AN EVALUATION OF THE ROLE OF TRIBUTARY STREAMS FOR RECOVERY OF ENDANGERED FISHES IN THE UPPER COLORADO RIVER BASIN, WITH RECOMMENDATIONS FOR FUTURE RECOVERY ACTIONS

Final Report

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Upper Colorado Endangered Fish Recovery Program

by

Harold M. Tyus and James F. Saunders, III

Center for Limnology
Cooperative Institute for Research in Environmental Sciences
University of Colorado at Boulder
Boulder, CO 80309-0216

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LIST OF KEY WORDS

Colorado River, Green River, tributary streams, endangered fishes: Colorado pikeminnow, *Ptychocheilus lucius;* razorback sucker, *Xyrauchen texanus*; humpback chub, *Gila cypha*; bonytail, *Gila elegans*. Endangered species recovery. Environmental constraints. Fish habitat, water flow, sediment, water quality.

EXECUTIVE SUMMARY

The Green and Colorado River basins include a network of tributaries that contribute to the well-being of endangered Big River fishes. Some tributaries provide habitat used directly by one or more of the fishes, and all tributaries add flow, sediment, and solutes that indirectly affect mainstream habitat. An understanding of the role played by tributaries in direct and indirect ways can aid in developing fish recovery measures.

We evaluated the role of major tributary streams for endangered fish recovery using a matrix approach based on quantitative information. However, the need for ranking tributaries for direct and indirect contributions (i.e., assignment of high, medium or low importance) required a more subjective approach. Some streams differed in actual and potential importance because barriers deny fish access to suitable habitat. We have not assigned relative importance to the different types of contributions; to a large extent that may involve policy issues better addressed by the Recovery Program.

Tributaries in the Upper Colorado River Basin vary widely in terms of habitat used by the endangered fishes and contributions of flow, sediment, or other constituents affecting habitat in mainstream reaches. We considered the Colorado and Green rivers subbasins separately for assessing contributions, such as flow inputs, and obstacles to recovery, such as nonnative fish. We also considered the Colorado River above its confluence with the Gunnison River, and the Green River above the Yampa River to be tributaries. Highest ranked tributaries of the Colorado River subbasin were the tributary Colorado and Gunnison rivers. Highest ranked tributaries in the Green River subbasin were the Yampa River, tributary Green River, and White River.

The Yampa River (including its tributary the Little Snake River) is unique among all of these tributaries because it supports populations and known spawning areas of three of the endangered fishes, and it is considered a recovery area for the fourth. The U.S. Fish and Wildlife Service has designated critical habitat for the Colorado pikeminnow from the Yampa River mouth upstream to Craig, Colorado, and shorter reaches have been designated for the other three endangered fishes. From the standpoint of indirect contributions to the system, the Little Snake River was considered an integral part of the Yampa River basin, because of its role in providing a significant sediment source for the lower Yampa River and mainstream Green River. The movement of Colorado pikeminnow and humpback chub into the lower part of the Little Snake River also indicates an important linkage related to habitat. The Yampa River has escaped much of the water development activity that has greatly altered many other stream reaches, leaving the it mostly unregulated and without significant barriers to endangered fish movement. On an annual basis, the Yampa River contributes about half of the water in the Green River downstream of the confluence of these two rivers. Historically, operation of Flaming Gorge Dam (since 1962) eliminated most or all of the runoff pulse in the downstream Green River. However, most of the water supplied by the Yampa River occurs during spring runoff, producing the runoff pulse observed in the Green River below the Yampa River confluence. Recovery efforts presently underway will

result in additional releases from the dam to increase peak flows. However, Yampa River runoff will remain the most important influence in producing an elevated runoff pulse in the mainstream Green River.

In addition to altering the natural hydrograph of the Green River, Flaming Gorge Dam has eliminated sediment transport from upstream reaches and introduced cold water into a warmwater river. The effects of these alterations to physical habitat used by the native fishes are ameliorated gradually with distance below the dam. Although native fishes have been displaced by cold water immediately below the dam, the endangered fishes continue to use warmer reaches in Browns Park and Lodore Canyon. Colorado pikeminnow continue to use mainstream habitat in Lodore Canyon and venture into Browns Park. Some adult razorback suckers occupy the lower part of Lodore Canyon. Furthermore, bonytail have been reintroduced into Browns Park. This part of the river system is not now included as critical habitat, but actual and potential habitat use by endangered fishes suggests that a review would be in order.

The White River is heavily used by adult Colorado pikeminnow, especially in the 20 miles above the mouth and immediately below Taylor Draw Dam. Although critical habitat is designated as far upstream as Rio Blanco Lake, about 32% of historic habitat is not accessible to the fish due to Taylor Draw Dam, which poses an impassible barrier. Kenney Reservoir, impounded by the dam, is a major source of nonnative fishes that move downstream into high priority recovery areas, and is rapidly filling with sediment. Various alternatives have been evaluated for reducing the sediment impacts, and several of these could benefit Colorado pikeminnow recovery efforts. Serious consideration should be given to implementing measures to restore passage of Colorado pikeminnow upstream of the dam, including various alternatives that incorporate bypasses and dam removal.

The Duchesne River is used by Colorado pikeminnow and razorback sucker, especially near the mouth, although an occasional fish has been recorded much further upstream. Critical habitat for the razorback sucker now includes 2.5 miles of river above the mouth. Recent captures of Colorado pikeminnow and razorback sucker warrant further evaluation of the Duchesne River for its recovery potential. Habitat conditions have been altered significantly by flow depletions and introductions of nonnative fish species. The Duchesne River provides a steady supply of nonnatives to mainstream habitat in the Green River.

The Price and San Rafael rivers make relatively minor contributions to flow and sediment in the Green River system, but both furnish some habitat used by the endangered fishes. A few adult Colorado pikeminnow have been recorded in the Price River, and larval razorback suckers and juvenile pikeminnow have been found in the lower San Rafael River. Critical habitat has not been designated in either river, except that the mouth of each stream is in the 100-year floodplain of critical habitat designated for the Green River.

The mainstream Colorado River above Palisades, Colorado potentially offers habitat for some endangered fishes and has been designated critical habitat for the Colorado pikeminnow as far upstream as Rifle, Colorado. Habitat suitability for endangered fishes is likely due to their prior historical distributions and an abundance of other native fishes. Potential use of that habitat has not been realized due to barriers (Price-Stubb and Government Highline dams) that preclude upstream movement of fishes. Re-establishing access to this area for the Colorado pikeminnow should benefit recovery of the population now centered in the 15-Mile Reach. Reintroduction of razorback suckers and humpback chub also may be desirable.

The Gunnison River provides significant indirect contributions to the Colorado River mainstream, despite the presence of major water development projects. Direct contributions are more limited, primarily due to barriers to fish movement. A few Colorado pikeminnow live and reproduce in the lower Gunnison River, and a stocking program for razorback suckers is now underway. The lower Gunnison River has been designated as critical habitat for both of these species. Although a fish passage structure now makes it possible for Colorado pikeminnow and other native fishes to traverse the Redlands diversion, more fish would probably move upstream if the barrier was removed. Passage through the Hartland Dam also deserves more consideration.

Little is known about historical use of the Dolores River by endangered fishes. For many years, poor water quality presumably prevented fish from using the lower part of the river. Water quality has improved in recent years and there may now be a greater potential for use of this river for endangered fish recovery.

The Dirty Devil and Escalante rivers now empty into Lake Powell and have little indirect affect on mainstream fish habitat. In addition, it seems unlikely that either stream provided a great amount of historic habitat for the endangered fishes, except perhaps at the river mouths. In the present setting, however, the arms of Lake Powell that receive these two streams seem to be attractive to Colorado pikeminnow and razorback suckers that presumably reside in the lake. It is not known why the fish congregate in these arms, but the topic merits further study if Lake Powell is targeted for more recovery effort.

The four “Big River” endangered fishes of the upper Colorado River basin are most abundant in mainstream habitat, and past recovery efforts have concentrated on the larger rivers. As more is understood about the recovery needs of the endangered fishes, it is becoming obvious that recovery can benefit by better integration of tributaries into the ongoing recovery effort. The Recovery Program is evolving an ecosystem view, which also should include priority efforts to maintain other native fishes of the Big River fish community in addition to listed species. However, the process is slow and far from complete. Greater involvement of the tributaries could include a review of the appropriateness of critical habitat designations. This review would entail an evaluation of the importance of habitat for life history stages, presumably from patterns of fish use. A unified view of habitat use needs to be developed by

understanding of the life history and movement patterns of each population. For the Colorado pikeminnow, for example, each life history stage has a different geographical locus, and the fish must be able to move freely between different areas. Moreover, the tendency of adults to make extensive use of tributaries argues for maintenance of a web of interconnected habitat in which physical fragmentation is avoided. Development of this perspective on recovery cannot be achieved simply by listing the distribution of individuals in each of the tributaries. It would be aided, however, by setting recovery goals established in an ecosystem perspective. Such an expanded perspective would result in more consideration of maintaining other native fishes as a necessary part of recovering the endangered fishes.

The decision by the Recovery Program to commission this evaluation of the role of tributaries in the recovery of the endangered fishes is a clear signal that the program is taking a broader view of recovery needs. In the time that the program has been in existence, much has been learned about the ecology of the endangered fishes. The steady accumulation of knowledge has driven an evolution of ideas about recovery. We see this culminating eventually in an ecosystem view that will be guided by a multi-species or ecosystem recovery plan.

We developed the following recommendations during the course of this study :

– The Recovery Program should expand efforts to circumvent or eliminate barriers to fish movement, especially in high priority tributary streams.

– The Recovery Program should reevaluate alternatives for providing fish access to upstream areas. Endangered fish populations in tributary reaches provide the best opportunities for range expansion, but a comprehensive system is needed to evaluate recovery success.

– The Recovery Program should develop and implement plans for removing nonnative fishes from tributaries and controlling nonnative fish movement into mainstream rivers from source areas in tributary streams.

– The Recovery Program should determine environmental attributes of the mouths of tributary streams that result in utilization by larval razorback sucker.

– The Recovery Program should establish which tributaries are primary sediment sources for Colorado pikeminnow nursery habitat.

– The Recovery Program should initiate a study to measure the release of metals from selected reservoirs in Utah that are known to experience seasonal depletion of dissolved oxygen.

– The Recovery Program should participate actively in the development of Total Maximum Daily Loads (TMDLs) for suspended sediment in any tributary for which a TMDL has been proposed by state water quality agencies.

– The Recovery Program should develop management plans for tributaries in accordance with their perceived importance to endangered fish recovery .

INTRODUCTION

Native fishes of the upper Colorado River (UCR) basin have declined in distribution and abundance. Alteration of the natural riverine environment during the last 100 years is the most likely cause of their decline, principally by human actions that resulted in physical habitat loss and the introduction of nonnative species. Construction of water development projects began in the UCR basin in the early 1900s (Fradkin 1984, Carlson and Muth 1989), and by the 1960s, more than 50 dams and major diversions had been constructed on mainstream rivers (Figure 1). Impoundment by these structures converted many river reaches into lacustrine habitat, and operation of dams has altered the natural timing, duration, and magnitude of annual flood flows. Flow regulation and the presence of structures also have caused changes in water temperature, sediment load, nutrient transport, and other facets of water quality (Carlson and Muth 1989). In some reaches, sediment load has been reduced 90% (Fradkin 1984). Most existing mainstream habitats are now different than the historic habitats in which the native fishes evolved, and some have been modified so extensively that native fish can no longer survive in them.

The historic riverine habitat also has been changed by the introduction and proliferation of nonnative fish species, including many that are predaceous, highly competitive, and harmful to the native fish fauna (reviewed by Hawkins and Nesler 1991, Lentsch et al. 1996, Tyus and Saunders 1996). Although the native fishes were well adapted to their natural environment, alterations to the physical habitat may have created conditions that are now more favorable to many of the introduced species. Even where physical habitat has been altered relatively little, nonnative fish abundance has increased, and the abundance of native fishes has been reduced. As a result, most of the native fish habitat is occupied now by introduced species (Minckley 1982, Tyus et al. 1982a, Carlson and Muth 1989).

Physical and biological changes to the river system have resulted in endangerment of four native fish species: Colorado pikeminnow *Ptychocheilus lucius* (formerly Colorado squawfish), humpback chub *Gila cypha*, bonytail *G. elegans*, and razorback sucker *Xyrauchen texanus*. These and other fishes native to the main channels of the Colorado River system ("Big River Fish Community") were once widespread and abundant (e.g., Jordan 1891, Jordan and Evermann 1896, Quartarone 1993), but they have disappeared from most of their original habitat. Their endangerment is attributable to a suite of environmental factors that is essentially the same for all four species. The problem exists at the ecosystem level because an entire fish community is threatened, and threats include biotic and abiotic factors.

Successful recovery of all four of the endangered "big river" fishes in the upper Colorado River basin will depend on the maintenance and expansion of present endangered fish populations, and in some cases the establishment of new populations. In both cases, expansion of the occupied range of the existing populations will be a requirement for recovery to a less-endangered status (U.S. Fish and Wildlife Service

[USFWS] 1990ab, 1991, 1998). In addition, recovery goals established by the Upper Colorado Endangered Fish Recovery Program (Recovery Program) include the criterion that recruitment to populations of the endangered fishes must be produced by natural reproduction in the wild (Nesler 2000).

In the past, recovery efforts focused on maintaining or improving habitat for endangered fish populations in main channel reaches of the Colorado and Green Rivers, and in large tributaries, such as the Yampa and Gunnison Rivers. More recently, there has been increasing interest in other streams, and the potential of tributary streams for aiding fish recovery has been recognized in official recovery plans (USFWS 1991) and by the designation of critical habitat (USFWS 1994). Although it is universally agreed that tributary streams have a potential to aid in recovery of the listed Colorado River fishes, there are concerns that the need to satisfy a continuing demand for water will especially affect tributary streams. Although critical habitat designation provides some protection to identified tributaries, this protection does not extend to all tributary streams that have potential for supporting the recovery effort.

Some tributary streams in the upper Colorado River basin provide direct benefits to the listed fishes by providing suitable habitat for one or more of the fish during some part of their life cycle. For example, razorback sucker utilize the lower portions of some tributary streams as staging areas prior to spawning and for adult habitat (e.g., Duchesne River and Ashley Creek; Tyus 1987). Colorado pikeminnow subadults and adults utilize tributary streams presumably for spawning (e.g., Yampa and Gunnison Rivers; Tyus 1990, Burdick 1995) and also for feeding, growth, and overwintering (e.g., Duchesne, Little Snake, and Price Rivers; Tyus and McAda 1984, Wick et al. 1991, Cavalli 1999). As an example, the need for tributary habitat is evidenced by adults that continue to ascend the White River upstream to a point where their historic habitats are blocked by a dam (Irving and Modde 1994, 2000). Humpback chub seasonally occupy habitats in the Little Snake River, perhaps for several purposes (Wick et al. 1991).

Tributary streams also can provide indirect benefits to fish populations in mainstream rivers by influencing river flow regimes, water quality, nutrient concentrations, or other conditions in the downstream receiving waters. Some tributaries (e.g., Yampa River) essentially have unregulated flows and improve habitats in downstream systems that might otherwise be less acceptable for the listed fishes (Tyus and Karp 1989, Modde and Smith 1995). Other tributaries (e.g., Little Snake River) provide sediment sources needed to maintain habitat features of the natural river ecosystem (e.g. backwaters). However, the present or potential role of most tributaries is not well understood. There are larger tributary streams in different areas of the basin that have the potential for supporting the endangered fishes, but are virtually unoccupied by them (e.g., Dolores River; Holden and Stalnaker 1975, Valdez et al. 1992). Some streams or stream segments have been isolated by barriers, others may be effectively isolated because of human-induced habitat change. Except for a very few of these streams, their potential for supporting populations of the endangered fishes, or even assisting in the overall recovery effort remains unknown.

The Recovery Program for Endangered Fish Species in the Upper Colorado River Basin (Recovery Program; USFWS 1987) has sponsored evaluations of tributary streams, both from a biological (e.g., Price, upper Colorado, and Upper Green Rivers habitat assessment or restoration projects) and hydrological perspective (e.g., in stream flow studies in the upper Colorado, Duchesne, Little Snake, and White Rivers) (1994 - 1997 work plans). Thus, there is a considerable amount of information about tributary streams that would be useful in evaluating their role in recovery of the listed fishes in the upper basin. However, the relative importance of the various tributaries has not been evaluated with standardized criteria. A more comprehensive, comparative assessment of the potential contributions of tributaries has been needed to clarify valuable hydrologic, water quality, and ecological linkages within the basin; identify potential limiting factors influenced by tributaries; and clarify the role of tributaries in maintenance of the native fish community that supports populations of the listed species. Knowledge of the actual or potential recovery benefits within and downstream of each tributary can provide the basis for predicting how management actions may optimize the recovery benefits that tributaries may offer. However, the potential benefits of a tributary may not be fully realized at this time, because of the existence of one or more obstacles to the recovery effort. There remain some cases in which access to habitat potentially valuable to adult or juveniles is totally blocked by barriers (e.g., the upper Colorado River, the upper White River), or influenced by water quality or other unknown factors (e.g., Dolores River). In other cases, the presence of a formidable population of nonnative predators may not allow establishment of endangered fish populations (e.g., Marsh and Brooks 1989). Finally, recovery potential of large areas of habitat where the mainstream river has been converted to a reservoir, but where large areas of tributary streams remain has not been fully evaluated (e.g., Lake Powell and associated tributaries: Dirty Devil, Escalante, and lower San Juan Rivers). The potential benefit to the endangered fishes by future recovery actions in tributary streams remains to be evaluated.

This study is viewed as a first step in evaluating the significance of tributary streams in the UCR basin by providing a systematic review. The following goals guided this study:

1. To determine the direct contribution of each tributary for supporting the life history needs of the endangered fishes;

2. To evaluate the potential of tributary streams to support expanded or additional populations of the listed fishes;

3. To determine indirect abiotic contributions of tributary streams, such as water, sediment, and other factors judged to be important for recovery downstream in the basin;

4. To identify obstacles that prevent a stream from reaching its potential in terms of support for populations of listed fishes; and

5. To provide recommendations to the Recovery Program outlining research and management actions to improve our understanding of the role of tributary streams in recovery of listed fishes.

In a narrow sense, the project is a review and synthesis of existing information concerning the potential of selected tributaries to make significant contributions either directly or indirectly to recovery of the endangered fishes. In a broad sense, the project encourages a system-wide view of management options for optimizing habitat conditions for the native fish community.

In addition to the five broad goals outlined above, specific objectives of this study included:

1) determining the geographic extent and frequency of use of endangered fish habitat in upper basin tributaries that were evaluated;

2) determining which tributaries may especially influence endangered fish habitat in downstream areas because of the location in the river system;

3) determining direct and indirect benefits that may accrue for each of the selected tributaries;

4) relating identified benefits with specific life history strategies and stages of the affected fish or fishes;

5) evaluating potential obstacles that may limit use of any identified benefits by the fish;

6) integrating stream characterizations to contrast potential benefits against obstacles that may preclude realization of recovery measures, and

7) providing recommendations to the Recovery Program about the relative importance of various tributaries for recovery of the endangered fishes and measures that may need to be taken to increase the effectiveness of the recovery effort.

STUDY METHODS AND APPROACH

This study constitutes a review and synthesis of existing information with two assumptions: (1) some tributary streams are important for endangered fishes, and (2) there may be opportunities to enhance recovery of the endangered fishes in some tributaries by informed management actions. The study area for this project is confined to certain tributary streams of the upper Colorado River basin above the confluence with the San Juan River, as identified by the Recovery Program. At some point in all streams a decision is made about what is tributary and what is the mainstream river. In

some cases, these decisions may be relatively arbitrary, as in the case of the Colorado River above its confluence with the Green River, which was formerly known as the Grand River (until it was changed by legislative action). Flows of the Colorado and Green rivers are almost equally divided at the Gunnison River in the UCR basin and the Yampa River in the Green River basin. For purposes of this study, the Green River above the Yampa River, and the Colorado River above the Gunnison River are considered to be tributaries. All of these stream reaches once supported large standing stocks of the endangered fishes.

Numerous other tributary streams (e.g, Little Snake, White, Duchesne, Price, San Rafael, Dolores, Dirty Devil and Escalante rivers, and Plateau Creek) are potentially important due to their proximity to occupied habitat in the UCR basin. A comprehensive view of the existing and potential roles for tributaries was developed by drawing on information about the role of other important tributaries (e.g., the Little Colorado River) that have merit in providing information useful to recovery of the fishes, even though they are beyond the geographic confines of the upper basin.

For our evaluation, we divided the UCR basin into six geographic areas: (1) Yampa River and tributaries, (2) Green River and tributaries above its confluence with the Yampa River, (3) Green River from the Yampa River to the Colorado River confluence, (4) the Colorado River and tributaries above the Gunnison River, (5) the Colorado River from confluence with the Gunnison to confluence of the Green River, and (6) the Colorado River below confluence with the Green River to Lake Powell. The main focus of this study was to evaluate the role of tributaries and not the mainstream rivers, but it was deemed necessary to provide some information about mainstream areas to aid in understanding what, if any, indirect effects tributaries may have on habitats located downstream of them.

A review of existing published and unpublished information, historical and present, about use of tributary streams by the endangered fishes and the role of tributary streams in maintaining endangered fish habitat in downstream areas was a major portion of our evaluation. Present and historical distributions, habitat use, life histories, and life history strategies of the four Colorado River fishes provided a basis for: (a) evaluating direct and indirect effects of tributary streams on extant populations of the fishes, and (b) assessing future recovery potential. Examples of important reviews that provide excellent background information and extensive references include recovery plans prepared by the USFWS for all four of the listed species (USFWS 1990a,b; 1991, 1998), Critical Habitat designation and supporting documents (Maddux et al. 1993; USFWS 1994), Recovery Action Plans (e.g., USFWS 2000), Flaming Gorge Studies Muth et al. 2000), and biological recovery goals and criteria development (Nesler 2000). Published compendia, such as works edited by Miller et al. (1982b), and Minckley and Deacon (1991), which provided critical reviews and voluminous references to published and unpublished works also were useful. Numerous archival (unpublished) reports (available through the Recovery Program) review, summarize, and present much

additional information about life histories and habitat use of the listed fishes for the river segments covered by this report, and include, in part, the following:

(1) Yampa River and tributaries, including the Little Snake River: Miller et al. (1982a), Wick et al. (1983, 1991), Haynes et al. (1984), Nesler et al. (1988), Tyus and Karp (1989), Wick and Hawkins (1985,1989), Marsh et al. (1991), Modde and Smith (1995).

(2) Green River and tributaries above its confluence with the Yampa River: Vanicek (1967), Vanicek et al. (1970), Holden and Crist (1981), Valdez and Masslich (1989), Muth et al. (2000), Bestgen and Crist (2000).

(3) Green River and tributaries downstream of the confluence of the Yampa River; including the mainstream Green River: Tyus et al. (1982b, 1987), Valdez and Masslich (1989), Tyus and Karp (1991), Muth et al. (1998, 2000); the Duchesne River: Cranney (1994), Utah Division of Wildlife Resources et al. (1999); the White River: Lanigan and Berry (1981), Miller et al. (1982c), Chart and Bergerson (1985, 1992), Martinez (1986), Chart (1987), Irving and Modde (1994, 2000), Day (1995), Lentsch et al. (2000); and the Price River: Masslich and Holden (1995), Cavalli (1999), Cavalli and Lentsch (1999).

