plot cumulative depletions from the Little Snake and Yampa rivers and flow pattern changes from the Green River.
    b. Apply bias correction factors to rating curves.
    c. Remove the low flow bias in the sediment rating curves.
    d. Apply rating curves for a range of discharges to assess how flow depletions or flow pattern changes affect sediments in nursery habitat reaches.
5. Refine flow recommendations with new information collected above.

Recommendation 3*: Determine if humpback chub spawn or attempt to spawn in the Little Snake River and if so, then estimate the flows necessary to create and maintain spawning habitats and enhance larval survival.*

Tasks:

1. Initiate Yampa River and Little Snake River humpback chub life history studies to locate spawning areas.
2. Intensively collect and PIT tag humpback chub from the Yampa River and Little Snake River to identify movements between rivers.
3. Radiotag humpback chub from both rivers and monitor early spring movements to identify spawning areas.
4. Develop methodologies that allow identification of humpback chub larvae (i.e., genetic technologies).
5. Establish drift-net and/or light-trap stations in Yampa and Little Snake rivers if capture data suggest adults have spawned in specific parts of either river.
6. If spawning sites are located on the Little Snake River, then:

    a. Identify unique physical characteristics (location, habitat type, depth and velocity profile, substrate, discharge, and temperature) of the sites and
    b. Initiate field studies to describe the hydrological events that create and maintain these features.
7. Refine flow recommendations with new information collected above.

Recommendation 4: *Investigate if flows or flow patterns influence the distribution or abundance of nonnative and native fishes in the Little Snake River.*

Tasks:

1. Identify physical processes that affect native or nonnative species abundance or distribution in the Little Snake River.
2. Conduct field studies to determine if low-flow periods or spates during baseflow limit nonnative fishes in the Little Snake River.
3. Develop flow recommendations that limit immigration, reproduction, or survival of nonnative species while maintaining native fish communities in the Little Snake River.

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