(4) Colorado River and tributaries above the Gunnison River: Valdez et al. (1982), Anderson (1996), and Van Steeter (1996).

(5) Colorado River and tributaries downstream of the confluence with the Gunnison River to the Green River confluence, including the mainstream Colorado River: Valdez et al. (1982), Archer et al. (1985), Osmundson (1998, 2000), Osmundson and Kaeding (1989, 1991), Osmundson and Burnham (1998), Osmundson et al. (1995, 1998); and the Gunnison and Dolores Rivers (Valdez et al. (1992), Burdick (1995,1997).

(6) Colorado River below the confluence with the Green River, including Lake Powell and tributaries: Persons et al. (1981), Valdez (1990), Muth et al. (1998), Mueller et al. (1999).

In addition to the above archival reports prepared by Recovery Program participants, tagging lists of endangered fishes captured by the Colorado River Fishes Project, Colorado River Fishes Monitoring Project, Interagency Standardized Monitoring Program (ISMP), and other state, federal, and private agencies from 1978 to 1997 were obtained from the USFWS to determine most recent distribution trends for larger fish specimens. This information is presented with some reservation, because sampling varies among reach with respect to methods, including different gear, effort, and locations. Some rivers were sampled each year since 1978 and some have only been sampled for a year or two. Nevertheless, in absence of a recent systematic program

that covers all rivers at the same time, using the same methods (such as for the Yampa, Green, White, Colorado, Gunnison and Dolores Rivers in 1979-81: Miller et al. 1982ac, Tyus et al. 1982b, Valdez 1982), it was judged more acceptable to provide the raw data than to artificially divide the database. Thus, the capture data are used with caution and they are supplemented with additional information as available.

The relative importance of tributary streams for supporting populations of each of the listed species was evaluated using a life-history approach. This approach has both a spatial and temporal component, because life history stages may occupy different habitats seasonally. Life history information was coupled with distributions of existing populations in order to obtain a geographical perspective on potential roles for tributaries. Next we assessed possible sites for establishing new populations, taking into account the contributions that tributaries might make.

We determined the relative value of tributary streams as habitat for the endangered fishes by assessing their direct habitat use, or potential for use above areas that are blocked by barriers. Although native fish diversity is an important component of endangered fish habitat, the presence of other native fishes was not a factor in our ranking of tributary streams. The presence of other native fishes does not guarantee that the four endangered fishes will occur sympatrically, and it remains to be proven whether it will or will not be possible to recover the endangered fishes in the absence of a native fish community. However, the Endangered Species Act dictates that efforts be made to conserve the ecosystem upon which listed species depend, and we provided general information about native fish abundance to depict the present condition of the streams in our evaluation.

We were unable to obtain much information about the relative amount of fish habitat among tributaries, except as expressed in number of miles of river occupied by endangered fishes. To obtain a crude basis for comparing tributaries, we obtained measurements of habitat used by the endangered fishes from USGS topographic maps. We obtained surface area and the volume of physical habitat in each tributary by using a map wheel to measure the distance along the thalweg between adjacent contour lines during the base flow period. Within each section thus delineated we determined channel slope, width, and surface area. Using Manning's equation (Gordon et al. 1992), we computed mean depth at base flow (median across years), assuming that the roughness coefficient was 0.035 at all sites, and that the hydraulic radius is essentially the same as depth for channels that are relatively wide. Mean depth was then used to compute habitat volume and mean water velocity for each tributary reach considered useful for one or more of the endangered fishes.

In addition to providing benefits to the endangered fishes, tributary streams also may pose obstacles to recovery, due to a variety of factors. We identified certain obstacles when they were obvious, such as the presence of a barrier to fish movement, potential water quality problems, presence of large numbers of nonnative fishes, and others. However, we do not provide detailed analyses of these potential recovery obstacles.

In addition to evaluating the direct benefits that may accrue to endangered fish populations, we also evaluated the relative contribution of various tributary streams to endangered fish habitat downstream. We are especially sensitive to the need for evaluating whether water flow regimes, water quality, and sediment supply provide critical inputs for the endangered fish populations in receiving waters. In determining relative tributary inputs of water, sediment, and other materials, we have relied on information obtained from state and federal agencies, and especially data maintained by the U.S. Geological Survey (e.g., water flows: http://waterdata.usgs.gov/nwisw/us/ ; sediment: http://webserver.cr.usgs.gov/sediment), and the U.S. Environmental Protection Agency (EPA: http://www.epa.gov/surf/).

In pursuing our goals and objectives, we focus primarily on Colorado pikeminnow, humpback chub and razorback sucker. Sufficient information does not exist for a substantive evaluation regarding the importance of tributaries to the bonytail.

THE UPPER COLORADO RIVER BASIN

Environmental Setting

The Upper Colorado River Basin (UCRB) consists of about 98,000 mi^2, including parts of Colorado, Wyoming, Utah, New Mexico, and Arizona (Iorns et al. 1965). The UCR basin has been divided into three major hydrologic subbasins – the Green River, upper mainstream Colorado River, and San Juan River (Iorns et al. 1965, Carlson and Carlson 1982) -- all of which have been altered significantly by human activities. The Colorado River system is characterized by a wide range in temperature and flow conditions. Most of the water in the system originates as melting snow that fills high mountain streams generally above 10,000 ft msl, and travels downstream to arid regions and hot deserts. Tributary streams at lower elevations add comparatively little water, but can be important for contributions of sediment and for seasonal inputs of water. The natural hydrograph reflects the regular and prominent influence of spring runoff in May and June (Maddux et al. 1993, Stanford 1994), when peak flows produce extensive seasonal inundation of the floodplain. Smaller tributaries, generally at lower elevations, are prone to flash flooding after unpredictable summer storms. Storm events contribute sediment that creates turbidity in the main river during the base flow period. Historic flows ranging from 759 to 300,000 cfs have been documented at Lee's Ferry, Arizona, which averaged about 0.6% sediment by volume and carried 100,000 AF of soil to the Gulf of California (White and Garrett 1988, USFWS 1991). As a consequence, native Colorado River fishes have had a long evolutionary history of adaptations to a river system that has been characterized by turbid water and extreme seasonal variations in river flow and water temperature.

Water in the warmwater reaches of the historic Colorado River system also contained relatively high concentrations of mineral salts, including carbonates, sulfates and chlorides. The native fishes evolved in a system that was high in dissolved solids and

other potential pollutants, and numerous studies have demonstrated a tolerance to these water quality parameters in the endangered fishes (e.g. Bulkley et al. 1982, Beleau and Bartosz 1982, Bulkley and Pimental 1983, Pimental and Bulkley 1983, Black and Bulkley 1985, Marsh 1985, Nelson and Fickinger 1992).

In addition to temporal changes in the UCRB that have historically occurred, spatial differences also are important. Three different stream zones are recognized in the basin (Minckley et al. 1986), and each contains a characteristic native fish fauna, albeit with overlap. At high elevation, the Headwater Zone is a productive region of cold water, high gradient streams that have rocky substrate and support cold water fishes (predominantly salmonids). The Intermediate Zone, which may receive input from the cold water streams, has streams of lower gradient and finer substrate. The water is warmer and more turbid, and productivity remains substantial, but benthic fauna are limited to rocky outcrops. Streams of the Intermediate Zone are dominated by cyprinids and catostomids, but some cool water salmonids (e.g., whitefish) also occur. Streams of the Lower Zone, also called the large-river zone, are characterized by even lower gradients and warmer, more turbid water. In the Colorado River, this Lower Zone is composed of two major habitats: canyons and alluvial reaches. Native fishes in this region were exclusively minnows and suckers. The inhabitants of the main channels comprised the Big River fish community.

Evolutionary forces have produced a fish community adapted to a riverine system, but flexible enough to make use of conditions ranging from lacustrine to riverine. The fishes are extreme generalists that exploited every available natural habitat and evolved some complex life histories to facilitate survival in the Colorado River (e.g., see Minckley and Deacon 1991, Smith 1981, Minckley et al. 1986). For example, the ancient Colorado River watershed was a much wetter environment than now exists (Smith 1981). The evolution of native fishes was strongly influenced by an ecological history of long pluvial episodes, each lasting about 100,000 years, that were separated by short interpluvial episodes of desert climates lasting only 10-20,000 years. During pluvial episodes, portions of the river system included extensive lacustrine habitat (Stanford and Ward 1986a, Minckley et al. 1986) used by ancestral Colorado River fishes. In recent times, the climate of the basin has been extremely arid. Nevertheless, the native fishes persisted and thrived even during such dry periods. The key to survival of these fishes no doubt includes physiological and behavioral adaptations which are not completely understood. However, a great tolerance to changes in water temperature, suspended and dissolved solids, complex behavioral patterns such as highly adaptive selection of spawning locations over a long time period (Wick et al. 1983, Tyus 1990), and high mobility to exploit diverse habitats (e.g., Tyus 1986) provides some explanation for documented adaptations of Colorado pikeminnow, the species for which we have the most information.

Endangered Fishes

Status

At present, four of the seven large fishes of the Big River fish community are federally listed as endangered species. These fishes, the Colorado pikeminnow *(Ptychocheilus lucius)*, razorback sucker *(Xyrauchen texanus)*, humpback chub *(Gila cypha)*, and bonytail *(Gila elegans)* once populated warm water reaches of the mainstream rivers of the Colorado River basin from Wyoming to Mexico. The numbers and ranges of these formerly abundant fishes have been drastically reduced, and these species are now threatened with extinction. Little was known about the Big River fishes in the UCR basin until the late 1960's and 1970's when research studies at Utah State and Colorado State Universities were done, mostly by graduate students. Beginning in 1979, government agencies have invested heavily in surveys to establish the distribution and relative status of each species as part of the effort to recover them, and an excellent baseline record exists. Subsequent monitoring efforts have been less comprehensive in terms of spatial coverage and sampling gear, but can detect changes in distribution patterns and major trends in abundance (McAda et al. 1994). However, identifying trends in fish abundance has been hampered by high variability in capture data among years due to local changes in the riverine environment. In addition, high mobility and migratory habits of species like the Colorado pikeminnow and difficulties of identifying early life history stages of the endangered species (especially when those stages may be segregated spatially from the adults) has made data difficult to interpret.

Populations of three of the four endangered fishes presently exist in the UCR basin above Lake Powell, while historical populations of bonytail have been extirpated. Populations of the remaining three fishes are now restricted to sections of the Green and Colorado Rivers, where populations appear relatively stable. However, anecdotal information suggests that populations of the fishes have declined in tributary streams. Of these tributaries, the Yampa and Gunnison Rivers continue to support adult Colorado pikeminnow and spawning areas for them. A large standing stock of the fish also occurs in the White River. A population of humpback chub exists in the Yampa River and individuals have been reported in the Little Snake River (Wick et al. 1991). The tributary UCR above Palisade, Colorado, probably supported individuals recently (Valdez et al. 1982). Adult razorback suckers have recently been reported in the lower Yampa River, tributary Green River, Gunnison River, and in a pond once connected to the upper Colorado River near Palisades, Colorado. In addition, razorback suckers stocked in the Gunnison River have been repeatedly recaptured, indicating that habitat conditions there remain suitable for them.

Life History Requirements

The role of tributary streams in maintaining populations of the endangered Big River fishes can be best determined by understanding the direct ways (such as providing physical habitat) and indirect ways (such as providing inputs of water, sediment, and

food sources) in which streams provide the environmental (abiotic and biotic) conditions that each life history stage needs for survival, growth, and reproduction. This requires a knowledge of habitat use, incorporating information such as the path and timing of migrations, location and time of spawning, location of nursery areas, time of occupation, habitats occupied by juveniles and adults at different times of the year, and other pertinent information. The amount of such information varies greatly among the four endangered fishes, from excellent information on Colorado pikeminnow to mostly anecdotal accounts for the bonytail (e.g., see reviews in recovery plans: USFWS 1990ab, 1991, 1998; surveys: Quartarone 1993; and other information: Osmundson et al. 1997,1998; Osmundson and Burnham 1998; and Muth et al. 2000).

In their natural riverine habitat, the timing of most life history events for the four endangered fishes is due to interactions among the environmental variables that provide cues, and of these, flow is an important component (Nesler et al. 1988;Tyus and Karp 1989, 1991; Tyus 1990; Figure 2). Seasonal changes in temperature and photoperiod also are likely involved in the timing of life history events, but are difficult to separate from flow events such as spring runoff. Flow also plays a significant role in the availability of certain types of habitat (e.g., habitat in the floodplain will only be inundated during peak flows), and in the physical dimensions of habitat (higher flow usually means deeper, wider habitat). However, relatively simplistic attempts to provide habitat utilization profiles as a way of describing usable area of habitat for the endangered fishes as a function of flow has been frustrated due to fish use of different habitat parameters (e.g., water depth or velocity) depending on: location (e.g., river), time of year or life stage, and by use of habitats such as eddies and backwaters that are not amenable to flow models (Valdez et al. 1986, 1990; Tyus 1992).

Superimposed on the spatial and temporal map of physical habitat are biological habitat components, which are defined largely by predator-prey or competitive interactions. The endangered fishes must have access to an abundance of suitable food species, but not be exposed excessively to predation. In some locations, high predation by introduced nonnative fishes may be the greatest impediment to expanding or reestablishing populations of the endangered fishes (e.g., Marsh and Brooks 1989, Marsh and Douglas 1997).

A less obvious biological aspect that influences habitat selection and use is learned and/or instinctive (genetic) behavior. Major behavioral attributes tend to have a phylogenetic basis and are commonly shared among related taxa. Examples include a propensity for selecting certain habitats, prey selection, extent and direction of migrations, and orientations to flow, temperature or substrate. Learned responses such as imprinting, are essential to some migratory species (e.g., acipenserids, clupeids, salmonids, and catostomids), which may rely on subtle environmental cues, such as chemical composition of the water, to guide them back to the spawning areas from which they emerged several years earlier (e.g., see reviews by Hasler and Scholz 1983; McKeown 1984, Smith 1985). Concern about the role of these cues is raised whenever the natural habitat, or access to it, is altered.

Determining habitat requirements of endangered species is inherently difficult: the large habitats they occupy are difficult to reproduce experimentally and few individuals exist in the wild. In addition, it has been difficult to associate individuals of different life history stages with preferred habitat. The situation in the UCRB is further complicated by extensive alterations to physical and biological characteristics of the natural habitat. Thus, for example, if studies of adult Colorado pikeminnow indicate preference for deep runs, is it because eddies or "slack" waters are not available? Or have the fish been displaced from other, more suitable, habitat by physical changes or by introduced fishes?

There are legitimate concerns whether present-day field studies of rare species will provide an accurate representation of their life history requirements, however there is no practicable alternative but to make the best use of such information. Field studies conducted where a species is relatively abundant, and where the habitat is altered least (all habitat now occupied by the endangered fishes has been altered some), are most likely to provide an accurate view of life history requirements (discussed in Tyus 1992). The optimal remaining habitat is closest to the conditions in which the native species evolved and presumably are the conditions in which the species are most likely to maintain an adaptive advantage over introduced species. Unfortunately, there has been little synthesis of life history requirements throughout the range of the endangered fishes. As a result, localized studies provide a narrow geographic focus that can lead to a fragmented view of recovery needs. Although local adaptations can and do occur, recovery efforts could benefit from a synthesis of general life history needs.

Various locations in the UCR differ greatly in the degree of anthropogenic alteration. Thus, all are not suitable for determining life history needs of the fishes. Criteria are needed for selecting areas that may provide the most representative information; a relatively abundant population in which successful recruitment is occurring would seem to be ideal. However, it is not possible to find one location where all of the endangered fishes are presently most abundant.

The Green River basin has long been identified as perhaps the most suitable location to determine management measures necessary for recovery of Colorado pikeminnow and razorback sucker because it supports the largest riverine populations of these species. Furthermore, flows of two major tributaries, the Yampa and White Rivers, remain largely unregulated. Similarly, the Little Colorado and Colorado Rivers in the Grand Canyon and Black Rocks-Westwater canyons of the upper Colorado River are the logical places to study the life history needs for the humpback chub because there are large populations sustained by natural recruitment. Information obtained from "optimal" situations can be supplemented, albeit cautiously, with observation from sites where habitat has been altered, but where the species is relatively abundant. A good example of the latter condition is Lake Mohave, AZ-NV, which supports the largest extant population of razorback sucker. The bonytail presents a special challenge because it is not sufficiently abundant anywhere in nature to afford opportunities for meaningful study of "natural" behaviors.

An understanding of the motivations guiding behavior and habitat use of individuals of the endangered fishes at different stages of development is highly desirable for determining the needs of each species. The task is difficult because the subjects are hard to locate and there are confounding factors, as mentioned previously. Nevertheless, such an understanding is needed for determining the potential role of tributary streams in the recovery effort. At present, the knowledge is incomplete.

The Colorado pikeminnow has been studied in greater detail than the other three endangered fishes, and aspects of its life cycle have previously been reviewed by several authors (e.g., USFWS 1991; Haynes et al. 1984, Tyus 1986,1990,1991ab, Nesler et al. 1988; Tyus and Haines 1991; and Muth et al. 2000). Its life cycle is relatively complex, including spatial separation of life stages and energetically-costly migratory behavior. These components, mostly involving widespread movements, are tactical parts of the life strategy that has maximized fitness of the Colorado pikeminnow over millions of years. In general, adults spend most of the base flow period (September – April) in main-channel habitats of upper river reaches that may extend upstream as far as the transition zone of cold water habitat. Each fish occupies a home range in which physical habitat conditions are variable, and habitat selection is probably related to prey abundance. Adults exhibit considerable tolerance to cold and remain active throughout the winter.

Adult pikeminnow become very active in spring when snow melt causes the rivers to rise. Most of the adults move into seasonally inundated habitat, presumably to seek more acceptable habitat conditions and also to take advantage of terrestrial food sources. Rising flow, increasing temperatures and photo period, and other environmental influences stimulate gonadal development and reproductive behavior. During peak runoff, usually in May, adults begin migrating to spawning areas. Although not proven conclusively, we presume that homing, guided mostly by olfactory cues, takes the mature adults to spawning sites from which most emerged as sac-fry. Spawning activity occurs over a 3-4 week period when flows are declining after peak runoff, and when water temperatures typically are in the range of 22-25°C. Adult fish may use large backwaters, mouths of tributary streams, gravel pit ponds, or flooded bottoms for staging because ambient warming can produce higher temperature than in the mainstream river, and this may hasten the maturation of ova. Reproductively active Colorado pikeminnow utilize eddy habitat for staging and cobble bars for deposition of the adhesive eggs.

After about 7-10 days newly emerged sac-fry drift downstream and reach nursery habitats, primarily shallow (ephemeral) backwaters and eddies in alluvial reaches. Backwater nursery habitat is created by the declining flows that follow peak runoff. If peak flows are low, few backwaters are formed. If flows remain high, potential backwaters are inundated. In the nursery area, the larvae and postlarvae feed on zooplankton and benthos. As the young fish grow larger, they begin to consume fish. Juveniles (60-200 mm) continue to feed actively throughout the winter but can withstand extended periods of starvation if food is unavailable. The juvenile fish occupy

backwater areas in the spring of their first year but they are difficult to find after spring runoff, apparently because they begin using deeper habitats.

By the time the fish have reached subadult size (250 - 400 mm), they become increasingly piscivorus. Gradually, the subadults begin moving upstream, perhaps drawn to more suitable habitat and abundant supplies of larger food items. Over a period of years, these fish move downstream into adult habitat many miles from the nursery area. Because the movement is so gradual, they become widely distributed in the system. Male Colorado pikeminnow do not mature until about 6 years of age and females do not mature until at least 7 years of age (USFWS 1991).

The life history of the razorback sucker has been documented in less detail, but there is still a large body of information derived from many years of research (reviewed by USFWS 1998). Adult razorback suckers spend most of the base flow period (September-April) in low velocity habitats (e.g., backwaters, eddies, etc.) of the main channel. They remain active even in cold water, but movements are local. In the spring, when temperatures warm, photo period lengthens, and flows increase during runoff, the adults begin spawning migrations. The fish move into off-channel staging areas (backwaters, oxbows, flooded bottomlands) where warmer temperatures probably facilitate the final maturation of gametes. Females remain ripe for an extended period of time (perhaps weeks) in such areas. Responding to some stimulus, the ripe females eventually move into the main channel where they deposit eggs in flowing water over coarse (gravel and cobble) substrate. Hatching occurs during, or slightly before peak runoff. Historically, larvae would have access to flooded bottomlands and probably spent a few weeks there. When water levels receded in the overbank areas, the larvae would have returned to the main channel. Adult razorback suckers can survive and apparently do well as individuals in large reservoirs (e.g., Bradford et al. 1999), but there, as elsewhere, recruitment of young fish is virtually nonexistent, presumably due to predation (Minckley et al. 1991, Marsh and Langhorst 1988, Pacey and Marsh 1998, Johnson and Hines 1999,)

In contrast to the Colorado pikeminnow and razorback sucker, the humpback chub was historically restricted to only a few river reaches. This species is relatively sedentary (i.e., not known to make extensive migrations). Its populations are now isolated from each other due to dams and lack of intervening preferred habitat (USFWS 1990b). Less is known about its life history requirements than in the preceding two species accounts, especially in the UCR basin. The fish may remain in or near specific eddies for extended periods of time. The fish spawn shortly after peak runoff with increasing water temperatures . In the UCR basin, spawning has been recorded between mid-June and late July when the ripe fish are captured mainly in shoreline eddies. In general, humpback chub exhibit certain preferences for distinct geomorphic reaches (USFWS 1990b) and also make use of various types of cover (Converse et al. 1998).

Life history information about the bonytail is scant and its habitat requirements are virtually unknown (USFWS 1990a). Most of the information available has been

obtained from fish stockings (e.g., Pacey and Marsh 1998). Thus, biotic and abiotic factors influencing decline of bonytail are not understood. Very few fish have been reported in the UCR basin and it is not known if the fish was ever widely abundant, although they were reported "numerous" in the Green River in Dinosaur National Monument (DNM; Vanicek and Kramer 1969). The last bonytail reported from the UCR basin was captured in 1984 near Black Rocks (Kaeding et al. 1986). Some bonytail have persisted in large reservoirs of the lower basin (e.g., Lake Mohave and Lake Mead), indicating an ability to live in lacustrine habitat (Minckley 1973, Valdez and Clemmer 1982, Foster et al. 1999). Results of telemetry studies have demonstrated that the fish can make substantial movements over short time frames, but may remain in certain areas for weeks (Marsh and Mueller 1999). Adult bonytail introduced into the upper Green River in 1988 and 1989 exhibited crepuscular movements, and were relatively quiescent during the day and night (Chart and Cranney 1992). Studies are in progress to determine basic ecological requirements that may be needed for successful reintroduction (Crowl et al. 1996).

ENVIRONMENTAL CONSTRAINTS

General

The four endangered fishes successfully adapted to the many environmental constraints imposed by the historic Colorado River system. However, in the present, altered system, new constraints have been added with little time for the fishes to adapt to them, and some constraints, such as dewatering and high dams, cannot be overcome by adaptive capability of the fishes. Recovery of threatened or endangered (i.e., listed) species to a less-endangered status requires, at the least, reduction of pervasive threats, increased geographic distribution, and increases in population abundance, all of which will aid to increase population viability. For most listed species, the removal of threats is usually addressed immediately, while determining how to increase distribution and abundance. Reduced to its simplest element, if recruitment to the breeding population does not equal or exceed loss to all sources of mortality, other factors being equal, the population will decline. For most endangered species, loss has significantly exceeded recruitment in the recent past. Using the Colorado pikeminnow as an example, recruitment has failed in over 80% of its historic range (USFWS 1991). For the bonytail, it has been 100%. For all of the four listed fishes, successful recovery will require increasing recruitment (survival of young to complete the life cycle as reproducing adults) and maintaining populations of adults. This may be viewed as two recovery goals: to increase relative survival of offspring and to increase carrying capacity (and longevity) of adults. Both will increase standing crops providing other constraints, or limiting factors, do not come into play.

The factors contributing to recruitment gain and loss may be abiotic (physical or chemical), biotic, or both. Physical factors could include the quality or abundance of habitat required for one or more life history stages. For example, loss of habitat through channelization, or degradation of substrate by sediment accumulation, will

reduce the number of larvae produced. Other things being equal, a drop in production of larvae would decrease recruitment. The condition of the physical habitat also is strongly influenced by the hydrologic regime because of relationships between flow and extent of habitat, or between flow and sediment transport, for example. Water quality, another abiotic factor, could cause mortality via pollutants, or reduce recruitment by more subtle effects like delay of spawning due to colder water temperatures. In general, however, water quality effects other than temperature have been studied little. Biotic factors are most likely related to predator-prey relationships, biodiversity, and changes in productivity. In the present altered environment, predation and competition for food and/or space by nonnative fishes also may be factors.

Environmental factors that regulate the abundance of a life history stage, or a population, are considered "limiting factors." There are abiotic and biotic factors that regulate growth and mortality, and the relative importance of these limiting factors may vary in time (e.g., with season or with life history stage) or space (habitat occupied by a particular life history stage at a particular time of year). Especially for species that are endangered, and thus rare, it may be difficult to define rigorously the factors limiting population size. A certain amount of inference based on best professional judgment therefore becomes necessary. At least some of the endangered fishes require large geographic areas and have a complex life cycle (including spatial separation of life history stages). It is essential to understand there is not one set of limiting factors to overcome if recruitment is to be improved. Each life stage must be addressed.

Basin-Wide Limiting Factors

Abiotic

Abiotic limiting factors may be viewed as those factors that affect the suitability of the physicochemical components of habitat or alter productivity Physical habitat parameters such as water flow, depth, passage, etc., have been changed in most locations of the Colorado River and its tributaries. Water quality in some locations in the basin has been degraded due to various causes, but historic records are scant.

Rivers are often used to remove unwanted debris, and the UCR basin is no exception to this. Dead cattle, sheep, chickens, and other domestic and agricultural wastes have been dumped into UCR basin streams (all have been observed by HMT). In addition, most of the UCR basin is an oil producing region, and refuse oils and other toxic substances have been found its streams, to the detriment of fishes. One report that documented contaminated water samples taken from the Green River that contained 50% oil also recorded heavy losses of fishes, ". . . particularly Colorado River salmon (*Ptychocheilus lucius*). . ." (Anonymous 1953). Oil spills have occurred more recently, including a spill from a broken pipeline at a Yampa River crossing near Craig, Colorado. In 1989, 13,200 gal. of crude oil escaped from a broken 6" pipe (Garner 1989). This spill occurred during the annual Colorado pikeminnow spawning migrations and may have interfered with olfactory cues (Woolf 1989) or destroyed eggs or larvae, because

the production of young pikeminnow that year was lowest on record (reviewed by Woolf 1989, McAda et al. 1994).

Other substances of an even more toxic nature have been introduced into the rivers of the UCR basin, including fish poisons. Especially disturbing was a fish eradication program in the Flaming Gorge Impoundment area, which was treated with the fish poison rotenone to establish more favorable conditions for introductions of nonnative game fish species. Details of this poisoning program have been provided by various sources, including USFWS (1991) and Holden (1991). Many endangered Colorado River fishes were killed, primarily Colorado pikeminnow. Fortunately, Binns et al. (1963) reported little long-term impact occurred to native fishes outside of the reservoir basin.

Native Colorado River fishes have a long history of adapting to fluctuations in water quality parameters, and as previously suggested, the endangered fishes have developed a high tolerance to different temperature regimes, salinity concentrations, pesticides and other potential pollutants (e.g. see controlled studies by Bulkley et al. 1982, Beleau and Bartosz 1982, Bulkley and Pimental 1983, Pimental and Bulkley 1983, Black and Bulkley 1985, Marsh 1985, Nelson and Fickinger 1992). Even with all of the previous studies, the effects of changes in water quality parameters on the decline and endangerment of the endangered fishes is not well understood. However, the adverse effects of most water quality parameters would generally occur in short reaches of streams and these effects have not been attributed to basin-wide declines of the Big River fishes (Minckley et al. 1991, USFWS 1991; however see Hamilton 1999).

Construction of dams and diversion structures in the Colorado River basin converted much riverine habitat and off-channel streams into reservoirs and smaller lacustrine habitats (e.g., ponds). Loss or alteration of habitat has been extensive and is documented elsewhere (e.g., Carlson and Muth 1989, Minckley and Deacon 1991). This loss is, for practical purposes, irreversible. The presence of these structures and their role in regulating flows have other, albeit less direct, effects on fish habitat. Impoundments are stocked (directly or indirectly) with predaceous and competitive nonnative fishes that may not only prey on native fishes located in the reservoir, but provide a continual supply of predators into downstream reaches (e.g., Kenney Reservoir on the White River). Structures in the channel also constitute physical barriers to dispersal and seasonal migration. Affected have been upstream and downstream spawning migrations of Colorado pikeminnow to spawning habitat, which have been blocked at several locations, including Flaming Gorge Dam on the Green River and Taylor Draw Dam on the White River. In addition, seasonal upstream movements of adult pikeminnow into previously occupied adult habitat have been affected by the same structures named above, by three diversion dams above Palisade on the upper Colorado River, and the Redlands Diversion Dam on the Gunnison River. These structures also block or reduce pikeminnow access to areas of highest prey density and depress the physiologic condition of adult fish (Osmundson 1998).

The operation of reservoirs and other components of the water storage and distribution system affects fish habitat by altering water depth, water velocity, temperature and sediment load. These properties are critical for provision and maintenance of fish habitat and also for providing environmental cues associated with the timing of life history events such as migration and spawning. Loss of habitat has been especially evident during flood events, which have been reduced by reservoir operation. At least two of the listed fishes, Colorado pikeminnow and razorback sucker, utilize flooded wetland areas for feeding and perhaps for reproductive conditioning. It is thought that flooded lands once provided the bulk of habitat for younger life stages of razorback sucker (Modde 1996,1997). In addition, clear water released by reservoirs may not provide adequate shelter for endangered fishes. Lack of suspended sediment as cover can increase predation on young native fishes. Razorback suckers are especially vulnerable: one study demonstrated that young razorback suckers preferred clear to turbid water, but there numbers were decimated by a sight-feeding predator (Johnson and Hines 1999). However, some fishes may retreat from clear water to turbid areas provided by inputs of tributary streams (Maddux et al. 1987). Cover is considered to be important for all of the endangered fishes (e.g., see Converse et al. 1998). More information is needed about the importance of suspended and deposited sediment for warmwater fishes. However, effects of sediment on fish habitat have historically been treated as undesirable, primarily due to habitat problems of sediment deposited in trout streams (e.g., Waters 1995).

There is a dynamic relationship between riverine flow regimes and physical habitat conditions, and geomorphic investigations in the Colorado River system have shed some light on this subject (e.g., Pitlick and Van Steeter 1998, Wick 1997). A quantitative hydrodynamic connection between flow and habitat, or habitat quality for the endangered fishes also is emerging (e.g., see Modde et al. 1999, Trammel and Chart 1999b), but relationships are complex. Some established correlations do exist, however, between standing crops and environmental conditions, such as changes in young Colorado pikeminnow abundance with alterations in flow patterns. Although other native fishes appear to do well in high flow years, Colorado pikeminnow apparently do not (McAda and Ryel 1999). High mortality and low growth of young Colorado pikeminnow in the Green River has been linked with inundation of backwaters by high flows from Flaming Gorge Dam during an inappropriate time of year (Tyus and Haines 1991). Also, the tendency of larval fishes to seek out quiet shoreline habitat makes them vulnerable to stranding when water levels decline rapidly. Natural fluctuations in river level usually occur slowly enough to afford larvae an opportunity to escape from backwaters and other off channel habitats (mechanisms explored by Tyus et al. 2000). However, in the regulated river, changes in water level occur can more abruptly, increasing the chance that larvae can be stranded in an isolated pool and increasing their vulnerability to predation, high temperature, or dessication. In addition to water flow changes, there is a link between tributary input of sediment and downstream habitat. Backwaters used as nursery areas by Colorado pikeminnow form in alluvial reaches of the mainstream rivers, which are greatly dependent on sediment supply from upstream areas (e.g., USFWS 1991, 1994; Wick 1997).

The operation of reservoirs also has had some effect on temperatures in the rivers. Reservoirs store cold runoff (meltwater) in spring and, even though the surface layer of each reservoir will warm during the summer, water released from reservoir depths will be very cold during much of the summer. The result is a depression of water temperatures below reservoirs during the months when the native fishes have spawned historically. The association between water temperature and initiation of spawning is relatively well known for the Colorado pikeminnow, razorback sucker and humpback chub. Colder temperatures could also reduce growth and diminish survival of young larvae in the drift (Berry 1988).

The research available on the temperature requirements of the endangered fishes does not lead to unambiguous conclusions about the effects that lower river temperatures have had on fish in the wild. Specifically, it has proven difficult to apply the results of laboratory studies of temperature preference to fish in the riverine environment. Some endangered fish utilize temperatures in nature that are not preferred in laboratory tests, such as temperatures used by spawning razorback suckers (Tyus and Karp 1989; 1990) and winter habitat use of adult Colorado pikeminnow (Valdez and Masslich 1989, Wick and Hawkins 1989). In addition, the natural habitat is complex and the range of temperatures actually available to wild fish is greater than would be expected on the basis of temperatures recorded in the main channel (cf., Valdez et al. 1982, Tyus 1991b). In this case, behavioral adaptations allow wild fish to select from the range of temperatures available in the different habitats in or adjacent to the main channel, and can provide a mechanism for ameliorating the adverse effects of low temperatures in the main channel (e.g., see Tyus 1991b). In the case of adult Colorado pikeminnow, it is probable that the fish may forage in cooler water, but seek warmer areas nearby that are more optimum for metabolism (e.g., Wick and Hawkins 1989). However, egg and early larval stages are more vulnerable to lower river temperatures because eggs deposited in the main channel cannot seek more favorable conditions and the mobile larvae still have limited capacity for movement.

Biotic

Biotic limiting factors include those biological attributes of the niche that produce food and influence predation and competition. Food production in the UCR basin has not been substantively addressed, but it is obviously related to the supply of allochthonous and autochthonous organic matter that provide nutrients for production of food items used by fishes. Understanding how food production, suitability, and availability is related to standing crops of the endangered fishes is made more complex by different needs of the fishes as they pass through various life history stages in different habitats. If food production could be viewed in the historic environment, perhaps it would be relatively easy to determine trophic relationships and thus how food production is related to each life stage of the four fishes. However, due to invasion and proliferation of nonnative competitors and predators, trophic structure is more complex. Although some work has been done in identifying the relative concentrations of nutrients in some river reaches (Grabowski and Hiebert 1989), there is no monitoring of relative

productivity or standing crops of food organisms at lower trophic levels that can be used in making comparisons between river reaches, or river systems for that matter.

Although nonnative fishes have influenced food webs in unknown ways, relative food availability and utilization can be approximated for the large piscivorus Colorado pikeminnow. The relative abundance of this predator and standing crops of its historic food items (i.e., suckers and chubs) have been documented throughout the UCRB from capture records. Low standing crops of Colorado pikeminnow have been associated with low food availability or lost access to areas with high food supply. For example, it has been suggested that carrying capacity of adult Colorado pikeminnow has been exceeded in downstream reaches of the UCR due to limited food supply. Osmundson et al. (1998) reported that food for small Colorado pikeminnow was not limited in nursery habitat in the UCR, but as the fish grew their relative condition declined, presumably due to the difficulty or energy expenditure of capturing small minnows, which were the prevalent fishes there. The primary motivation for upstream dispersal of larger life stages of the Colorado pikeminnow in that system is apparently to seek food, which is more abundant in upstream reaches (Osmundson 1998).

Competition and predation by introduced fishes has emerged as a major biotic factor limiting the survival and recovery of endangered fish populations. For at least 50 years, scientists have been concerned about the role nonnatives have played in the decline of native fishes. Dill (1944) was one of the first to suggest that nonnatives were responsible for declines observed in native fish populations in the lower Colorado River basin. He recognized that the decline began about 1930 coincident with a large increase in the abundance of nonnative fishes, especially channel catfish and largemouth bass. By 1960, populations of the big river fishes had been reduced greatly. Recent studies and reviews add to the case for a decline in the abundance of native fish species as nonnative species have increased in abundance. It is not unusual now for nonnative fishes to comprise a significant portion (>25%) of standing stock in river channels, and to comprise 90% or more of the fishes in backwaters (e.g., McAda et al. 1994) and flooded wetlands (e.g., Modde 1997). Recent findings indicate that high numbers of Colorado pikeminnow larvae in the drift do not necessarily result in large standing crops of young fish in backwaters, i.e., high recruitment variability between years is related to differences in survival and growth of larvae after the drift period (Bestgen et al. 1998; Trammel and Chart 1999a). This suggests that conditions in nursery habitat, such as food availability and/or nonnative fish interactions, is the likely cause. Control of nonnative fishes may be quite difficult due to the expense of capturing and destroying problem species. As appealing as habitat modification would be as a control measure, a recent study was unable to identify any habitat manipulation that would favor native fishes and not favor nonnative fishes (Pacey and Marsh 1998).

An increasing body of evidence characterizes the negative interactions of nonnative fishes with the endangered Big River fishes (Hawkins and Nesler 1991, Lentsch et al. 1996, Theide et al. 1999, Tyus and Saunders 1996, 2000). Indirect field evidence establishing a link between the decline of native fishes and the proliferation of

nonnative fishes has been given by many workers who have postulated that competition for food and/or space was occurring. Laboratory studies have documented agonistic behavior, resource sharing, and vulnerability to predation. Direct observations, including stomach content analyses, of predation by nonnative fishes on Colorado pikeminnow, razorback sucker, and humpback chub should leave no doubt that predation by nonnatives is a powerful force.

The nonnative fishes have been divided roughly into three assemblages based on the threat posed to recovery of the endangered fishes (Tyus and Saunders 1996). The first is comprised of small cyprinid species (e.g., red shiner, sand shiner, and fathead minnow) that are abundant mainly in backwater habitats of the warmer, low-gradient river reaches. Although these cyprinids are small, they are very aggressive and will attach and prey on larvae in backwaters that serve as nursery habitat for the Colorado pikeminnow (e.g., Dunsmoor 1993, 1996; Bestgen et al. 1999). The second group consists of centrarchid fishes (e.g., largemouth bass, crappies, green sunfish) that occupy deeper and more permanent pools that may or may not be connected with the channel at low water, but which can be connected at high water. These piscivorus fishes can displace native fishes and will consume juveniles of the native fishes (Burdick 1996, Osmundson 1987). The third group of nonnatives is a diverse collection of species (including channel catfish, common carp, walleye, and northern pike) that are better adapted for riverine existence, and which may displace or prey on larger sizes of native fishes in main channel habitat for part or all of the year (reviewed by Lentsch et al. 1996, Tyus and Saunders 1996).

ROLE OF TRIBUTARY STREAMS

Little effort has been devoted to the creation of a conceptual framework suitable for defining and evaluating present and potential roles for tributaries to the mainstream rivers of the Colorado River basin. In this study, we make a distinction between present and potential roles to show where opportunities exist for future recovery actions. We define the dimensions of the role, present and potential, in terms of system attributes that support the endangered fishes. Those attributes are divided first into direct and indirect contributions.

Direct Contributions : Endangered Fish Habitat

The Recovery Program has long recognized the importance of certain areas as "sensitive" for the four endangered fishes and assigned recovery priorities to various reaches in the UCR basin (Biology Subcommittee 1984, USFWS 1987). An updated summary of fish distribution, concentration, and spawning areas, derived from more recent data from a number of sources, is presented in Table 1. Our changes mostly include expansion of adult distribution patterns, and the addition of areas that are considered suitable for reintroduction areas. The Biology Subcommittee (1984) developed criteria and prepared a list of sensitive areas, depicting the role of various parts of the upper basin as concentration areas for life stages of the endangered fishes,

spawning areas, nursery areas, and migration routes. This concept was subsequently adopted by the Recovery Program in 1985 (USFWS 1987) and used to prioritize UCR basin river reaches with respect to relative importance for the four listed fishes. The Colorado River Fishes Recovery Team (e.g., USFWS 1991) also identified highest priority recovery areas, and this concept continues to form the basis, in part, for subbasin recovery priorities presented by the Recovery Program (USFWS 2000).

Table 1. Distribution of the life stages of endangered big river fishes in streams tributary to the Green and Colorado Rivers. Tributary Green River = Green River above the Yampa River; Tributary Colorado River = Colorado River above the Gunnison River confluence. A = adult, J = juvenile, Y = young of year, S = spawning area, M = migration route, C = concentration area, D = distribution. Locations (RM = river miles) refer to adult distribution (AD). (Revised from USFWS 1987)

Tributaries	Colorado pikeminnow	Humpback chub	Razorback sucker	Bonytail
Tributary Green River	AD; <RM377		AD; <RM 366	Reintroduction
Yampa River	AC, J,Y,S,M <RM 150	AC,J,Y,S <RM 55	AC,Y,S,M,<RM 55	Reintroduction
Ashley Creek	AD; <RM 3		AC, S; <RM 3	
Duchesne River	AD; Y<RM 35		AD,S; <RM 12	
White River	AC;Y:M<RM 150[1]		AD; <RM 20	
Price River	AD, M; <RM 85			
San Rafael	AD; <RM 35		AD;Y; <RM 0.1	
Tributary Colorado River	AC,Y,S,M <RM188; Reintroduction	Reintroduction	Reintroduction	
Gunnison River	AD,S,M;<RM50		Reintroduction	Reintroduction
Dolores River	AD; <RM 1			
Dirty Devil River	AD; Lake Powell			
Escalante River	AD; Lake Powell			
Little Snake	AD<RM 60	AD<RM10		

[1]Access now blocked at RM 100.

Critical Habitat designation by the USFWS (1994) also identified important recovery areas and included certain reaches of tributary streams that provide habitat or may potentially support future recovery efforts (reaches reviewed in detail by Maddux et al. 1993). Nesler (2000) summarized data and information on present population sizes of the endangered fishes in the upper Colorado River basin, and presented recovery goals.

The following accounting of habitat use for each of the endangered fishes is taken from the published and unpublished works of a number of investigators. Emphasis has been placed on studies that have used standardized methods to sample fish populations and to describe physical habitats for larger sections of rivers of the UCRB. Table 2 provides capture information for various tributary streams, including the number and distribution of endangered fishes captured by recovery program cooperators for the years 1978 to 1997. The purpose of Table 2 is to establish the most recent distribution of the endangered Colorado River fishes in tributary streams.

Colorado Pikeminnow

Natural populations of Colorado pikeminnow persist in five locations, all located in the upper Colorado River basin: Yampa River below Steamboat Springs, Green River below Browns Park, upper Colorado River from the Grand Valley downstream to Lake Powell, the lower Gunnison River, and the lower San Juan River (USFWS 1991). The distribution and relative abundance of the Colorado pikeminnow in the upper Colorado basin was extensively documented by Tyus et al. (1982a). The ISMP and other efforts have provided additional information on abundance and short-term population fluctuations (McAda et al. 1994, Osmundson et al. 1998) and numerous reports have added additional areas, principally of seasonal or incidental use (e.g., Wick et al. 1991, Marsh et al. 1991, Platania et al. 1991, Modde 1998, Cavalli 1999; Bestgen and Crist 2000; Muth et al. 1998, 2000). However, the distribution appears to have changed little from the time of earlier surveys conducted by Holden and Stalnaker (1975) and Seethaler (1978).

Nesler (2000) provided a valuable discussion of population abundance data for Colorado pikeminnow populations. Although a precise population estimate has not been accomplished in the Green River, a wide distribution and high catch rates of the fish (e.g., Tyus et al. 1982b, Valdez et al. 1982, McAda et al. 1994) indicated that the two largest extant Colorado pikeminnow populations occur there: one that spawns in the lower Yampa River, and one that spawns in the lower Green River (Tyus 1991a). Estimates of unknown confidence by Tyus (1991a) suggests that about 8,000 adult-size pikeminnow were present in the mainstream Green River in the 1980's, and Nesler (2000) reported a range of 2,000 to 7,400 of the fish more recently.

Table 2. Captures of endangered fishes by adult sampling programs of the Recovery Program, 1978-1997. Sampling effort varied among tributary streams, and not all streams were sampled each year. RM = river mile of most upstream capture. Data provided by U.S. Fish and Wildlife Service, captures by other sources not included.

Tributaries	Colorado pikeminnow	Humpback chub	Razorback sucker	Bonytail
Tributary Green River	29 <RM 377		2 <RM 366	
Yampa River	757 < RM 140	172 <RM 44	31 <RM 37	
Ashley Creek	1 <RM 3		44 <RM 1	
Duchesne River	20 <RM 3		41 <RM 3	
White River	435 <RM138		2 <RM 20	
Price River	19 <RM 85			
San Rafael Tributary Colorado River	215 <RM 207	suspected	41 <RM 225	
Gunnison River	127 <RM 37			
Dolores River	3 <RM 1			

Adult pikeminnow in the Green River basin occupy about 520 mi of river channel divided almost equally between the mainstem Green River and its two main tributaries, the Yampa and the White Rivers. Adults presently occur in the Yampa River from its mouth to Craig, throughout the downstream Green River, in the White River from its mouth to Meeker (most of the fish are now restricted to the 100 mile river section below Taylor Draw Dam), and in the Green River from the Yampa confluence upstream to Swallow Canyon in Browns Park. Two other pikeminnow populations exist in the UCR basin. The largest consists of approximately 600 - 650 subadult and adult fish in the mainstream Colorado River above its confluence with the Green River (Osmundson and Burnham 1998), and another, smaller population occurs in the lower Gunnison River (Burdick 1995). Some adult Colorado pikeminnow have been captured in the UCR in Cataract Canyon and in Lake Powell and tributaries, including the San Juan River which contains the remaining small population of Colorado pikeminnow (Platania et al. 1991; Ryden and Ahlm 1996). Individual Colorado pikeminnow also have been captured in the lower reaches of most of the larger tributaries (e.g., Ashley Creek, Price,

Duchesne, and Dolores Rivers), and in other channels such as drainage ditches, throughout their range (e.g., Minckley 1973, Quatarone 1993).

In general, each of the known populations is associated with a primary nursery area located downstream in an alluvial river reach, which provides habitat for larvae from one or more spawning sites. In the UCR basin, the Green River basin, and the San Juan River, adults are most prevalent in river reaches at, or upstream of, spawning areas (Tyus 1986, Tyus and Haines 1991, Osmundson and Burnham 1998, Ryden and Ahlm 1996). However, the present concentrations of adults may be restricted to river reaches below barriers that block migrations. Examples of such total or partial blockages include Flaming Gorge Dam on the Green River (Vanicek 1967), Taylor Draw Dam on the White River (Trammell et al. 1993), Price Stubb Dam on the Colorado River (Osmundson et al. 1995) and Redlands Diversion on the Gunnison River (Burdick 1995), which still may constitute a partial barrier even with a fish ladder in place.

Humpback Chub

In part because the humpback chub was not described as a species until relatively recently (Miller 1946), information about its historical distribution is very limited (Valdez and Clemmer 1982, Tyus 1998). The fish presently exists in six distinct population segments (i.e., Little Colorado River, Black Rocks, Westwater, Cataract Canyon, Yampa-upper Green, and Desolation Canyon) and has sustained a loss of about 68% of its known historic habitat (Valdez and Carothers 2000). A thorough discussion of population sizes of humpback chub populations in the upper Colorado River basin was presented by Nesler (2000), who acknowledged considerable uncertainty in the estimates. The largest extant population of humpback chub occurs in the Little Colorado and Colorado rivers in the Grand Canyon. Recent estimates place the number of adults to perhaps 10,000 fish (Douglas and Marsh 1996). The existence of humpback chub in the UCRB was first reported in the 1970s (Holden 1977, Valdez and Clemmer 1982). The humpback chub has persisted in the Colorado and Green Rivers, and is reproducing successfully in the Yampa and upper Colorado Rivers (Tyus et al. 1982ab, Valdez 1982, Archer et al. 1985, Kaeding et al. 1990, Karp and Tyus 1990), and presumably in the Green River. In the upper mainstream Colorado River, Valdez et al. (1982) captured 238 humpback chub, and nearly all (229) came from Black Rocks and Westwater Canyon. The population in Westwater Canyon probably consists of several thousand fish, but the precision of the estimate is very poor (B. Burdick, personal communication; T. Chart, unpublished data). Population size is thought to be relatively stable in Black Rocks(Kaeding et al. 1990, McAda et al. 1994, Chart and Lentsch 2000), but may be declining in Westwater Canyon (Nesler 2000). Estimates of humpback chub population sizes elsewhere is very low (Nesler 2000). The adults probably do not travel far at any time in upper basin streams (Valdez et al. 1982, Archer et al. 1985), but some fish have been captured in the Little Snake River, a tributary of the Yampa River, where they are presumed to have invaded from (Wick et al. 1991).

Razorback Sucker

Historically, razorback suckers were common in portions of the UCR basin (reviewed by Minckley et al. 1991; USFWS 1998). The available information suggests that a small population of this species continues to reproduce in at least three locations in the Green River basin (i.e., lower Yampa River, middle Green River from Jensen to Ouray, and in the lower Green River downstream of Green River, Utah (Muth et al. 1998), however, recruitment has been very low or lacking. Standing crops are very low in the Colorado River mainstream and no reproduction has been documented there in many years. The largest remaining riverine population occurs in the Green River near the confluence with the Yampa River; it consists of less than 1,000 fish and may be declining (Lanigan and Tyus 1989, Modde et al. 1996). Reproduction continues in the Green River, where larvae (n= 2,175) were captured in the middle (79.8%) and lower (20.2%) Green River from 1992 to 1996 (Muth et al. 1998). A few adult fish also have been collected in the mainstream Colorado River and in the lower San Juan River. In the upper Colorado River, 47 adult razorback suckers were collected during the two years of the baseline survey, but most of these (79%) came from two flooded gravel pits: Walter Walker State Wildlife Area (RM 164) and Clifton Pond (RM 118; Valdez et al. 1982). Captures of razorback suckers declined in the UCR from 1974 to 1988 (Osmundson and Kaeding 1991), and only one individual was captured in the six years of the ISMP (McAda et al. 1994). Razorback suckers have been reintroduced by recent stocking, but fish spawned in nature have probably been extirpated from the UCR. Furthermore, there is no indication that recruitment is adequate to support any of the existing populations (McAda and Wydoski 1980; Meyer and Moretti 1988; Lanigan and Tyus 1989; Minckley et al. 1991, Modde et al. 1996).

Bonytail

The bonytail was apparently common in some portions of the UCR basin, including the Green River (USFWS 1990a), but it wild stocks are thought to have been extirpated. The last individual reported in the basin was captured near Black Rocks in 1984 (Kaeding et al. 1986), and suspected bonytails have been captured in Cataract Canyon (Valdez 1990). The few individuals that have been captured in Lake Mohave may represent the last of the species in nature. All other individuals exist as hatchery stocks that are being cultured for reintroduction. Virtually nothing is known about the life history of this species except that it inhabited the main channel of large rivers and that adults can survive in reservoirs (USFWS 1990a). Bonytails have been recently reintroduced into the Green, Yampa, and Colorado rivers, but no viable populations have been established to date.

Direct Contributions: Maintenance of the native fish community

Physical Habitat

Little has been done to compare the relative amount of aquatic habitat provided by the various tributaries in the UCRB. A gross measure of the relative contribution of habitat by each of the tributaries is linear distance, and we also have reported the number of river miles occupied by the endangered fishes. However, the volume of aquatic habitat used by the endangered fishes also can be compared for each tributary. We used data obtained from topographic maps to compute channel slope, width, surface area, and habitat volume of certain tributaries during the base flow period (Table 3). The reaches of tributaries that we selected provided habitat for one or more of the endangered fishes. We were unable to obtain measurements for all habitat utilized in each tributary, and we selected representative reaches to use in comparing attributes of each stream section. Slope (stream gradient; i.e., drop in elevation per foot of travel) represents means of stream sections entering the mainstream rivers (i.e., potamon sections). As might be expected, slopes are similar due to averaging fall zones and slow-moving reaches. Tributary streams varied greatly in the volume of aquatic habitat provided. In addition (and as might be expected), streams with higher base flows have greater habitat volume per unit length. More importantly, several of the streams have such shallow water that the habitat may not be very useful during the base flow period.

Native Fish Diversity

The Colorado River fishes evolved in a community of native fish species and it is likely that the endangered fishes cannot be sustained without the other components of its ecosystem, including other native fishes. However, populations of the native Colorado River fishes have been swamped by introductions of aggressive, competitive, and predaceous nonnative species; all of the tributary streams that we studied have been altered by introductions of nonnative fishes. Shoreline habitats of all of these tributaries are now dominated by nonnative fishes, mainly introduced cyprinids (e.g., as high as 70% to 80% of the fish captured; Valdez et al. 1992). However, all of the studies we have accessed indicate that native fishes predominate in the deeper channels of all of the major tributaries (Table 4). This presents a dilemma. Some tributary habitats (i.e. , larger runs and pools) support a diverse native fish community that offers forage and provide a supply of native fishes into habitats occupied by the endangered fishes. This is considered a direct benefit because it aids in maintaining the native fish community. But more shallow, shoreline habitats are occupied with nonnative fishes that compete with or prey on the young of the native fishes and provide a steady supply of nonnative fishes to mainstream. This is considered to be an obstacle to recovery of the endangered fishes.

Table 3. Attributes of tributary streams obtained by measurement from topographic maps. All measurements taken during base flow conditions. RM = miles of river upstream from river mouth.

River	RM	Mean Slope	Width (ft)	Acres	Acre/mi	Flow (cfs)	Depth (ft)	Velocity (ft/s)	Volume (Acre-feet)
Yampa	86.0	0.00188	171	257686	2,996	461	1.3	2.1	37,864
Little Snake	61.0	0.00111	172	205622	3,369	54	0.4	0.8	1,359
Duchesne	36.5	0.00187	99	59303	1,627	168	1.0	1.8	1,550
White	95.5	0.00117	98	227888	2,385	482	2.1	2.4	4,945
Price	84.1	0.00264	52	165081	1,962	60	0.7	1.7	1,335
San Rafael	33.7	0.00100	54	108999	3,237	43	0.7	1.1	2,363
Gunnison	48.3	0.00117	177	193707	4,012	1888	3.3	3.2	13,286
Dolores	11.2	0.00236	86	32260	2,872	252	1.2	2.4	3,535

Table 4 provides collection data that highlight the presence of native fish populations for various tributaries. Although biased toward sampling in deeper habitats, this table demonstrates the predominance of native fishes in some tributary habitats. Although the data are not directly comparable (i.e. in terms of methods and catch per effort), most of the tributaries have sections that are more characteristic of a native fauna than does most sections of the mainstream rivers. This will be discussed more fully as each of the river sections are discussed.

Table 4. Relative abundance of native fishes in selected Upper Colorado River Basin tributaries determined from surveys of deeper habitats. (Data provided by T. Chart, U.S. Bureau of Reclamation, 2001)

River	*RM*	*Dates*	*Investigator*	*%*	*Species* [a]	*Comments*
Little Snake	4 -64	1994	Hawkins et al 1997	69	BH, FM, SD, RT, MS	Collections include small and large bodied fishes.
Yampa River	62-66	1998-1999	Anderson and Stewart 2000	71	FM, BH, RT, CPM	Fish > 15cm collected with electrofishing.
White River	72-115	1984-1985	Chart 1987	84	FM, BH, RT, SD, MWF ,CPM, MS	Electrofishing
Duchesne River	0- 34.5	1999	Modde and Christopherson 1999	51.7	FM, MWF, BH, SD, MS	Electrofishing
Price River	0- 48.7	1996-1997	Cavalli 1999	71.7	FM, BH, SD, CPM, US	Boat electrofishing.
San Rafael	0 -80	1998	T. Chart and P. Cavalli (pers comm)	~70%	FM, BH, RT, SD, CPM	Canoe electrofishing and seining.
Plateau Creek	0.0-7.5	1984	Carlson and Platania 1984	74	BH, FM, SD, RT	Seines and other collection methods.
Gunnison River	0- 75	1992-1993	Burdick 1995	79	BH, FM, RT, SD, MS, CPM, HB	Fishes collected electrofishing.
Dolores River	0- 177	1990-1991	Valdez et al. 1992	62.4	FM, RT, BH, SD, MS	Boat and canoe electrofishing.

[a] FM=flannelmouth sucker; BH = bluehead sucker, RT = roundtail chub, SD = speckled dace, CPM = Colorado pikeminnow, MWF = mountain whitefish, MS = mottled sculpin, HB = humpback chub, US = unidentified sucker (native). Species are listed in decreasing order of abundance.

INDIRECT CONTRIBUTIONS

Definition

Indirect contributions of tributary streams include flow, sediment, or water quality attributes that aid in creating or maintaining habitat essential to one or more life history stages of the endangered fishes. These contributions are indirect in the sense that they originate at a point some distance from the geographical location where they may make a difference for recovery; these contributions are typically in motion and are not a static part of the physical habitat occupied by the fish. For example, the water that scours a spawning bar in the spring comes from tributaries upstream of that bar. Sediment carried by runoff from Plateau Creek may travel down the Colorado and be deposited to form nursery habitat near Moab. Solutes from the Uncompahgre River may impair the health of fishes in the Colorado River. In all three examples, the contribution is indirect because the effect is observed at considerable distance from the source. It is also clear that an evaluation of indirect effects must involve spatial and temporal considerations.

The location of a tributary relative to important physical habitat downstream establishes a spatial context for indirect contributions. Some tributaries join the mainstem above important habitat and others do not. For example, the Duchesne and the White rivers join the Green River not far upstream of spawning habitat for the Colorado pikeminnow. Conversely, the Escalante River flows into Lake Powell and makes no detectable indirect contribution. The spatial context for tributary contributions will be evaluated by quantifying flow (or sediment) at the confluence with the mainstem as a measure of the influence a tributary has in the creation and maintenance of habitat downstream of the confluence. A broader context will also be established by assessing the contribution of each tributary to flow at the mouth of the Green River and in the Colorado River just above the confluence with the Green. The broader perspective helps define the role that tributaries play in accounting for the downstream sequence of changes in the mainstem rivers.

The time when an indirect contribution is delivered sets temporal context on two levels: across years and within years (i.e., with respect to the typical annual hydrograph). Because the intent of the study is to provide an accounting of indirect contributions in the *present* river system, the time period for the assessment commences after closure of the most-recent, large impoundment in a tributary basin. (Size of the impoundment was judged in terms of storage capacity in relation to annual flows in the tributary; not on the basis of absolute storage.) Annual contributions from tributaries give a general picture of relative importance, but life history events of the fishes are usually related to seasonal influences (e.g., peak runoff and spawning). We examine contributions to three components of the annual hydrograph: peak runoff, base flow, and storm flow. The timing and magnitude of peak runoff have important implications for spawning, base flow levels influence the availability of, and access to, nursery habitat, and storm flows may be very important for delivering sediment to the mainstem.

The purpose of the section is to provide a basis for assessing the relative importance of contributions for the various tributaries. Each step involves analysis of data, and the methods and assumptions used in those analyses are described in connection with each variable.

Flows

Data Record

Flows in streams of the Green and Colorado River basins have been measured for many years (Table 5). The record of daily flows, which spans nearly a century at some gaging stations, was obtained from the USGS web site (http://waterdata.usgs.gov/nwis-w/US/). Daily records for most of the key stations are available for the last 45 years or more. However, flow records for the Price and the Dirty Devil Rivers were discontinued in the early '90s, and the record for the Colorado River near Palisade, Colorado, is very short (since 1 October 1990). The record for the White River is based primarily on the gage near Watson, Utah, except for the period from 4 October 1979 through 30 September 1985, when records from the gage near Ouray, Utah were substituted (daily flows at the 2 stations were almost identical: regression slope=0.99, R^2=0.97, N=2380).

Impoundments

Most impoundments alter natural hydrographs to some extent, but not all alterations are significant for the purpose of this assessment. Almost all of the tributaries have one or more impoundments in their respective basins. We will use cumulative storage capacity for identifying significant potential for altering the natural flow regime (Table 5). As the cumulative storage capacity of a basin increases, it becomes increasingly likely that the hydrograph downstream will be affected in a discernible manner. The effect of impoundments on the hydrograph at the mouth of a tributary may be affected by additional factors such as location, number, operating schedule, etc. A run-of-the-river reservoir, for example, would exert less influence on the hydrograph than a reservoir operated for irrigation storage. Nevertheless, we think it is reasonable to assume that storage capacity in excess of a year's flow is a good indicator that downstream changes are occurring in the natural hydrograph.

In the Green River basin, the closure of Flaming Gorge Reservoir in 1962 is the most important recent event affecting flows and sediment transport. Peak flows have been attenuated, base flows have been augmented, and sediment transport has been reduced (Andrews 1986, Wick 1997). In short, the river has been altered significantly and permanently; it is the new set of conditions that provides the context that will be considered in this report. Perhaps the most striking characteristic of Flaming Gorge Reservoir is its storage capacity in comparison to annual flows in the Green River; the reservoir has the capacity to retain the flow of nearly three typical (median flow) years (Table 6).

Table 5. Primary sources of hydrologic data from USGS. (Missing data may be for all or part of a water year.)

Gage	River	Locator	Area mi^2	Period of Record	Missing Data
9095500	Colorado	Cameo, CO	8050	10/01/33-09/30/98	
9105000	Plateau	Cameo, CO	592	04/26/36-09/30/98	WY84-85
9106150	Colorado	Palisade, CO	8753	10/01/90-09/30/98	
9152500	Gunnison	Grand Junction, CO	7928	10/01/16-09/30/98	
9163500	Colorado	CO-UT line	17843	05/01/51-09/30/98	
9180000	Dolores	Cisco, UT	4850	12/01/50-09/30/98	
9180500	Colorado	Cisco, UT	24100	10/01/22-09/30/98	
9234500	Green	Greendale, UT	15090	10/01/50-09/30/97	
9251000	Yampa	Maybell, CO	3410	05/01/16-09/30/98	
9260000	Little Snake	Lily, CO	3730	10/01/21-09/30/98	
9261000	Green	Jensen, UT	25400	10/01/46-09/30/98	
9271500	Ashley	Jensen, UT	383	10/01/46-10/01/83	
9271550	Ashley	Jensen, UT	389	07/09/91-09/30/98	
9302000	Duchesne	Randlett, UT	4247	10/01/42-09/30/98	
9306500	White	Watson, UT	4020	04/01/23-09/30/98	
9306900	White	Ouray, UT	5120	03/27/74-09/30/86	
9307000	Green	Ouray, UT	31240	10/01/47-09/30/66	WY56
9314500	Price	Woodside, UT	1540	12/01/45-10/08/92	
9315000	Green	Green River, UT	40590	03/01/05-09/30/98	
9328500	San Rafael	Green River, UT	1628	10/01/45-09/30/98	
9333500	Dirty Devil	Hanksville, UT	4159	06/07/48-10/11/93	
9337500	Escalante	Escalante, UT	320	10/01/42-09/30/98	WY56-72, 97

Flaming Gorge Reservoir was closed in 1962. Thus, we delay the start of analyses for three years until water year (WY) 1966 to allow for filling and stabilization of operations (based on a hydraulic residence time of 2.7 y in the reservoir). Because Flaming Gorge Reservoir exerts a major effect on Green River hydrology, the period of record for almost all hydrologic analyses in the Green River basin was WY66-98. In a few cases, tributary contributions have been evaluated for a different set of years depending on the role that other impoundments play (see Table 6). For example, the virtual absence of impoundments on the Yampa and Little Snake Rivers makes it possible to use the entire record for the Little Snake when assessing its contributions to the Yampa. On the other hand, construction of impoundments in the Duchesne and San Rafael River basins since 1962 dictated use of a shorter period of record. In all cases, the cumulative storage capacity helps determine how long to wait after construction of the final reservoir before defining the period of record for present conditions.

Table 6. Cumulative storage capacity of reservoirs in each basin. Residence times calculated with flow at mouth of each tributary. Flows are not adjusted for depletions. Storage data from Ruddy and Hitt (1990) and Liebermann et al. (1989).

River	Median Flow, AF	Total Storage, AF	Residence Time, Year	Major Reservoirs
Green (Greendale)	1419526	4401895	3.10	Flaming Gorge, Fontenelle
Little Snake	432535	0	0.00	
Yampa (Maybell)	1232419	105720	0.09	
Duchesne	350624	1392220	3.97	Strawberry, Starvation
White	532298	25008	0.05	
Price	71586	73600	1.03	Scofield
San Rafael	61521	128280	2.09	
Dirty Devil	64027	15582	0.24	
Escalante	6949	2320	0.33	
Green (mouth)	4354026	6144625	1.41	
Colorado (Cameo)	2892197	1309581	0.45	Granby, Dillon, Green Mtn Ruedi, Williams Fork
Plateau	136175	40120	0.29	Vega
Gunnison	1874962	1441389	0.77	Aspinall Unit
Dolores	375031	430569	1.15	McPhee
Colorado (Cisco)	5219561	3221659	0.62	

There is a long history of constructing impoundments in the Colorado River above Cameo, but no impoundment is as large as Flaming Gorge in absolute or relative terms. Even the cumulative storage capacity of all reservoirs in the basin above Cameo is not large relative to flow in the river, when compared with conditions in the Green River basin (Pitlick et al.1999). The useable period of record for the Colorado River basin is determined by construction of impoundments on the tributaries. With respect to evaluating flows for this study, the most important water development project in the Colorado River basin above Cisco is the Aspinall Unit, which consists of three reservoirs (Blue Mesa, Crystal, and Morrow Point) on the Gunnison River. The largest of the three (Blue Mesa), completed in 1966, has the capacity to hold about half of the expected annual flow. Allowing for filling and stabilization of operations in Blue Mesa Reservoir, the point of departure for hydrologic analyses related to the Colorado River system as a whole begins 1 October 1967, subject to exceptions noted in Table 6.

The cumulative storage capacity of impoundments in the upper Green, Duchesne, Price, San Rafael, and Dolores basins exceeds runoff in a typical year (Table 6). Impoundments in the Green River above its confluence with the Colorado River have a capacity that is at least 40% greater than flow in a typical year. Flows are essentially unregulated in only two basins -- Yampa (including the Little Snake) and White -- both

in the Green River system. Cumulative storage capacity in the Colorado River basin is about half that of the Green River basin in absolute terms.

Flow regulation is a more conspicuous feature of hydrology in the Green River basin than it is in the UCR basin. Total storage capacity in the Green is about twice that in the Colorado, and the annual flow in the Green is only about 80-85% of what is in the Colorado. If flow regulation has been a significant agent in the decline of endangered fishes, it is surprising that populations are generally doing better in the Green than in the Colorado. This might be explained by the presence of two tributaries with essentially unregulated flows (Yampa and White rivers) in the Green system. None of the streams considered in the Colorado system is as free of regulation as the Yampa or White rivers. As discussed later, these two rivers are considered of great importance to recovery effort of the listed big river fish, and care should be taken that future flow regulation does not limit recovery efforts.

Annual Flow Contributions

Annual contributions of flow have been assessed on the basis of water years, and without adjustment for depletions (Table 7). The initial spatial frame of reference for each tributary is its confluence with a mainstem unit. The Little Snake River comprises about one quarter (median = 27%) of annual flow in the Yampa River, despite comprising about half of the drainage area. Flow in Yampa River at its mouth (including the Little Snake) matches the flow in the Green River at Greendale, Utah (Table 8).

The Duchesne and White Rivers also make important contributions to flow, but the amount of water they deliver is less than the Yampa River. The Price and San Rafael rivers contribute relatively little flow.

Within the study area, there are fewer tributaries to consider in the Colorado River system than in the Green River system. Plateau Creek makes a relatively small contribution to flow in the Colorado River in De Beque Canyon. Flows in the Gunnison are about equal to flows in the mainstem Colorado above their confluence. The Dolores also makes an important contribution (ca. 11%) despite sending about 136,000 AF annually to Montezuma Valley (Vandas et al. 1990).

The Green River at its mouth, without adjusting for depletions, derives about one-third of its flow from Flaming Gorge Reservoir, about one-third from the Yampa River, and the balance from four other tributaries. Most (90%) of the flow in the Colorado at Cisco, Utah (just above its confluence with the Green River) is comprised of roughly equal contributions from the upper Colorado and Gunnison Rivers. The Green and the Colorado Rivers are about equal in flow where they join, and their combined flow dwarfs contributions from the Dirty Devil and the Escalante Rivers (which now flow into Lake Powell; Table 8).

Table 7. Relative contributions of tributaries to annual flow. The upper portion of the table shows contribution relative to flow below confluence of each tributary with mainstem. The lower portions of the table show contribution to the Green at its mouth, the Colorado at Cisco, or the Colorado below the Green. Sites are described in Table 5. (POR = period of record in water years, i.e. 10/1 - 9/30).

Tributary	Main	Relative Flow Contribution to: Median	Min	Max	Period of Record
Little Snake	Yampa	27.3%	17.5%	35.3%	1922-1998
Yampa	Green	49.8%	18.1%	66.0%	1966-1998
Duchesne	Green	9.5%	2.7%	18.1%	1976-1998
White	Green	13.2%	8.0%	18.4%	1966-1998
Price	Green	2.0%	0.8%	4.3%	1966-1991
San Rafael	Green	1.5%	0.5%	4.2%	1975-1998
Plateau	Colorado	4.5%	2.4%	8.2%	1961-1998
Gunnison	Colorado	47.4%	40.8%	54.4%	1991-1998
Dolores	Colorado	10.7%	3.7%	18.6%	1988-1998
Green (Greendale)	Green[1]	36.8%	25.3%	71.3%	1966-1998
Yampa	Green[1]	37.0%	16.3%	52.1%	1966-1998
Duchesne	Green[1]	7.8%	2.5%	15.6%	1976-1998
White	Green[1]	12.7%	8.1%	18.5%	1966-1998
Price	Green[1]	2.0%	0.8%	4.3%	1966-1991
San Rafael	Green[1]	1.5%	0.6%	4.4%	1975-1998
Colorado (Cameo)	Colorado[2]	55.4%	41.4%	73.6%	1968-1998
Plateau	Colorado[2]	2.7%	1.8%	4.4%	1968-1998
Gunnison	Colorado[2]	36.5%	29.0%	43.1%	1968-1998
Dolores	Colorado[2]	10.7%	3.7%	18.6%	1988-1998
Green[1]	Colorado[3]	45.7%	34.2%	59.2%	1968-1998
Colorado[2]	Colorado[3]	54.3%	40.8%	65.8%	1968-1998
Dirty Devil	Colorado[3]	0.7%	0.5%	1.2%	1968-1998
Escalante	Colorado[3]	0.1%	0.0%	0.2%	1968-1998

[1] – at mouth
[2] – at Cisco
[3] – at Hite

Table 8. Present characteristics of tributaries and mainstem stations. Explanations for flows are given in the text. Sediment loads are estimates using a bias correction technique described in the text.

	Flow			
Tributary	Annual 10^3 AF	Peak 10^3 AF	Base cfs	Sediment 10^3 Tons
Little Snake	433	365	35	2487
Yampa (at mouth)	1728	1383	461	3506
Duchesne	276	68	168	135
White	532	183	482	3724
Price	72	15	60	424
San Rafael	62	27	35	378
Green at Greendale	1420	116	1649	19
Green at Jensen	3226	1263	3163	N/A
Green at Green River	4256	1619	4030	9665
Green at mouth	4354	1652	3565	10457
Gunnison	1875	422	1888	636
Dolores	375	194	252	598
Dirty Devil	64	15	0	N/A
Escalante	7	1	3	N/A
Colorado at Cameo	2892	1201	2544	1358
Colorado at 15-Mile	2795	1428	1965	N/A
Colorado at State Line	4743	1488	4535	3558
Colorado at Cisco	5216	1743	4714	6049

Components of the Hydrograph

Temporal resolution at a scale finer than a year requires partitioning each annual hydrograph into components for which we believe there is some ecological relevance. The initiation of spring runoff is an important event for triggering spawning migrations of the Colorado pikeminnow, the magnitude of spring runoff may be an important determinant of conditions in spawning habitat, and base flow conditions may influence the quantity and quality of nursery habitat. Storm flows may contribute sediment that is essential for creation and maintenance of nursery habitat. Each of these components can be quantified, and the contribution of each tributary assessed.

Timing of Peak Snowmelt Runoff

Hydrographs in most rivers in the study area are dominated by runoff from annual snowmelt. The timing of runoff is reasonably predictable, but magnitude is not. Records from the USGS database give the date and magnitude of instantaneous peak flow in each water year for each station. The date of the instantaneous peak flow is convenient to obtain, although it may not be as useful a measure as a centroid of flow (analogous to the center of mass) during the runoff event. For most stations, peak flow

occurs in a relatively narrow time window associated with spring runoff (Table 9). In the larger tributaries, peak flow tends to occur within a relatively narrow time window at the end of May or in early June (Figure 3). These tributaries have headwaters in high elevation areas. In some basins (Figure 4), runoff clearly begins in March, and may extend well into July (e.g., Little Snake, Yampa). The smaller tributaries in relatively arid basins (e.g., Price, San Rafael, Dirty Devil, and Escalante) tend to have peak flows after the snowmelt runoff period; storm events occurring in the months of July through early November are a significant feature of the hydrograph for these rivers (Figure 5).

Tributary streams in the UCRB may be placed in one of two groups based on the timing of peak flow: larger tributaries for which the hydrograph is dominated by snowmelt runoff in spring, and smaller tributaries in which late summer storms produce brief pulses of high discharge. The former group will be more important for flows, but the latter group may have some importance for sediment delivery.

Base Flow

Base flow represents the contribution of groundwater to total stream flow (Gordon et al. 1992). In a regulated system, base flow may be augmented with releases from reservoirs or depleted by diversions. In the context of the annual hydrograph, the complement of base flow is direct flow contributed by precipitation events. For streams in the upper Colorado basin, the annual hydrograph tends to be dominated by the direct flow contribution of a single large runoff event that is the result of spring snowmelt. Flows from late summer through most of the winter tend to be low and are usually representative of base flow, except for the occasional storm event. Although the concept of base flow is readily understood, the practice of determining the baseflow contribution tends to be subjective and not amenable to rapid, quantitative characterization. However, a rapid analysis of many large data sets from streams with very different hydrologic regimes is necessary to create an overview.

Table 9. Timing of runoff peaks. (Some percents may not total 100 due to rounding.) May -June is the typical time for snowmelt runoff peaks.

River	Locator	Median Date	% of Annual Peaks Occurring in: Mar-Apr	May-Jun	Jul-Oct	Nov-Feb
Colorado	Cameo, CO	7 Jun	0	100	0	0
Plateau	Cameo, CO	14 Jun	3	93	0	3
Colorado	Palisade, CO	31 May	0	100	0	0
Gunnison	Grand Junction	19 May	10	87	0	3
Colorado	CO-UT line	8 Jun	0	100	0	0
Dolores	Cisco, UT	22 May	9	91	0	0
Colorado	Cisco, UT	31 May	3	97	0	0
Green	Greendale	22 May	6	42	21	30
Yampa	Maybell, CO	24 May	3	97	0	0
Little Snake	Lily, CO	21 May	12	85	3	0
Green	Jensen, UT	24 May	3	97	0	0
Duchesne	Randlett, UT	12 Jun	9	78	9	4
White	Watson, UT	28 May	4	93	0	4
Price	Woodside, UT	27 Aug	0	11	78	11
Green	Green River, UT	28 May	0	100	0	0
San Rafael	Green River, UT	18 Aug	4	38	50	8
Dirty Devil	Hanksville, UT	1 Aug	15	12	65	8
Escalante	Escalante, UT	7 Aug	15	46	35	4

We developed a simplified approach that can be applied in a practical sense to many large data sets. It involves a non-standard definition of base flow for the purpose of characterizing flows in the year following each runoff event. This approach, although somewhat simplistic, enables comparisons across water years that are influenced by diverse climatic conditions, and across streams with dissimilar hydrologic regimes. June 1st is used as the beginning of each base flow year because it is representative of the peak of the annual hydrograph for most sites in most years. Variations in the timing of peak runoff have little impact on this procedure as will be explained later. The next step entails calculation of the harmonic mean of daily flows for each time interval from June 1 to May 31. The base flow year is offset from the water year by four months, and it spans parts of two water years. Thus, the 1996 base flow year extended from 1 June 1995 through 31 May 1996; it includes parts of WY95 and WY96, and is influenced primarily by peak flows from WY95.

The harmonic mean is used in preference to flow percentiles because it weights low flows in a manner that has been used frequently for regulatory purposes related to water quality (e.g., Rossman 1990). It is also relatively insensitive to high peak flows associated with runoff or storms. From inspection of several data sets, the harmonic mean flow is always less than the median, and is usually close to the 40th percentile. We will treat base flows as if they were additive so that tributaries can be compared.

Base flow in the Green River is dominated by releases from Flaming Gorge Reservoir (Table 10). Even the Yampa River, which matches the annual release from Flaming Gorge Reservoir, adds relatively little (typically less than 20%) to base flow in the Green River at their confluence. Only the White River is on a par with the Yampa in terms of its contribution to base flow in the Green River. In the Colorado River system, the Gunnison makes a substantial contribution to base flow, typically exceeding the mainstem where the rivers join. Impoundments in the Gunnison and upper Colorado basin increase base flows relative to the natural hydrograph, whereas the same is not true of the Yampa basin.

In the system as a whole, the regulated portions of the drainage play a prominent role in setting base flow levels; this is to be expected because impoundments are releasing water for irrigation during the growing season. Each mainstem source (Flaming Gorge and Colorado below the Grand Valley diversion) accounts for about half of the base flow measured at the Colorado-Green confluence. The only tributary that makes a large contribution is the Gunnison, which is also regulated.

Maintenance of base flows differ in Green and Colorado River mainstreams. Base flows in the Colorado River are dominated by the Gunnison River, while base flow in the Green River is set by operation of Flaming Gorge Reservoir. The relatively small contributions of large tributaries like the Yampa and the White Rivers to base flow in the Green underscore the importance of the alteration to the natural hydrograph of the Green River. By increasing base flow, impoundments shift the chemical composition of water because mass transport from impounded sources is increased relative to unregulated sources. Changing the chemical composition of water in the mainstem may have unanticipated outcomes, for example, it is known that olfactory cues, used as signals and for locating spawning areas in many fishes may involve a subtle mix of components that could be altered by changing water sources (e.g., Hasler and Scholz 1983).

Peak Runoff

The ratio of peak daily flow in each water year to base flow in the following year (Table 10) helps to characterize the tributaries with respect to flushing flows (Gordon et al. 1992). The very smallest tributaries (e.g., Escalante and Dirty Devil) have very high ratios because base flows are very low, and peak flows typically represent intense storm events with rapid runoff (Table 10; NB: We emphasize again that these ratios are based on peak daily flows, not instantaneous flows, and consequently these ratios may differ from those reported elsewhere). The general tendency is for the ratio to be in excess of 10 for the larger, unregulated streams in the basin. However, the ratio is not uniform: the White River, which is regulated little in terms of storage capacity; shows a ratio of about 6.

Table 10. Relative contributions of tributaries to base and peak flows, and the median ratio of annual peak day to base flow. Upper portion of the table shows contribution relative to flow below confluence of each tributary with the mainstream. Lower portions of the table show contribution to the Green at its mouth, the Colorado at Cisco, or the Colorado below the Green.

		Relative Contribution at:		Ratio Within
Tributary	Main	Base Flow	Peak Flow	Tributary
Little Snake	Yampa	7.5%	28.3%	143.1
Yampa	Green	17.0%	109.0%	25
Duchesne	Green	5.6%	7.5%	16.6
White	Green	13.1%	11.9%	6.6
Price	Green	1.4%	2.1%	28.4
San Rafael	Green	1.0%	1.6%	37.3
Plateau	Colorado	4.3%	4.0%	13.7
Gunnison	Colorado	53.5%	38.3%	8.9
Dolores	Colorado	5.4%	19.2%	20.5
Green at Greendale	Green	44.3%	6.9%	3.1
Yampa	Green[1]	12.2%	89.6%	
Duchesne	Green[1]	4.6%	5.8%	
White	Green[1]	12.0%	11.8%	
Price	Green[1]	1.4%	2.0%	
San Rafael	Green[1]	1.0%	1.6%	
Colorado at Cameo	Colorado[2]	51.7%	62.8%	7.5
Plateau	Colorado[2]	2.5%	3.1%	
Gunnison	Colorado[2]	40.1%	24.3%	
Dolores	Colorado[2]	5.4%	18.9%	
Green[1]	Colorado[3]	44.9%	45.7%	7.3
Colorado[2]	Colorado[3]	55.1%	54.3%	7.5
Dirty Devil	Colorado[3]	0.0%	0.5%	3780
Escalante	Colorado[3]	0.0%	0.1%	26.7

[1] – at mouth
[2] – at Cisco
[3] – at Hite

Ratios are very low below Flaming Gorge dam and in the Gunnison River at its mouth. At Greendale, the peak daily flow in the Green River is typically only 2.5-3 times the ensuing base flow. Under present conditions, the ratio may be constrained on the high side by the capacity to release water from the structure and on the low side by obligations to meed downstream commitments during the base flow period. The ratio increases to about 6 at Jensen (not shown in Table 10), which reflects flows added by the Yampa River. In the Gunnison River, the ratio near its mouth is now about 4.

For historical perspective, we also analyzed flows recorded by USGS prior to construction of Flaming Gorge Reservoir. The ratio was almost 14 at Greendale, and 12.5 at Jensen. Siimilarly, the ratio in the Gunnison River was 12 prior to the

construction of the Aspinall Unit. The reduction in the ratio may be due as much to increased base flow as to diminution of the peak , and that issue deserves more attention.

Peak Flow Contributions

The relative importance of each tributary also can be assessed by the amount of water added to the system during spring runoff. Although the conceptual basis for such a calculation is simple, the practical aspects warrant comment. Peak flows associated with snowmelt almost always occur in May or June. Snowmelt begins much earlier, however, in some parts of the system. For example, the typical hydrographs of the Little Snake and Yampa Rivers show flows increasing in March. For simplicity, we define peak runoff as the flows in excess of base flow that are delivered in April-July. Flows at some stations may still be elevated slightly above base flow in August, but August is not included in the peak runoff period because focus shifts to storm events in that month. The simple calculations used to derive base flow and peak flow components are designed primarily to show the relative importance of the tributaries and are not likely to produce values that are additive in a strict sense. A more refined approach is possible, but would entail a much more sophisticated hydrograph separation analysis.

Relative contributions of tributaries to peak flows in the mainstem are shown in Table 10. Perhaps the most striking feature is the role of the Yampa River in creating peak flow conditions observed downstream in the Green River After closure of Flaming Gorge Dam, virtually all of the peak flow at Jensen and most of the peak flow at Green River have been the result of spring runoff from the Yampa River basin (including the Little Snake). Historically, Flaming Gorge Dam has been operated to decrease flows in response to the Yampa flood peak to prevent flooding in the Uinta basin (Schmidt 1996). Recent flow recommendations (Muth et al. 2000) would require increased spring releases from Flaming Gorge Dam to augment yearly peak flows. However, Yampa River flows remain the major force in maintaining a natural shape to the hydrograph in the mainstrem Green River (Muth et al. 2000). The White River also makes an important contribution to peak flow in the Green River, although it contributes much less than the Yampa River.

In the Colorado River system, sources of peak flows are more evenly distributed. The Gunnison and the Dolores make major contributions, but are not dominant in the way that the Yampa River is within the Green River system. Spring runoff is still a very conspicuous feature of the hydrograph of the Colorado River at Cameo, unlike the Green River below Flaming Gorge.

Unregulated flows of the Yampa River produce almost all of the spring runoff signal observed in the Green River downstream of their confluence. To the extent that the runoff event is important for the life cycles of the native fishes, this contribution is indispensable. The nature of flow regulation in the Colorado River system yields peak

flows composed of contributions distributed more evenly among different sources. In part, this is because individual impoundments and cumulative storage capacity are smaller in the Colorado River system than in the Green River system, where one impoundment exerts a dominant influence on the hydrograph.

Storm Flow

Although storms may occur within any of the basins, they are only a notable part of the hydrograph in four small tributaries that originate in Utah (Price, San Rafael, Dirty Devil, and Escalante). In those basins, less than 35% of the instantaneous peak flows occur within the typical window for snowmelt runoff peaks (May-June; Table 9). However, storm flows are a defining attribute of these lower elevation drainages and provide inputs of sediment and nutrients to the main channel during the base flow period. When these conditions occur outside of the typical runoff window, they may contribute an important source of flow and sediment to mainstem reaches.

Sediment

Sediment Data Record

Our goal was to estimate the contribution that each tributary makes to transport of suspended sediment in the mainstem reaches under present conditions. The data record available for suspended sediment in the upper Colorado River basin is very extensive, including a few stations where daily measurements have been taken for many years. A network of sites with daily measurements was set up initially to aid with decisions related to planning and design of reservoirs in the Colorado River basin (Andrews 1991). These records are available from a USGS suspended sediment database that is on-line (http://webserver.cr.usgs.gov/sediment/). For most locations, however, the data record is more meager, consisting of grab samples taken several times a year. When values are not available for each day in the record, rating curves must be created from the grab sample data and used to calculate transport on days when suspended sediment was not measured.

Standard procedure for preparing the sediment rating curve involves a power function:

> ($\mathbf{L = aQ^b}$, where L is load, Q is discharge, and terms a and b are estimated by linear regression; Crawford 1991).

Different rating curves were prepared for different parts of the hydrograph. A curve describing sediment transport on the ascending phase of the hydrograph was developed for the months March-May, when flows rise prior to the typical peak near 1 June. A second curve was applied to the months of June-August when flows are typically declining to base flow levels. The ascending and descending phases of the hydrograph are separated because suspended sediment concentrations often show hysteresis (e.g., Reid and Frostick 1994). Rather than examine each data set for

hysteresis, we will assume that it is present in all cases. The remainder of the year (September-February) will be characterized with a third equation for base flow conditions. These simplifications were necessary for handling large data sets efficiently. The data sets are large enough that even after dividing the data into three groups based on time of year, sample size exceeds 30 for most regression analyses. Rating curves were applied to all daily flows in order to avoid some of the limitations inherent in the use of flow duration curves (e.g., Walling 1977).

Our estimates of sediment load do not include bedload, and thus are not estimates of total sediment load. Nevertheless, suspended load, as a percent of total load, tends to be high in most of these rivers: 78% in the Yampa at Maybell (Andrews 1978), 93% in the Little Snake at Lily, CO (Andrews 1978), 95% in the Yampa at Deerlodge Park (Elliott et al. 1984), 97% in the White River (Tobin 1993), and 98% in the Colorado near De Beque (Butler 1986).

Uncorrected Sediment Estimates

The relative contributions of the tributaries to sediment transport in the mainstem of the Green River offer a sharp contrast to the relative contributions to flow. This is evident in Table 11, which is based exclusively on calculated sediment loads because observed loads are available for so few stations and years. The release from Flaming Gorge contains very little suspended sediment. The estimated contribution released from Flaming Gorge Reservoir is even less than that of Red Creek, which carries only a fraction of the water. The Little Snake River, which contributes a relatively small amount of water to the system, is responsible for about 70% of the sediment carried by the Yampa below their confluence. The Yampa and the Little Snake together contribute about a third of the sediment transported by the Green River. The importance of the Little Snake in this regard has been noted previously (Andrews 1978). Matching the Yampa in sediment delivery is the White River, which was only of moderate importance for its contributions to flow. The smaller tributaries (Duchesne, Price, San Rafael) typically contribute little, although the contribution may be highly variable from year to year.

In the Colorado River, the relative importance of sediment sources more closely resembles relative importance based on flows. In part, this is because the mainstem of the Colorado River, in contrast to the Green River below Flaming Gorge, still makes a significant contribution to sediment load. Estimated transport of suspended sediment in the Colorado River increases greatly (ca. 4x) between Cameo and Cisco (Table 12). Estimates based on rating curves suggest that the Gunnison and Dolores Rivers account for less than half of the observed increase. Plateau Creek may account for some of the increase, but sufficient data are not available for constructing a rating curve. Our results differ somewhat from estimates made by Pitlick and Cress (1999) who estimated a greater role for the Gunnison River. We suspect that our rating curve at Cisco may be unduly influenced by a small number of exceptionally high sediment concentrations.

Table 11. Relative contributions of each tributary to sediment transport in each mainstem unit (at mouth). Contributions are shown on the basis of uncorrected sediment load estimates and also for estimated loads that have been corrected for bias. (Ratio = median values of corrected:uncorrected sediment transport)

		Median % Contribution		
Tributary	Main	Uncorrected	Bias-Corrected	Ratio
Little Snake	Yampa	71	76	1.94
Green at Greendale	Green[1]	0.2	0.2	1.91
Yampa (mouth)	Green[1]	30.6	31.6	1.76
Duchesne	Green[1]	1.3	1.2	1.50
White	Green[1]	33.2	36.7	1.78
Price	Green[1]	4.1	6.4	2.28
San Rafael	Green[1]	2.6	4.0	2.54
Colorado at Cameo	Colorado[2]	24.5	23.0	1.57
Gunnison	Colorado[2]	11.7	9.7	1.38
Dolores	Colorado[2]	19.3	19.4	1.65
Colorado at Cisco	Colorado[3]	38.4	38.3	1.69
Green at mouth	Colorado[3]	61.6	61.7	1.66

[1] – at mouth
[2] – at Cisco
[3] – at Hite

At the junction of the Colorado and Green Rivers, the Green River carries more sediment even though the two rivers are roughly equal in flow. The Green River delivers about 60% of the total carried by the river below the confluence. The proportion may actually be higher if our sediment relationship overstates transport in the Colorado at Cisco.

Bias-Corrected Estimates

Rating curves derived from linear regression that are applied to log-transformed flow and sediment data will tend to underestimate sediment loads because back-transformation introduces a bias (Crawford 1991, Duan 1983). At least three bias correction methods have been proposed, but the minimum-variance unbiased estimate (MVUE) approach is generally recommended (Crawford 1991). The computational procedure is cumbersome because it involves a separate correction for each daily flow. We have implemented the correction using algorithms described in supporting documentation for the USGS suspended sediment database (http://webserver.cr.usgs.gov/sediment/). Bias correction increases estimates of sediment transport at each site, especially for the smaller streams in which discharge tends to be “flashy.” In general, correction for bias raised the transport estimates by 40-70% in the Colorado River system (Table 11). These adjustments are more modest

than those applied to most stations, especially the smaller tributaries, in the Green River basin.

Comparisons

The sediment estimates can be compared with a relatively long record of daily measured values in the Green River at Green River, Utah, and in the Colorado River near Cisco. Our uncorrected estimates of annual sediment transport at Green River were about 30% less than measured values, while the bias-corrected estimates were about 30% high. Application of bias correction to rating curves for the Colorado River produced more satisfactory results in the sense that estimates were closer to observed values. Uncorrected rating curves for the Colorado River near Cisco yielded annual sediment transport values that were typically about 50% of the measured values. Correction for bias using the MVUE approach yielded estimates that were about 90% of the measured values.

Other workers have produced sediment transport estimates for rivers in the basin. The most applicable studies are those of Andrews (1986) on the Green River basin and Pitlick (Pitlick and Cress 1999, Pitlick et al. 1999) on the Colorado River (Table 12). To some extent the differences among studies are the result of using data from different time periods and estimating transport by different methods. Nevertheless, it is encouraging that the general patterns are similar, especially for the Colorado River system.

Table 12. Comparison of average annual sediment transport estimates (millions of tons) in this study with those published previously.

Location	This Study	Previous	Citation
Colorado at Cameo	1.80	1.65	Calculated from data in Pitlick and Cress 1999
Colorado at state line	4.33	3.98	
Colorado at Cisco	8.22	5.48	
Yampa at Maybell	0.81	0.39	Andrews 1986
Little Snake at Lily	2.36	1.29	
White at Ouray	4.24	1.67	
Price	1.2	2.18	
Green at Green River	10.81	8.83	

The Green River carries a higher sediment load than the Colorado River, and the Yampa basin supplies flows and sediment to the Green River in a seasonal pattern that is largely unaltered. Suspended sediment is important for the creation and maintenance of certain habitats (e.g., nursery habitat for the Colorado pikeminnow), but

there is much uncertainty in existing sediment transport estimates and more research is needed. Thus, the mechanisms involved with habitat formation are not understood. Moreover, most existing estimates of transport focus on suspended sediment, and there is a need for more comprehensive inclusion of those sediment materials that become a part of habitat.

Sediment transport in the Green River was altered by closure of Flaming Gorge Dam (Andrews 1986). Although a comparison of pre- and post-impoundment conditions is not part of our study, ecologically significant changes in geomorphology have occurred, and one of those changes merits comment here. The effective discharge (most important for sediment transport) decreased in the Green River after closure of the dam. The change was most noticeable at Jensen, where the value dropped to 11,500 cfs from 20,500 cfs (Andrews 1986). Wick (1997) believes the change has significant implications for razorback suckers because mobilization of sediment at lower flows may deposit sand on spawning bars at a vulnerable time in its life history. The general view from studies in the upper Colorado River basin is that effective discharge is very close to bankfull discharge (Andrews 1980, Pitlick and van Steeter 1998). Channel shape should adjust to a new equilibrium as a result of the new flow regime imposed by operation of Flaming Gorge Reservoir. Andrews (1986) showed that the channel was narrowing and this is consistent with a reduction in effective discharge. The more important question from an ecological perspective concerns the period of disequilibrium until the new channel is established: Is there risk to razorback sucker spawning habitat while channel conditions are shifting to a new equilibrium?

Water Quality

Definition of Concerns

Rather than providing a general review of water quality in the upper Colorado River basin, we restrict our attention to water quality issues of concern to previous investigators in connection with recovery of the endangered fishes, which include selenium, metals, suspended sediment, and temperature. However, we do not devote effort to temperature for two reasons: 1) much study has already been devoted to the topic (e.g., Muth et al. 2000), and 2) there is little basis for judging tributary contributions without undertaking a massive modeling project.

We have also assembled a brief overview of hazardous materials in each basin drawn from information obtained through an EPA website (http://www.epa.gov/surf/) entitled "Surf Your Watershed." The website lists Superfund sites, toxic release inventories (TRI), and hazardous material generation sites within each basin. Not all such sites pose any potential threat to endangered fishes. This list is included to highlight those risks that might be experienced by all aquatic organisms.

State agencies responsible for water quality issues produce reports, including "303(d)" lists, that highlight water quality concerns within each basin (Utah Department of

Environmental Quality 1998, Colorado Department of Public Health and the Environment 1998). The reports also list constituents slated for total maximum daily load (TMDL) development in each basin, and the priority for developing each TMDL.

Selenium

Selenium concentrations in two parts of the UCR basin are high enough to elicit concerns from state water quality agencies. There also are concerns that selenium contamination historically hastened the decline of native Colorado river fishes and continues to inhibit recovery of the endangered fishes (Hamilton 1998,1999). Especially of concern is the possibility that selenium interferes with endangered fish reproduction (reviewed in USFWS 1998). Studies have suggested a link between selenium concentrations and reproductive failure in razorback suckers (Waddell and May 1985, Hamilton and Waddell 1992). In a study of the Stewart Lake Waterfowl Management Area, Doyle et al. (1988) reported high selenium concentrations in irrigation drains as well as in carp tissues. Another study reported selenium in concentrations high enough to have adverse effects on the biota of the Desert Lake Wildlife Management Area and Olsen Reservoir, both in the Price River basin.

The Recovery Program is concerned about selenium exposure to razorback sucker in Stewart Lake and Ashley Creek (USFWS 2000) and the State of Utah has identified the reach of Ashley Creek above its confluence with the Green River as a target for future TMDL development. Levels of selenium in fish tissue were high enough to warrant a fish consumption advisory. Seepage from a municipal wastewater lagoon causes selenium to be leached from a geological formation. TMDL development within this basin is low priority and not planned for the near future.

The State of Colorado has noted some concern about selenium in the North Fork of the Gunnison, the lower Uncompahgre, and the Gunnison below its confluence with the Uncompahgre. The State also recognizes the need for additional data on concentrations of selenium in the Colorado River downstream of its confluence with the Gunnison. A recent federal report lists average concentrations of 7 ppb in the Gunnison and 5.7 ppb in the Colorado River near Cisco (USDI 1997). The Uncompahgre basin appears to be the primary source of the selenium in the watershed above Lake Powell (Apodaca et al. 1996).

Heavy Metals

Even in low concentrations, metals tend to be toxic to aquatic life. A recent study has suggested that metals like copper and zinc may be affecting reproduction of razorback suckers (Buhl and Hamilton 1996). In Utah, metals are not identified as a concern in stream reaches of the tributaries covered in this study. The subject may still merit further evaluation because of a particular water quality problem in many lakes. Many of the lakes and reservoirs in the basins of the tributaries experience seasonal depletion of dissolved oxygen (Utah Department of Environmental Quality 1998). Of 26 lakes and

reservoirs listed in the Green River drainage (which includes the Duchesne, Price and San Rafael rivers) as needing TMDL analyses, 25 show dissolved oxygen as a specific pollutant. Reservoirs on the list include Fish Lake, Pelican Lake, Scofield Reservoir, and Strawberry Reservoir. When dissolved oxygen is lost from the hypolimnion in summer, or from lakes under ice cover, metals may be released from lake sediments. This phenomenon received some attention in a study of Scofield Reservoir where potential problems with manganese and zinc were identified (Stephens et al. 1996). Particularly in lakes with bottom withdrawal, there is potential for elevated concentrations of metals in the outflow at certain times of year. Elevated concentrations may not occur often and thus could be missed by a monitoring program with infrequent sampling.

Several stream reaches in the study area of the Colorado River and its tributaries (Uncompahgre and San Miguel) have been listed by the State of Colorado because of high concentrations of metals (e.g., zinc, copper, cadmium). Elevated concentrations are typically associated with mining sites (Deacon and Driver 1999). In most cases, the sources are relatively far from habitat used by the endangered fishes, and the State has not registered concern about metals concentrations in the mainstem of the Colorado (as it has for selenium). In general, reservoirs in this part of Colorado are not as likely to show oxygen depletion as reservoirs mentioned previously in Utah, and thus there is less potential for the mobilization of metals in these lake sediments.

Suspended Sediment

Suspended sediment is one of the more complex water quality issues with regard to the endangered fishes. An abundance of sediment may help create important habitat, and high concentrations in suspension may screen native fishes from visual predators (Johnson and Hines 1999). On the other hand, sediment that settles on spawning habitat may be detrimental to reproduction. More importantly, managers of cold water fisheries typically view suspended sediment as a problem requiring management action (e.g., Waters 1995). For example, the U.S. Bureau of Land Management (BLM) has long been concerned about sediment from Red Creek and its potential for degrading water quality in the Green River (BLM 1981). Their plan recommends construction of sediment retention dams and other erosion control measures, ostensibly for the benefit of the trout fishery below Flaming Gorge Reservoir. In the plan, no attention is given to the effect that a reduced sediment supply might have on habitat of the endangered fishes. Other federal agencies have expressed concern about this plan and no action has been taken as a result. The issue goes well beyond the potential effects of sediment from Red Creek alone. The irregular timing and amount of sediment deliveries caused by storm events in small drainages may have important implications for habitat quality from the perspective of the endangered fishes, and this possibility cannot be assessed adequately with the information available.

The State of Utah lists concerns about sediment in two tributaries to the Duchesne, and in the Escalante. TMDL development is expected soon for the reach of the Uinta just

above its confluence with the Duchesne. The State of Colorado has identified potential sediment problems in the lower Uncompahgre, the lower Gunnison, much of the White River basin, the lower Yampa, the Little Snake, and the Colorado River above its confluence with the Gunnison. Although the Colorado streams are now listed for monitoring and evaluation, it is reasonable to expect that some or all of those stream reaches will be targeted for TMDL development in the future.

Most of the concerns for sediments in streams have been in response to deleterious affects on trout habitat. In this regard, State water quality agencies have identified several stream reaches for implementation of TMDLs for suspended sediment. We believe that these management decisions have been shaped primarily for the benefit of cold water fisheries (e.g., see Waters 1995). If so, the standards could potentially harm recovery efforts for the warmwater endangered fishes.

Hazardous Materials

The EPA maintains extensive lists of facilities that generate hazardous materials, as well as those industries that have released toxic substances to the environment, and locations of Superfund sites. These lists are organized by watershed and are summarized briefly in Table 13. All of the Superfund sites, except a plume of trichloromethane in Vernal, Utah, are along the Colorado River mainstem or in the Gunnison basin. The RCRA (Resource Conservation and Recovery Act) sites given in Table 13 reflect the location of industrial sites and is not necessarily an indication of actual or potential hazards to water quality. Any facility that generates hazardous materials must be counted even if all materials are properly handled and disposed. The toxic release inventory list applies only to certain types of facilities, and thus is not inclusive. It indicates only that a release has occurred, and does not allow us to reach conclusions about specific risks to aquatic organisms. Nevertheless, the greater the release of toxic substances in a particular watershed the greater the risk to aquatic life, including the endangered fishes.

Table 13. Hazardous waste facilities in each basin based on EPA inventories. Includes Superfund (CERCLA) sites, toxic release inventory (TRI) sites, and generators of hazardous wastes (RCRA). See text for explanation.

	Number of Facilities			
Tributary	CERCLA	TRI	RCRA	Comments
Ashley-Brush	1	0	29	
Little Snake	0	0	5	
Yampa	0	0	41	Mostly in Steamboat and Craig
Duchesne	0	1	29	
White	0	0	53	Mostly oil and gas industry
Price	0	2	22	
San Rafael	0	0	8	
Gunnison	2	3	92	Downstream of Aspinall Unit
Dolores	0	0	28	
Dirty Devil	0	0	1	
Escalante	0	0	0	
Mainstem Green	0	0	6	Downstream of Flaming Gorge
Mainstem Colorado	5	13	71	Downstream of Parachute

Overview of Indirect Contributions

We used each of the indirect contributions and factors addressed above to rank tributaries using an ordinal scale (high, medium, low) that provides a qualitative overview of all tributaries together (Table 14). We emphasize that indirect contributions are secondary to direct contributions in terms of support for recovery. In other words, if a stream has habitat that is used by the endangered fishes, that consideration outweighs issues related to indirect contributions of flow, sediment, and water quality. For attributes related to the amount of flow or sediment transport, rankings are based on a subjective assessment of quantitative contributions, as presented in Tables 7,10, and 11. (For example, in Table 14 the highest ranks for flows in the Green River are given to the Yampa and tributary Green rivers; each provides about 37% of the annual flow. Lowest ranks in the Green River are given to the Price and San Rafael rivers; each of these streams provides only about 2% of the flow. The remaining tributaries that are ranked “moderate” provide an amount of flow that is intermediate between these two extremes.) Ranks based on the “natural hydrograph” attribute are different in the sense that they are independent of the amount of flow; large or small tributaries that still exhibit a natural hydrograph would be ranked high. Our basis for assigning ranks is the accumulated amount of reservoir storage in each basin (Table 6).

Tributaries vary greatly in terms of the relative importance of contributions that we could measure. Examination of that variation is instructive for understanding spatial and temporal features of the forces shaping habitat in the mainstem reaches used by the endangered fishes. In two cases, however, there seems to be little reason to continue

that examination. Contributions of the Dirty Devil and Escalante Rivers are scarcely noticeable in the Colorado River basin, and those contributions do not enter the system until Lake Powell. Because their contributions are quantitatively insignificant and geographically irrelevant, they are not included in the matrix of indirect factors (Table 14).

The Yampa River is mostly unregulated despite the existence of a few relatively small impoundments mainly in the upper part of the basin. The amount and timing of flows delivered to the Green River play a key role in shaping the present hydrograph of the Green River. In particular, peak flows from the Yampa constitute virtually all of the peak observed in the downstream Green River. This extraordinary situation occurs because the temporal pattern of release from Flaming Gorge Reservoir preserves little of the natural hydrograph in the Green River. Moreover, historic operation of Flaming Gorge elevates base flow so much that the base flow contributions of the Yampa and other tributaries are diminished in a relative sense. Although flow recommendations have been made to operate Flaming Gorge Dam in ways that will produce a more natural hydrograph, high flows are constrained by operational capability and Yampa River flows will remain important for producing a natural shape to the hydrograph. The Yampa is also important for its contributions of suspended sediment, most of which comes from the Little Snake sub-basin. The Yampa basin is essentially free of water quality impairments, except for rare events such as spills from pipelines.

The White River makes a very important contribution to suspended sediment in the Green River, and is of moderate importance for flow contributions. The White River is largely unregulated, but its direct importance for recovery was greatly diminished by construction of Taylor Draw Dam that has trapped sediment and blocks movement of Colorado pikeminnow into about one-third of the habitat that was once important for adults (Irving and Modde 2000).

Indirect contributions from the other three tributaries (Duchesne, Price, and San Rafael) are small in comparison to those of the White and the Yampa Rivers. All three of these tributaries contribute little and are strongly influenced by impoundments (each basin has enough storage to handle at least a year of typical flow).

Table 14 Matrix of flow and sediment attributes for tributaries, and obstacles for recovery presented by tributary streams to achieve potential support of endangered fishes. Attributes are ranked on an ordinal scale. (H,M,L = high, moderate, and low benefit to endangered fishes).

Tributary	Flow/Sediment Attributes					Recovery Obstacles
	Natural hydrograph	Annual flow	Base flow	Peak flow	Sediment	
Little Snake	H	M	L	M	H	Nonnatives
Yampa	H	H	M	H	H	Nonnatives
Tributary Green	L	H	H	L	L	Flow regulation, temperature, nonnatives
Duchesne	L	M	L	L	L	Flow depletion, nonnative
White	H	M	M	M	H	Barrier, nonnatives
Price	L	L	L	L	L	Flow depletion
San Rafael	L	L	L	L	L	Flow depletion
Tributary Colorado	M	H	H	H	H	Barriers
Plateau	M	L	L	L	L(?)	Barriers
Gunnison	M	H	H	M	H	Water quality, Barriers
Dolores	L	M	L	M	H	Water quality (?)

In the Colorado River system, the effect of flow regulation is pervasive; none of the tributaries can be considered unregulated. By the same token, the mainstem of the Colorado is less influenced by flow regulation than the mainstem of the Green. Plateau Creek is small enough that its contributions are relatively insignificant. The other two tributaries (Gunnison and Dolores) make important flow and sediment contributions, but their recovery value is reduced by water quality problems (Dolores River) and by partial and total barriers to fish movement (Gunnison).

SYNTHESIS AND DISCUSSION

The following section identifies direct and indirect benefits to the endangered fishes in specific areas that support populations of one or more of the listed fishes, and discusses potential recovery roles. The evaluation of the presence, relative number, and location of individual endangered fishes in tributary streams was greatly aided by fish collection records from 1979 to 1997, provided by the Recovery Program (Table 1). Other stream studies also were helpful in assessing recovery needs.

Reach 1: Yampa River and Tributaries

The Yampa River, largest tributary to the Green River, is important in its own right for supporting remnant populations of three of the endangered fishes. It also has been considered the key to maintaining habitat conditions and hence endangered fish populations in the downstream Green River (e.g., Holden 1978, 1980), due to its unaltered patterns of seasonal flows and sediment inputs (Andrews 1978,1980; Tyus and Karp 1989, 1991; Modde and Smith 1995). Originating at elevations of about 12,500 ft. amsl in the western slope of the Rocky Mountains near Yampa, Colorado, it flows about 200 mi, drops about 7,400 ft. in elevation, and drains a basin of about 7,600 mi^2. The river flows through agricultural valleys of relatively low gradient, short sections of higher gradient canyons (Juniper and Cross Mountain canyons), and enters Yampa Canyon (RM 47) before joining the Green River in Dinosaur National Monument. The Little Snake River, the Yampa River's largest tributary, joins the mainstream river (RM 51) in Lily Park, and comprises about 28% of the average annual flow of 1.2 MAF delivered to the Green River at Echo Park on the Yampa River. Present flows differ little from historic conditions, and spring flows can be high (e.g., 33,200 cfs on May 18, 1984). However, there was 110,000 AF of Yampa flows depleted by 1989 and further depletions also are occurring (Hydrosphere Resource Consultants1995) .

The Yampa River was intensively sampled in the 1960s by Paul Holden (Holden and Stalnaker 1975) and by the Colorado Division of Wildlife and USFWS in the 1970s and 1980s. Miller et al. (1982c) divided the lower 124 miles of the river into eight strata representing different physical habitat units. Differences between strata were considerable as indicated by stream gradients ranging from a drop of about 3 feet/mi in Deerlodge Park to 55 feet/mi in Cross Mountain Canyon. The Yampa River above Juniper Canyon grades into a coolwater stream.

Based on historic records and anecdotal information (e.g., see Quartarone 1993) the Yampa River continues to support all of its historic fish populations, including remnant populations of Colorado pikeminnow (435 captured by Recovery Program in lower 138 miles, 1981-97), razorback sucker (31 captures in lower 37 miles), and humpback chub (172 captures in lower 44 miles). Adults of these species utilize the river for all of the year and maintain spawning areas within the mainstream (Tyus and Karp 1989, Modde and Smith 1995). Native fishes dominate the fish community (Table 3), with native suckers abundant in the warmwater sections of the middle river (Miller et al. 1982a, Wick and Hawkins 1985; Modde and Smith 1995). However, at least 19 nonnative fishes have been introduced into the Yampa River, including problem species such as northern pike, smallmouth bass, channel catfish, and common carp (Tyus et al. 1982a, Lynch et al. 1996). There has been much discussion about potential northern pike predation and competition with the endangered fishes since their recent introduction and proliferation into and downstream of the Yampa River (reviewed by Tyus and Beard 1990), and several adult Colorado pikeminnow with wounds obviously inflicted by northern pike have been reported (J. Hawkins, Colorado State University, Personal Communication 2001). Northern pike have thrived in the upper Yampa River and numbers have increased so much that a significant recreational fishery has developed. As northen pike increased, some biologist believe that the number of Colorado pikeminnow may have declined. Northern pike invasion into the Green River is of concern because the Recovery Program has found that young pikeminnow constitute 5% of the pike diet (USFWS 2000). An effort is underway to remove larger northern pike from the Yampa River, but there has been no committed effort to eradicate them.

Other Yampa River tributaries, such as the Elk River and Elkhead Creek do not support the endangered fishes directly, but have delivered nonnative fishes into the mainstream Yampa River. Efforts are being explored that would reduce the numbers of nonnative fishes escaping from these drainages, but the efficacy of that initiative is unknown to us.

Although no precise population estimate has been made for any of the endangered fish populations in the Yampa River, our review indicated that adult Colorado pikeminnow population is the largest that exists in any tributary stream, and collections of larval fishes indicates that the population continues to successfully reproduce each year (Haynes et al. 1984, Nesler et al. 1988; McAda et al. 1994). Adult pikeminnow captures demonstrate the heavy use of Yampa Canyon during late spring/early summer spawning and use of the upper 70-100 miles of the river as an adult concentration area for the remainder of the year (Figure 7). The lower 30 miles of Yampa Canyon are extensively used by spawning Colorado pikeminnow, with heavily-utilized spawning bars at river miles 16.5 and 18.2 (Wick et al. 1983, Tyus 1990). Most, and possibly all of the larvae pass out of the Yampa River and the adult population is sustained mostly by in-migration of subadult fish from the mainstream Green River (Tyus 1986). Upper sections of the river near Juniper Canyon are used by overwintering adult pikeminnow.

A reproducing population of humpback chub also exists in the Yampa River (Karp and Tyus 1990), which is one of the only two humpback chub populations in the Green River

basin. Early specimens collected in 1948 (Tyus 1998) indicate that this population is historic and formerly had a wider distribution (i.e., was once common in Castle Park). Decline of that population may have been related to introductions of nonnative fishes, such as channel catfish.

The Yampa River also provides habitat for razorback sucker. Several adults have been captured as far upstream as Lily Park (Ed Wick, personal communication, 1983), and a spawning area has been located just upstream from the confluence of the Yampa and Green Rivers in Echo Park, Dinosaur National Monument (Tyus 1987, Tyus and Karp 1990).

Portions of the Yampa River from Craig, Colorado, to its mouth are federally designated Critical Habitat for all four of the endangered species: Colorado pikeminnow = RM 0 - 131, razorback sucker = RM 0 - 52, and humpback and bonytail chub RM 0 - 44 (USFWS 1994). Various reaches have also been determined to be sensitive areas designated as Recovery Program priority recovery areas including: Priority 1, 2, and 3 recovery areas for Colorado pikeminnow, Priority 1 and 2 for razorback sucker, Priority 1 and 2 for humpback chub, Priority 1 for bonytail reintroduction, and Priority 4 for Colorado pikeminnow migration route (Biology Subcommittee 1984; USFWS 1987). The Yampa River also is identified as a sub-basin recovery priority by the Recovery Program, which has focused recovery actions on maintaining and legally protecting the natural flow regime of this important tributary (USFWS 2000).

Yampa River flows have long been considered to be essential for maintaining endangered fish habitat in the downstream Green River, partially ameliorating regulated flows released from Flaming Gorge Dam (Holden 1980; Tyus and Karp 1989, 1991; Modde and Smith 1995). Not only does the Yampa River provide about one-half of the water in the Green River downstream of Echo Park, it provides most of the sediment supply. In addition, the Yampa River is singularly responsible for providing a more natural hydrograph in the downstream Green River by providing a sizable peak flow and low base flow (Tyus and Karp 1989, 1991; Modde and Smith 1995).

Little Snake River

The Little Snake River is the only Yampa River tributary that is used as habitat by the endangered fishes. Fish populations of the Little Snake River, largest tributary to the Yampa River, have been surveyed by various workers, including Holden and Stalnaker (1975), Miller et al. (1982a), Wick et al. (1991) and Marsh et al. (1991), and includes reproducing populations of five native fish species (Table 4). In addition to telemetry of pikeminnow near the mouth of the Little Snake River (Miller et al. 1982a) a total of four humpback chub and four Colorado pikeminnow were captured by the Recovery Program from the lower 9 miles of the Little Snake River in 1988 and 1995. In addition, one large pikeminnow was captured near Baggs, Wyoming by Marsh et al. (1991). It is presumed that these fishes move between habitats in the Little Snake River and the Yampa River, depending upon flow conditions.

The Little Snake River is a small contributor of flow to the Yampa River, but it supplies most of the sediment. Flow from the Little Snake River provides only about 20% of the water in the downstream Yampa River, but it supplies about 70% of the sediment supply.

At present, the Little Snake River has not been designated as Critical Habitat or included as a sensitive area for any of the listed fishes. However, the Little Snake River has an important role in maintenance of sediment supplies to the Yampa and Green Rivers, and also supports individuals of two of the listed species. Because of its importance in maintaining constituent elements in the system, it should be reviewed as potentially warranting critical habitat designation. The Little Snake River is identified as a subbasin recovery priority area by the Recovery Program (USFWS 2000).

Reach 2: Green River and Tributaries above the Yampa River Confluence to Flaming Gorge Dam

The tributary Green River above the Yampa River confluence was profoundly changed by constructing Flaming Gorge Dam and the filling of the resulting reservoir. Dam closure in 1962 resulted in significant change in the character of the historic Green River, and some effects are noticeable throughout much of the 400 mi reach extending downstream to the Colorado River confluence (e.g., cold water temperatures and elevation of base flows). Further adverse changes to the natural system occurred when native fishes in the reservoir basin upstream of the dam, and to some extent downstream as well, were killed in a pre-impoundment poisoning program (reviewed by Holden 1991). Although detailed scientific studies were not made before this time to document the abundance of the four endangered fishes in the upper Green River, some surveys, anecdotal information, and existing photographs have documented the existence of all four species in this area (e.g., Vanicek et al. 1970, Quartarone 1993). Although some fishes, including Colorado pikeminnow were documented upstream in the Green River into Wyoming, all are presumed extirpated there due to stream blockage and habitat loss (Baxter and Stone 1995). Migrations of Colorado pikeminnow during the known spawning period, and attempted migrations after dam construction suggest that a spawning area once existed in the Flaming Gorge canyon (Quartarone 1993, G. Ross, U.S. National Park Service, Personal Communication, 1984), and the last bonytail captured in the Green River were taken in Flaming Gorge (Vanicek 1967).

Below Flaming Gorge dam, the Green River has been converted to a tailwater trout stream throughout Red Canyon. However, the resultant cold (rarely $>14^0$ C) and clear water is changed further downstream. By the time the river reaches Swallow Canyon (RM 265) it is affected by ambient warming during winter months and from runoff from highly erodible clay soils. Downstream effects of Flaming Gorge Dam on conditions in the Green River have been thoroughly presented by Muth et al. (2000), who made recommendations for enhanced conditions by providing more suitable instream flows. Essentially, the distribution hydrograph produced by dam operation results in an annual hydrograph that is flattened, with little seasonal peak, and with great daily fluctuations in response to power generation. Native fish populations downstream of Flaming Gorge Dam also are

negatively affected by cold water temperatures, lack of sediment supply and hence extreme water clarity, elevated base flows, reduced peak flows, and other problems. Reduction of these effects occurs as one progresses downstream of the dam, and presence of any of the endangered fishes in this reach during most of the year is likely due to summer warming (to 18^0 C) that occurs as the river widens in Browns Park. Turbidity provided from Red Creek, and to a less extent Vermillion Creek and local drainage, change the river's appearance. Further warming and sediment inputs make the river less suitable for trout in Lodore Canyon (summer water temperature of 22^0 C). However, large brown trout persist in some locations (e.g. at the mouth of Pot Creek, HMT), and may prey on the endangered fishes. Flows of the Green River are greatly changed by input of the Yampa River downstream in Echo Park (RM 347).

Recent studies have demonstrated that Colorado pikeminnow have re-occupied the Green River mainstream above Echo Park (29 captures by Recovery Program, RM 345-377, 1985-1997), mostly in Lodore Canyon (17 fish; Bestgen and Crist 2000). A few fish venture into Browns Park in summer where they are captured by anglers (J. Creasy, USFWS, personal communication, 1982) and the fish have been captured as far upstream as Swallow Canyon (pictures of captured fish provided by J. Coyner, USFWS, personal communication, 1990). Adult razorback sucker also utilize the Green River in lower Lodore Canyon (2 captures below Rm 365; 1989 and 95) where individuals of both species also over-winter (Valdez and Masslich 1989). Although the humpback chub appear to have been extirpated from Lodore Canyon, the Green River in DNM provides a desirable location for expansion of populations by management action (Nesler 2000). Bonytail were once reported as "numerous" in the Green River in DNM (Vanicek and Kramer 1969) and bonytail stocked in Browns Park could move downstream into DNM. Given the potential for predation on humpback chub (Marsh and Douglas 1997), there may be a need to control or eliminate trout in Lodore Canyon to aid in reestablishment of chubs.

This river reach has not been included in critical habitat designation or considered a priority recovery area. However, changes in the operation of Flaming Gorge Dam could make the upper Green River important for recovery (reviewed by Bestgen and Crist 2000).

Red Creek joins the Green River at the lower end of Red Canyon and contributes about 6,200 AF of water annually. Historic flows range from 0 to 1440 cfs, due to runoff from snowpack in spring and intense localized thunderstorm activity during summer months. The Red Creek Watershed drains Clay Basin, a region of about 150 mi^2 in Wyoming and Utah. Clay Basin is an area of severe erosion due to soft bedrock, steep topography and precipitation patterns. Low rainfall (which produces sparse plant cover), intense grazing, road building and other human activities result in 84,400 T of suspended sediment and 22,000 T of bedload delivered to the Green River annually (BLM 1981). Fish access to Red Creek is blocked by a natural waterfall above the floodplain of the Green River. Land ownership of Clay Basin is abut 78% Federal trust lands managed by the Bureau of Land Management, which has proposed a plan to control erosion for the purpose of improving trout habitat in the Green River.

Reach 3: Green River and Tributaries from the Yampa River Confluence to the Colorado River

Downstream of its confluence with the Yampa River in Dinosaur National Monument, the Green River flows through distinctly different habitats in Whirlpool Canyon, Island and Rainbow Parks, and Split Mountain Canyon (Miller et al. 1982a), before entering the broad alluvial valley of the Uintah Basin. Downstream of this point, the river travels through six relatively homogenous geomorphic strata (Tyus et al. 1982b), receiving the flows of the Duchesne and White Rivers near Ouray, Utah (about RM 248). Below these major tributaries the Green River exits the Uintah Basin and enters Desolation and Gray Canyons, a region of white water rapids, quiet runs, and deep pools. The Green River receives flows from the Price River just below Gray Canyon, where it enters the Green River Valley near the city of Green River, Utah. About 25 mi below the city it receives flows of the San Rafael River, as it proceeds through Labyrinth and Stillwater Canyons on its way to join the upper Colorado River in Canyonlands National Park.

The mainstream Green River historically supported populations of Colorado pikeminnow, razorback sucker, humpback chub and bonytail. Presently, the Green River presumably supports the largest population of Colorado pikeminnow (Holden and Stalnaker 1975, Tyus et al. 1982ab, Tyus 1991a), which includes a desirable mix of all life stages of this fish. The absolute number of Colorado pikeminnow in the mainstream Green River remains unknown. However, Tyus (1991a) used an average of six approximations to provide an estimate of about 8,000 adult-size fish using data obtained from 1979-1987. Although the accuracy of this estimate is unknown (confidence limits not computed) this approximation seems reasonable when compared to other efforts. Nesler (2000) also provided a rough estimate of Colorado pikeminnow occurrence in the Green River as 2,000 to 7,400 fish, which is in the same order of magnitude as numbers previously generated by Tyus (1991a).

The distribution of adults is indicated by recent capture records (Figure 8), however, capture locations are greatly infuenced by capture effort and methods, and Figure 8 does not demonstrate seasonal use patterns. In addition to supporting one of the two largest known spawning areas for the pikeminnow, the Green River provides nursery habitat for two spawning subpopulations, which include fishes that reside in the Green, Yampa, White, Duchesne, and perhaps other rivers (Tyus 1990). Only two known spawning areas for the razorback sucker have been confirmed in the UCRB, one in the Green River near Jensen, Utah, and the other at the junction of the Green and Yampa Rivers. However, recent larval sampling (Muth et al. 1998; Chart et al. 1999) suggests that other spawning areas also exist in the lower Green River. Humpback chub are routinely collected in the Desolation and Gray canyon areas, but the status of that population has apparently declined (reviewed by Tyus et al. 1982a).

Important habitats occupied by the endangered fishes in the Green River include extensive floodplains used by Colorado pikeminnow and razorback sucker in spring (Tyus

and Karp 1991; Muth et al. 2000), white water canyon habitat used by humpback chub all year, and seasonally for pikeminnow spawning, cobble bars in alluvial reaches used for razorback sucker spawning, large eddies and backwaters used for staging and feeding by all species, smaller backwaters and eddies used as nursery habitat by pikeminnow and razorback suckers, and other habitats used for various purposes.

The Green River from Echo Park to its mouth is designated Critical Habitat for all four of the endangered fishes (USFWS 1994), and supports populations of other native fishes. In addition, the Green River has been classified as a Priority 1 recovery area for Colorado pikeminnow adults, juveniles, youngs, and spawning, and for humpback chub and razorback sucker (USFWS 1987). It also has been used as a recovery site for bonytail (USFWS 1987). Razorback suckers have been stocked several times in this reach.

Ashley Creek

Ashley Creek, a relatively small tributary located near Vernal, Utah, provides some habitat for razorback sucker and Colorado pikeminnow. These fish occur predominantly in a large eddy created in spring of the year by the junction of Ashley Creek, Stewart Lake Drain, and the Green River. A total of 44 razorback sucker have been captured in the lower 0.5 mile of Ashley Creek since 1981; an area presumably used by this species as a staging area prior to reproduction elsewhere (Tyus 1987; Tyus and Karp 1990). One Colorado pikeminnow was captured 3 miles up Ashley Creek in 1984. As previously discussed, Ashley Creek and Stewart Lake Drain are of concern due to high levels of selenium, which could pose a recovery obstacle to razorback sucker.

Lower Ashley Creek within the 100-year floodplain of the Green River is protected by Critical Habitat designation and the lower 0.5 mi also is a Recovery Program Priority 1 area for razorback sucker staging prior to spawning (USFWS 1987).

Duchesne River

The Duchesne River originates in the southern Uintah Mountains as a number of tributaries that join and flow to the Green River near Ouray, Utah. It is the largest tributary to the Green River within the Uintah Basin, with a drainage basin of about 4,200 mi^2. However, this river has been extensively changed by water development over the past 100 years.

The Duchesne River historically produced about 947 million m^3 of water annually, but according to a USFWS biological opinion (unpublished, 1998) about 676 million m^3 has been depleted and more depletions are planned due to needs of the Central Utah Project. Anthropogenic impacts occurring since the nineteenth Century are principally changing land use and stream diversion (reviewed by Brink and Schmidt 1996). Many diversions occurred from 1865 to 1899 with establishment of the Uintah and Ouray Indian Reservations. Substantial flows out of headwater streams have been exported to Utah Lake basin since about 1915. By 1930, most headwater lakes had been dammed for

irrigation. Transbasin transfers of water have increased since about 1906, principally through the Strawberry and Duchesne tunnels. Changes also have occurred in stream geomorphology (Brink and Schmidt 1996) and channel change has been profound in some areas.

Adult Colorado pikeminnow are widely distributed in the lower 35 miles of the Duchesne River (Figure 9). Early stream surveys by the Utah Division of Wildlife Resources (J.S. Cranney, personal communication 1988) documented the presence of Colorado pikeminnow in the Duchesne River in 1956 (n=8) and 1968 (no numbers given), and in the tributary Uintah River (Mullan 1975). In addition, 2 young-of-year Colorado pikeminnow (67 and 69 mm TL) were collected at RM 3.6 on July 1, 1999 (Michael Hudson, Utah Division of Wildlife Resources) where they likely entered from the Green River. Anecdotal information about captures by Native Americans (Seethaler 1978; personal observation HMT) and other anglers (Cranney 1994) also exists. Recovery Program captures begin in 1981 and include 20 Colorado pikeminnow in the lower 2.5 miles of the Duchesne River. Razorback sucker were first documented in the Duchesne River in 1978, when 10 fish were captured in the lower few miles of the river by BIO/WEST, Inc. (Cranney 1994). A total of 41 razorback suckers have been reported captured by the Recovery Program in the lower 2.5 miles of the Duchesne River, where radio tracking of both species also occurred (e.g., Tyus et al. 1982b, 1987). However, most first extensive endangered fish survey of the Duchesne River was done in 1993 by Cranney (1994), who sampled the lower 34.5 miles of the river beginning at Myton, Utah, using a combination of siening, netting, and electrofishing. He captured seven Colorado pikeminnow below RM 14, and two razorback suckers below RM 12. This area also was sampled by USFWS in 1998 during pre-runoff, runoff, and post runoff flows (T. Modde, personal communication, 1999; Utah Division of Wildlife et al. 1999) and 17 adults of Colorado pikeminnow and three razorback suckers were captured during this period. Both Colorado pikeminnow and razorback suckers in the Duchesne River appear to move in and out of the mainstream Green River during spawning season. However, one larval razorback sucker has been captured in Duchesne River at RM 1.6 (T. Modde, Personal Communication, 1999).

The fish population of the Duchesne River includes large numbers of introduced fishes, which constitute the majority of the fish population including red shiner, fathead minnow, carp, channel catfish, smallmouth bass, sunfishes, northern pike and others (Cranney 1994, Utah Division of Wildlife Resources 1999). Smallmouth bass recruitment results in a significant number of fish that move out of the Duchesne River and colonize portions of the Green River (Cranney 1994). However, deeper channels continue to provide important for native fishes (Table 4).

The lower 2.5 miles of the Duchesne River is designated Critical Habitat for razorback sucker (USFWS 1994). It has been classified a Priority 1 sensitive area for razorback sucker staging prior to spawning and a Priority 3 area for razorback sucker habitat (USFWS 1987). It presently is recognized as a recovery priority area for Colorado pikeminnow and razorback sucker (USFWS 2000). Recent upstream captures of Colorado pikeminnow and razorback suckers in the Duchesne River suggests that the river could

have a greater role in recovery than previously anticipated. However, future water depletions also could limit its potential.

White River

The White River arises in the Flat Top Mountains of western Colorado and flows westerly for about 250 miles before joining the Green River near Ouray, Utah. It drains about 4,000 mi^2 of northwestern Colorado and eastern Utah. Flows of the White River have not been appreciably altered by human activity, but completion of Taylor Draw Dam in 1984 at RM 100 has trapped sediment, reduced downstream turbidity, and blocked fish access to the upper river (Chart and Bergerson 1985,1992; Irving and Modde 2000). Although this dam had not appreciably affected the frequency of flooding, peak flood flows have been reduced 40% (Lentsch et al. 2000).

Fishes of the lower 150 miles of the White River, which extends to a cold water transition zone, was surveyed in by Lanigan and Berry (1981), and Miller et al. (1982c). Of 15 species collected by Miller et al. (1982b) from five distinct strata, seven native species were present, and upper reaches were dominated by native suckers. The remainder were nonnative species, whose presence have been linked to Rio Blanco Lake (Martinez 1986). Native fishes comprised 17.8 to 97.5% of fishes caught by various investigators, depending on the river segment (Lentsch et al. 2000). In the Colorado portion of the White River, native fish predominated (>75% Martinez 1986) prior to impoundment of Kenney Reservoir. Nonnatives, introduced by various legal and illegal actions, have flourished in Kenney Reservoir (Martinez 1986), and increasingly moved into lower and upper river reaches after construction of Taylor Draw Dam (Irving and Modde1994). Kenney Reservoir has been implicated in the decline of young native fishes from about 80% to 60% of the total catch below Taylor Draw Dam, presumably due to nonnative fishes (Chart 1987). Nonnative centrarchid predators (green sunfish, largemouth bass, and black crappie) now escape downstream of the reservoir and pose a threat to native fishes in pikeminnow nursery habitats in the Green River (L. Lentsch, Personal Communication, 1996; Lentsch et al. 2000).

A substantial population of Colorado pikeminnow historically occupied the White River, however, Taylor Draw Dam effectively blocked 32% (about 50 mi) of historic Colorado pikeminnow range (Martinez 1986, Irving and Modde 2000). Presently, adult Colorado pikeminnow continue to use the White River, and concentrations have been noted in the lower 20 miles of the river and below Taylor Draw Dam (Figure 10; Elmbladt 1999). The fish have aggregated below the dam in an apparent attempt to move upstream from completion of the dam to the present and some have been observed feeding in the plunge pool (Martinez 1986; Irving and Modde 1994). Recovery Program records indicate that 435 adult Colorado pikeminnow have been captured in the White River upstream to RM 138 (1980 to 1997), and one young-of-year Colorado pikeminnow (61mm TL) was captured at RM 6.4 on October 3, 2000 (Michael Hudson, Utah Division of Wildlife Resources) where it likely entered from the Green River. Two razorback sucker have been captured near RM 18 (1987 and 1996).

In the early 1980s, the senior author was involved in meetings pertaining to construction of Taylor Draw Dam. One of the reasons why the USFWS decided that Taylor Draw Dam would not seriously impact the Colorado pikeminnow under ESA provisions, was that no spawning areas existed in that river; instead it was just "adult habitat" and thus not considered very important to the fish. A better understanding of the life history strategy of the Colorado pikeminnow now reveals the fallacy of this reasoning. Adult habitat is just as important as any other habitat for the fishes, because as adult habitat maintains reproducing adults that support the population. Without the adults, standing stocks will decline. It makes little difference where adults that reside in the White River spawn, as long as they contribute to successful recruitment of the basin population. Colorado pikeminnow migrate out of the White River, access spawning areas in the Green and Yampa Rivers, and return to the White River after spawning (Tyus 1990; Irving and Modde 1994,1995, 2000).

The lower 125 miles of the White River (i.e., from its mouth to Rio Blanco Lake) is designated Critical Habitat for Colorado pikeminnow, and the lower 18 miles was designated for razorback sucker (USFWS 1994). The White River was earlier classified as a Priority 1 area for pikeminnow concentration, Priority 3 for pikeminnow range, and priority 4 for pikeminnow migration (USFWS 1987). It is presently recognized as a recovery priority area for Colorado pikeminnow (USFWS 2000).

The White River plays an important role in maintaining populations of adult Colorado pikeminnow in the Green River basin. However, Taylor Draw Dam, with a structural height of 81 feet, rises about 71 feet above the stream bed and construction of a passageway would be difficult, expensive, and perhaps ineffective. Kenney reservoir has a high retention rate for suspended solids (reviewed by Lentsch et al. 2000), amounting to 65 - 98% @ 1000 cfs (Tobin and Hollowed 1990). About 4,400 AF of sediment had accumulated by 1999 (GEI Consultants, Inc. 1999). At the normal maximum water storage elevation of 5,317.5 ft. AMSL, this constitutes a sediment volume of about 34% of the 13,800 AF of total reservoir storage. This sediment accumulation is readily observed in the upper shallow areas of the lake, and about 1/3 of the surface area of the reservoir is now dry. Thus, the lake will gradually be decreasing in value for water supply, recreation, and flood control purposes.

A sediment study completed in 1999 (GEI Consultants, Inc.) Evaluated 12 major alternatives, varying from large to small projects, that were considered potentially effective for reducing sediment problems in Kenney Reservoir. Serious consideration should be given for implementing one or more of these alternatives that may potentially benefit recovery efforts for the Colorado pikeminnow. However, in view of the large cost of major projects (i.e., $13.5-25 million, GEI Consultants, Inc. 1999) the additional alternative of removal of this dam, possibly to replace it with an off-channel or upper reservoir should be considered as well. This could re-open about 50 miles of Colorado pikeminnow habitat from the dam to Meeker, Colorado, and remove a source of predaceous nonnative fishes that now persist in the reservoir. In addition, it may be possible to encourage more use of

the White River by razorback sucker, if potential factors limiting present use can be determined and addressed by management action.

Price and San Rafael Rivers

The Price and San Rafael Rivers arise in the Wasatch mountains of central Utah and flow southeast to enter the lower Green River just above and below (respectively) the town of Green River, Utah. These small tributaries comprise about 4% collectively of the flow of the mainstream Green River, however, they are the largest tributaries in the lower Green River. Both are regulated by upstream reservoirs, so that highest flows generally occur due to local runoff from thunderstorms, or due to reservoir releases. Except for a small area at the confluence with the Green River that lies within the 100 year floodplain, neither of these streams are protected by Critical Habitat designation.

The Price River arises at about 9,000 feet amsl and drains a basin of about 1900 mi^2. According to Cavalli (1999), fish habitat changes dramatically from a warm to cold water stream near Helper, Utah. The Price River historically had an average flow of about 157,000 AF at Woodside, Utah, but the river has been regulated by releases from Scofield Reservoir since 1926, and suffered flow depletions of about 50% (USBR records). The proposed Narrows diversion project would further deplete Price River flows by about 5,700 AF (USFWS unpublished Biological Opinion).

Anecdotal information suggests that Colorado pikeminnow and razorback suckers once were abundant in the Price River (reviewed by Quartarone 1993, Cavalli 1999). However, there were no recent captures of either species until 1995, when one pikeminnow was captured 2.5 miles upstream by Masslich and Holden (1995). The first intensive survey effort for the endangered fishes was conducted by Cavalli (1999) who captured 19 Colorado pikeminnow downstream of RM 48.3, and also captured two pikeminnows above RM 83. Movements of pikeminnow between the Price and Green Rivers, probably occurs seasonally. Under present conditions, the upper Price River provides some adult habitat for a small number of Colorado pikeminnow, and it is probable that the mouth of the river provides habitat for more. The distribution pattern of pikeminnow in the Price River is provided in Figure 11. Deeper habitats of the Price River also support substantial numbers of native fishes (Table 4). At present, the role of the Price River in the recovery of the listed fishes is uncertain due to additional water development that is presently occurring.

The San Rafael River is formed by the union of Huntington, Cottonwood, and Ferron Creeks near Castle Dale, Utah. Flowing about 100 mi through portions of the Colorado Plateau, the San Rafael joins the Green River below the city of Green River, Utah. The San Rafael drainage basin includes about 1700 mi^2 of south-central Utah.

According to McAda, et al. (1980), the river is wide and shallow. Bottom substrates in lower reaches are dominated by sand and silt, but upper reaches have extensive deposits of gravel and rubble. The river becomes intermittent during years of low precipitation. Six

juvenile Colorado pikeminnow were captured by the State of Utah in the lower 35 mi of the San Rafael River immediately below the Hatt Ranch Diversion Dam (Tom Chart, U.S. Bureau of Reclamation, personal communication, 2000). The confluence of the Green and San Rafael Rivers appears to be important habitat for larval razorback suckers. A total of 73 larval and 2 adult razorback suckers were captured near the mouth of the San Rafael River by Chart et al. (1999). It is not known why the larvae utilize this area, but heavy bank stabilization by the exotic salt cedar has resulted in few sheltered areas in the mainstream Green River, and provides an explanation for this habitat use. Upper areas of the San Rafael River support populations of native fishes (Table 4), but no endangered fish. The San Rafael River appears to have a limited, but perhaps an important role in endangered fish recovery.

Neither the Price or San Rafael rivers have been recognized as sensitive areas or as recovery priority areas by the Recovery Program (USFWS 2000). However, both of these rivers provide some endangered fish habitat.

Reach 4: Colorado River and Tributaries above the Gunnison River Confluence

This reach includes the mainstream Colorado River and tributaries from the Gunnison River (RM 171) to Rifle, Colorado. The 15-Mile Reach, extending from the Gunnison River upstream, was formerly blocked from the remainder of the upper Colorado River mainstream by the presence of Grand Valley Diversion, a barrier which restricted endangered fish movement. However, recent construction has provided passage upstream of the Grand Valley Diversion (to Price Stubb Dam; e.g., FLO Engineering 1997). Figure 12 provides recent capture locations of Colorado pikeminnow in the upper Colorado River. This reach has been designated Critical Habitat for Colorado pikeminnow and razorback sucker (USFWS 1994). The Colorado River from Rifle, Colorado, to Lake Powell, Utah, has been identified as a recovery priority area by the Recovery Program (USFWS 2000).

Colorado River from Palisade to Rifle (RM 190 to 240)

This reach of the river is relatively high gradient although it has a lower gradient section near Rifle. Spring flows have been reduced by about 40% in this reach and baseflows have been increased by 20% (Anderson 1996). In addition, a decrease in suspended sediment load of 30 to 45% has resulted in a narrowing of the channel and reduced floodplain and bottomland habitat by an average of 10-15% (Pitlick et al. 1999). Fish migrations are blocked partially or completely by a series of barriers. the Grand Valley diversion (RM 185.4), the Price Stubb Dam (RM 188.3), and the Government Highline Dam (RM 193.6). This section of the river is included in the Critical Habitat designation (USFWS 1994). A fish passage slot has been constructed in the Grand Valley Diversion, and assessments for passage through the other two dams are in progress.

Surveys of fish abundance in this reach of the Colorado River have shown that native fishes (mostly flannelmouth and bluehead suckers) predominate (>80%), especially in De

Beque Canyon (Valdez et al. 1982, Anderson 1996; Table 4). Roundtail chub were abundant in De Beque Canyon (RM 194-197) and common upstream. A collection of putative humpback-roundtail chub hybrids in De Beque Canyon led Valdez et al. (1982) to suggest that these fish were remnants of a once larger population of humpback chub. Colorado pikeminnow and razorback sucker are known to have occupied this reach of the UCR in the past (Valdez et al. 1982, Westwater Engineering 1996), and 67 razorback sucker were captured from isolated ponds adjacent to the Colorado River near Debeque (USFWS 2000)..

Adult Colorado pikeminnow habitat in the upper Colorado River reach was surveyed by Anderson (1996) and the riverine section upstream of De Beque was judged excellent due to the abundance of forage fishes, including native suckers and whitefish. There were numerous pools and deep runs during the baseflow period, as well as ample backwaters and eddies during spring flows. Except for a few trout and centrarchid species, no large native or nonnative predators were common in the electrofishing surveys. The Colorado Division of Wildlife concluded that this reach has habitat suitable for reintroduction of adult Colorado pikeminnow and razorback sucker (Anderson 1996), and its potential as a reintroduction site for humpback chub should be evaluated.

Plateau Creek, a small tributary in this reach, maintains a natural hydrograph, but appears to be of little importance in providing habitat for the endangered fishes. Plateau creek does support a large number of nonnative fishes for its size (Table 4) and could provide forage for larger fishes in the mainstream UCR.

15-Mile Reach

The 15-Mile Reach, which has been prominent in recent discussions of recovery efforts, extends from the confluence with the Gunnison River (RM 171) upstream to the Grand Valley diversion dam at Palisade (RM 186; Osmundson and Kaeding 1989, 1991). Most of the reach lies within the Grand Valley, which contains the largest urban area in the upper Colorado River basin. It is heavily influenced not only by urbanization in Grand Junction, but also by extensive agriculture in the Grand Valley.

Flows in the 15-Mile Reach have been greatly altered by dams and diversions upstream. The mean peak flow is now only about 56% of historic, and flows in June have been reduced to 55% of historic levels (Osmundson and Kaeding 1989, 1991). The effects of water resource development on the hydrology and geomorphology of this part of the river were discussed recently by Van Steeter (1996), Van Steeter and Pitlick (1998), and Pitlick and Van Steeter (1998). In general, they found that areas of complex riverine habitats decreased 12% to 29% after major reservoirs were brought on line. Changes to physical habitat included loss of shoreline habitat, diking, and riprap. Although there are no major dams or diversions within the 15-Mile Reach, the Grand Valley diversion at the head of the reach prevents upstream migration of fish.

The significance of this reach to recovery of endangered fishes in the upper Colorado River and the need for instream flows to support those fishes have been a topic of several recent reports (Kaeding and Osmundson 1989, 1991; USBR 1992; Osmundson et al. 1995; Osmundson 2000,). Although this reach of the upper Colorado River comprises only about 8% of habitat used by endangered fishes, it is considered extremely important by the USFWS because of the high catch rates of native fishes, high catch rates of adult Colorado pikeminnow, and historic use of the area by razorback suckers in spring (Osmundson et al. 1995). According to the USFWS, the most critical habitat issue in the reach is the adequacy of instream flows. The USFWS believes that it is necessary to acquire or appropriate additional water in order to have sufficient flow for the endangered fishes, and have made flow recommendations to aid in maintaining the present population of Colorado pikeminnow (Osmundson and Kaeding 1991, Osmundson et al. 1995). Alternatives for providing water to meet these recommendations have recently been studied, but low flows may not be dependable or sufficient (USBR 1992). This reach has been determined critical habitat for razorback sucker and Colorado pikeminnow.

The 15-Mile Reach, and downstream portions of the Grand Valley, contained historical spawning sites of the Colorado pikeminnow and razorback sucker, but this area has been heavily influenced by gravel mining operations (Valdez et al. 1982, Archer et al. 1985). Larval collections have confirmed a low level of spawning by Colorado pikeminnow in the 15-Mile Reach, i.e., only a few larvae collected in two of 14 years of study (Osmundson et al. 1995) and once in five years of study (Anderson 1999). Apparent recruitment failure in this reach of the Colorado River is probably linked to the abundance of introduced nonnative fishes. Altered habitats in the 15-Mile Reach have been extensively colonized by nonnative fishes. This is especially true of gravel pit ponds which can be important sources of piscivorous fishes (Burdick 1994, Osmundson 1987).

The upper Colorado River is important, and perhaps pivotal, to the recovery of endangered fishes in the Colorado River portion of the upper basin. The area will presumably be invaded by Colorado pikeminnow as soon as access is provided by removal of barriers. If data and conclusions reached by Osmundson (1998) are correct, as we assume they are, the 15-Mile Reach could be less heavily occupied by Colorado pikeminnow as the fish move into more productive habitat upstream.

Reach 5: Colorado River and Tributaries from the Gunnison River Confluence to the Green River

Although adult and juvenile pikeminnow are found throughout this reach, adult Colorado pikeminnow tend to be more common above Westwater Canyon (RM 125), while younger fish were more common downstream (Valdez et al. 1982, Archer et al. 1985, McAda et al. 1994). Humpback chub are common only in Westwater and Black Rocks, and razorback sucker have been captured in riverine-connected gravel pits in the Grand Valley area. No bonytail were captured.

Flow in this reach is regulated chiefly by dams and diversions upstream on the Colorado and Gunnison Rivers. Upstream flow regulation has reduced the average instantaneous peak flows to only 48% of historic conditions (Osmundson and Kaeding 1989). There is no major flow regulation within the reach. The Gunnison and Dolores Rivers are tributaries to the reach, contributing more than 40% of the average annual flow at Cisco. Because there are no dams or major diversions, there are no significant barriers to fish migration. The reach is typically low-gradient alluvial habitat, but it is not entirely uniform. The reach includes two significant areas of canyon habitat, Black Rocks and Westwater, and is sufficiently heterogeneous that it was divided into seven distinct strata by Valdez et al. (1982), which include wide agricultural floodplains, open valleys, canyons and foothills. The Grand Valley, which occurs within the upper part of this reach, has been identified as important to recovery efforts for the listed fishes (e.g., Archer et al. 1985, Osmundson et al. 1995), principally due to the numbers of adult Colorado pikeminnow and razorback sucker captured there. The Grand Valley has been divided into two separate sections: the 15- Mile Reach discussed earlier and an 18-Mile Reach, which extends below the mouth of the Gunnison River (Archer et al. 1985). The 18-Mile Reach is greatly influenced by flows of the Gunnison River, which supplies about 40% of the total annual flow (Burdick 1997). A suspected spawning area for Colorado pikeminnow occurs in this reach (Valdez et al. 1982, Archer et al. 1985, McAda et al. 1994; Anderson 1999). In addition, ripe razorback sucker were historically numerous and may have spawned in inundated gravel pit habitats (Valdez et al. 1982). The 18-Mile Reach also contains important bottomland habitats. Further downstream, Black Rocks and Westwater Canyons support the largest concentration of humpback chub in the UCRB, and lower reaches of the UCRB from Potash to the confluence supports an important area of nursery habitat for the Colorado pikeminnow.

The USFWS (1994) has determined critical habitat for all four endangered species in this reach; Colorado pikeminnow and razorback sucker (entire reach), humpback and bonytail chubs (Black Rocks to Fish Ford) and provided recovery priorities by species: Colorado pikeminnow: Priority 1 for adults and young; Priority 2 for concentration and spawning areas, Priority 3 for distribution, and Priority 4 for migration routes; Priority 1 and 2 for humpback chub; Priority 1 and 3 for razorback sucker; and Priority 1 for bonytail reintroduction. This reach of the upper Colorado River has been designated a Recovery Priority Area (USFWS 2000).

Gunnison River

Historic flows of the Gunnison and its tributaries have been greatly altered by water development projects. Private development began in about 1880 and federal involvement began in 1909 with construction of the Gunnison Tunnel. Major projects on the mainstem of the Gunnison include the Taylor Park Dam which was completed in 1937 and three Aspinall unit reservoirs which began with construction of Blue Mesa in 1966 and concluded with the Crystal Reservoir in 1976. These reservoirs have resulted in extreme alteration of the historic flows in the Gunnison River. The Redlands Diversion, which was constructed at RM 2.3 in 1918, removed about 700 cfs flow and posed a complete barrier

to upstream fish migration until 1996 when a fish ladder was completed (Anonymous 1996ab, Burdick 1997).

Colorado pikeminnow and razorback sucker were once common or abundant in the Gunnison River (Jordan 1891, Jordan and Evermann 1896). Both species were reported from the Gunnison in the 1930s and the 1950s (Chamberlain 1946, Kidd 1977). Colorado pikeminnow were still present in the lower Gunnison River by the 1980s, but razorback sucker had virtually disappeared (Valdez et al. 1982). Recent studies of the Gunnison River have documented a remnant population of Colorado pikeminnow (Burdick 1995) and a low level of spawning, i.e., a total of 16 larvae in five years of sampling (Anderson 1999). The distribution pattern of Colorado pikeminnow in the Gunnison River is provided in Figure 13. Flow recommendations have been made by USFWS to assist fish in passing upstream through the Redlands Diversion during low flow periods (Burdick 1997). A razorback sucker stocking program is presently underway in the Gunnison River.

The Gunnison River fish populations are composed of about 80% native fishes (Table 4). Physical habitat and fish community composition in the Gunnison River have been further evaluated by Valdez et al. (1982) and Burdick (1995), who divided the river into seven geomorphic strata below its confluence with North Fork. Redlands Diversion Dam near the mouth of the Colorado River previously was a barrier to fish migration for most of the year. A fish ladder has been installed that allows some fish movement, but operation of the diversion results in occasional dewatering of the lower 3 miles of the Gunnison River. Above Redlands Diversion the river is bounded by a wide floodplain that has gravel pits and quarries, canyon habitat from White Water to Bridgeport, and from Bridgeport to Escalante the river is braided and bounded by floodplains with some fruit orchards. About 90% of the fish are native species. A suspected spawning area for Colorado pikeminnow occurs between RM 30 and 35. From Escalante to above the Hartland Diversion, the river flows through an extensive floodplain and open canyon as it makes a transition to a cold water fishery. The most abundant nonnative fishes above Hartland Diversion are white sucker, brown trout, rainbow trout, and white sucker hybrids. It has been recommended that a passage be installed in the Hartland Diversion to allow Colorado pikeminnow access to 18 miles of habitat above the Dam. This area is also considered for razorback sucker reintroduction (Burdick and Pfeifer 1996). Fish captures recorded by the Recovery Program include 127 Colorado pikeminnow from RM 36.4 to the mouth (1978-1997), however, 115 of these were captured below Redlands Diversion (i.e.,<RM 3, e.g., see Figure 13). None of the other endangered species have been captured recently.

Sixty miles of the Gunnison River (mouth to Uncompahgre River) has been designated Critical Habitat for Colorado pikeminnow and razorback sucker. It has been given a recovery priority of 3 for Colorado pikeminnow distribution (USFWS 1987) and included as a recovery priority area by the Recovery Program (USFWS 2000). The Gunnison River has potential for expansion of Colorado pikeminnow populations; however, its role may be limited by Redlands and Hartland Dams. Provision of fish passage at Hartland Dam has been recommended (Burdick and Pfeifer 1996) but it has not been implemented. Passage at Redlands Diversion has been provided by a fish ladder around the dam, but

the low number of Colorado pikeminnow using the ladder (averaging only about a dozen each year since the ladder was completed) suggest that the passage may not be satisfactory for expansion of endangered fish populations from the mainstream river. If so, other alternatives for providing passage need to be explored.

Dolores River

Little is known about the historical abundance of the endangered fishes in the Dolores River. Neither Colorado pikeminnow nor razorback sucker has been reported in the last 20 years, with the exception of four pikeminnow captured in the lower 2 mi of the river in 1991 (Valdez et al. 1992). The Dolores River once supported Colorado pikeminnow and captures have been reported from the 1950s and 1960s (Seethaler 1978) but no Colorado pikeminnow were captured by Holden and Stalnaker (1975) or by Valdez et al. (1982). Deeper channels of the Dolores River still support a native fish community (Table 4) and nonnatives continue to dominate shorelines (Valdez et al. 1992).

Flows in the lower portion of the Dolores River have been greatly altered by dams and diversions to the extent that nearly all water is removed at times of high demand. McPhee Dam was constructed near RM 200 in 1984. The dam has reduced the remaining high spring flows and increased base flows in summer, fall, and winter. However, flows during some years (e.g., 990 and 1991) were only 20 to 40 cfs and fish habitat was reduced (Valdez et al. 1992). Under those conditions, the San Miguel River provides most of the flow that appears in the lower part of the Dolores. Habitat in the lower part of the river was evaluated recently; although physical habitat may be suitable at some times of the year, flow regulation and pollution present serious problems (Valdez et al. 1992). Uranium, gold, and salt mining have resulted in severe pollution and fish kills as recently as the 1960s (Joseph et al. 1977). In one account, most of the fish in the lower 60 miles of the river were killed by mine pollution (Valdez et al. 1992). Fish tissues taken recently from the Dolores River have contained elevated levels of heavy metals (Kunkle et al. 1983, in Valdez et al. 1992).

In addition to problems with physical habitat, biological conditions also are degraded by the presence of nonnative fishes. In a recent study, 70% to 80% of the fish captured over a two-year period were nonnatives (Valdez et al. 1992). Poor water quality and severe flow depletions appear to have made the Dolores River poorly suited for the four endangered fishes (Valdez et al. 1992). However, water quality may be improved by cleanup efforts now mandated by regulatory agencies (Valdez et al. 1992). The role of the Dolores River in future recovery efforts is uncertain. It could have a greater role in recovery activities if conditions improve (Masslich and Valdez 1992). However, its role may depend upon a better understanding of the factors that appear to have excluded the endangered fishes. The Dolores River was included as a recovery priority area by the Recovery Program. Recovery actions have been limited to preventing escapement of nonnative fishes from McPhee Reservoir and stocking Colorado pikeminnow (USFWS 2000).

Reach 6: Colorado River and tributaries from the Green River to Lake Powell

The Colorado River is much expanded in size below its confluence with the Green River and it passes through Cataract Canyon before joining with the Dirty Devil River in Lake Powell, a distance of 47 miles. There are no major tributary streams in this reach.

Considerable interest in the fishes of Cataract Canyon was generated by capture of adult Colorado pikeminnow in 1980 (Persons et al. 1981). Valdez (1990) reported captures of Colorado pikeminnow, humpback chub, razorback sucker and suspected bonytail from Cataract Canyon. Tributaries immediately upstream of this reach (i.e., within 50 miles) are too small to be of any significant impact on the listed fishes or their habitat in this reach. Critical Habitat has been designated for Colorado pikeminnow and razorback sucker in the Colorado River in this reach (i.e., to the mouth of the Dirty Devil River in Lake Powell) and 30 miles of Cataract Canyon has been designated for humpback chub and bonytail.

Lake Powell and Tributaries

Colorado squawfish and razorback sucker have been taken sporadically from Lake Powell over a number of years, including 45 Colorado pikeminnow captured in 1980 (Persons et al. 1981) and 77 Colorado pikeminnow and seven razorback suckers reported by the Recovery Program since 1980. In 1984, seven razorback suckers and 22 Colorado pikeminnow (includes three recaptures) were captured in the Dirty Devil arm of the Reservoir and some fish also have been captured in the Escalante arm of the Reservoir. These tributaries provide some habitat features in the lake, however, it is not believed that these fishes utilize the upper, natural reaches of either of these tributaries (K. Lashmetts, U.S. Bureau of Reclamation, Personal Communication, 1999). It is known that some of these fishes make long-distance movements into upper parts of the Colorado River system. One pikeminnow radio tagged in the Dirty Devil Arm of the Reservoir was subsequently captured near a spawning area in Gray Canyon of the Green River (Tyus et al. 1987), and another Lake Powell fish was subsequently recaptured in the Grand Valley area (Archer et al. 1985). It is not known why the endangered fishes appear to congregate near the mouths of these tributaries, but it may be due to presence of more abundant prey or more preferred physical habitat conditions such as increased turbidity as previously discussed. The remaining large tributary to Lake Powell, the San Juan River, is critical habitat for Colorado pikeminnow and razorback sucker. A separate recovery program is in place for the San Juan River, that is not considered part of the upper Colorado River Recovery Program and it is not discussed further.

Endangered fishes in Lake Powell may not be directly contributing to recovery by expanding viable populations. There appears to be limited or no reproduction of any of the endangered fishes in the lake. Predaceous nonnative fishes are so abundant in Lake Powell that there is little prospect for recovery of viable populations of the endangered fishes there.

Relative Importance of Tributaries

Most of the tributary streams we evaluated contribute in some way to potential recovery of one or more of the endangered fishes. In addition, many of these streams have potential for greater contribution through management actions. As our study progressed, it became clear that the Recovery Program would benefit from the development of a system to rank tributaries according to their relative importance to the recovery effort. However, we found no simple ranking scheme to be useful for the entire upper basin due to the need for considering the Colorado and Green rivers subbasins as somewhat independent functioning systems. Thus, we present two ranking categories. In addition, concepts of direct and indirect contributions are very different. Direct contributions reflect habitat conditions in tributaries, but indirect contributions affect habitat conditions in the receiving waters of the mainstream rivers. In any ranking scheme, relative importance depends on information available when rankings are made, and thus our rankings could change as additional information is obtained.

The most important consideration in determining relative importance of tributaries is the direct contribution made by supporting standing stocks of endangered fishes. Thus, the number and abundance of life history stages that presently occupy habitat within a particular tributary become the primary determinants of importance. Ranking is based on those life stages known to occupy the habitat today, but it is also important to consider the potential for additional stages of one or more species to occupy habitat in that tributary.

Present habitat use by endangered fishes was placed in one of five categories. Assignment of a particular tributary to one of the categories depended on the information available at the time of this study, but assignments could be altered as new information becomes available. An attempt was made to separate consistent habitat use from the presence of the occasional itinerant individual.

When there is no significant present use of habitat by any of the endangered fishes, a tributary was assigned to Category 1. Some individuals may have been recorded in the past, but these are regarded as incidental. Tributaries in that category included Plateau Creek, Dirty Devil River, and Escalante River.

A tributary qualifies for Category 2 if one life history stage of one endangered fish species is supported. The tributaries included in this category (White, tributary Colorado, Price and Dolores rivers) all provide habitat for adult Colorado pikeminnow.

When at least two life history stages are supported in a tributary, it qualifies for Category 3 rank. These life history stages may represent one or two of the endangered fish species. The four tributaries included in this category are the Little Snake, San Rafael, Duchesne, and tributary Green rivers.

The final two categories require that the tributary support more than two life history stages of one or more of the endangered fish species. Category 4 includes only the Gunnison

River: it supports three life history stages representing two species. A distinction is made between habitat occupied by adults for most of the year and habitat used for spawning. In this sense, the Gunnison supports two stages of the pikeminnow. The present numbers of razorback suckers are from hatchery stock but these fishes have survived, indicating that habitat is suitable for adults.

Category 5 represents the apex in endangered fish habitat use because the full life cycle of at least one fish species can be completed using only habitat available in that tributary. In this case, a tributary would have habitat of importance comparable to the mainstream of the Green and Colorado rivers, which can support the full life history of one or more of the species. The Yampa River is the only tributary placed in this category.

Tributary rankings based on life stages of endangered fishes that they support are summarized in Table 15. However, at least four of the tributaries have potential for reintroduction and/or reestablishment of one or more life history stages of the endangered fishes. In particular, the upper part of the tributary Colorado reach, which does not now support the endangered fishes, has potential for three species. The Yampa, tributary Green, and White each have potential for at least one additional species. But the support of additional life history stages will require the elimination or circumvention of existing obstacles. In addition, there is potential for expanding the number of individuals in most of the tributaries now supporting endangered fishes.

Tributaries also have been ranked on the basis of the flow and sediment attributes comprising indirect contributions (Table 16). Because the indirect contributions are important for influencing conditions in the mainstream, interpretation of rankings is different than that used for direct contributions. The ordinal scale showing relative importance within each of the five attribute categories (Table 16) requires a subjective scheme for producing an overall ranking. It should be emphasized that rankings are based on present contributions which may change if obstacles are removed. Not surprisingly, the large tributaries tend to make the largest contributions to flow and sediment transport. The Yampa, tributary Colorado, and Gunnison have the most high ratings and no low ratings. These same tributaries are ranked high in terms of present or potential support of life history stages.

The relative importance of indirect tributary contributions also was assigned ranking values: a value of 1 was given for low scores, 2 for medium, and 3 for high. In this manner, an indirect score also can be assigned to each of the tributaries. The relationship between indirect scores and the potential direct contributions (Figure 14) shows general concordance of the two rankings, although the tributaries at the low end tend to clump in a manner that obscures importance on the basis of direct contributions. Larger tributaries (Yampa, Tributary Colorado, and White rivers) tend to be more important for recovery, but some of the small tributaries (Duchesne, San Rafael and Price rivers) still have potential for making contributions to recovery because they offer habitat that is presently used by one or more life history stages of the endangered fishes. We stress that both the direct and indirect contributions are important, and in the future both direct and indirect values

need to be considered to avoid taking a piecemeal approach to recovery. Because direct and indirect rankings are somewhat subjective, we prefer to maintain the separateness to promote understanding rather than launching a more sophisticated (and perhaps convoluted) ranking scheme.

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All of the important tributaries that we ranked supported substantial numbers of native fishes (Table 4). It was beyond the scope of this study to determine how the composition, abundance, and distribution of these other native fishes might affect recovery efforts for the four endangered fishes. Thus, we did not consider the importance of tributaries in supporting other native fishes and presence or absence of other nonnative fishes was not used as a ranking criteria in this study. However, the Endangered Species Act and USFWS policy requires consideration be given to recovering endangered species in an ecosystem context, and we do not doubt the importance of a native fish ecosystem for enhancing endangered fishes recovery.

Table 15. Life history stages of endangered fishes supported by tributary streams and potential for supporting reintroduction. (CP=Colorado pikeminnow, HB=humpback chub, RZ=razorback sucker, BT=bonytail)

Tributary	Fish Species Present					Recovery Potential	
	Colorado Pikeminnow	Humpback Chub	Razorback Sucker	Bonytail	Ranking Category	Species Reintroduced	Potential Ranking
Little Snake	Adult	Adult			3	--	3
Yampa	All	All	Adult, Spawning		5	BT	5
Tributary Green	Adult		Adult		3	HB, BT	4
Duchesne	Adult		Adult		3		3
White	Adult				2	RZ	3
Price	Adult				2		2
San Rafael	Adult		Larvae		3		3
Tributary Colorado	Adult				2	CP,RZ,HB	4
Gunnison	Adult, spawning		Adult		4		4
Dolores	Adult				1		1

Table 16. Ranking of tributaries by direct, potential direct and indirect contributions to the recovery of the four endangered Colorado River fishes. Direct scores are taken from Table 15. Indirect weighted score= (low)(1) + (medium)(2) + (high)(3) are derived from Table 14 (see text).

	Direct Values		Indirect Weighted Values			
Tributary	Direct Category	Potential Direct	Indirect Low	Indirect Medium	Indirect High	Weighted Score
Little Snake	3	3	1	4	6	11
Yampa	5	5	0	2	12	14
Duchesne	3	3	4	2	0	6
White	2	3	0	6	6	12
Price	2	2	5	0	0	5
San Rafael	3	3	5	0	0	5
Plateau	1	1	4	2	0	6
Gunnison	4	4	0	4	9	13
Dolores	1	1	2	4	3	9
Dirty Devil	1	1	5	0	0	5
Escalante	1	1	5	0	0	5
Trib. Green	3	4	3	0	6	9
Trib. Colo.	2	4	0	2	12	14

CONCLUSIONS

Most of the tributary streams we evaluated contributed in some way to recovery of the endangered fishes, either directly by supplying occupied habitat or indirectly by providing flows, sediments, and other inputs that contribute to downstream habitats used by the fish. This is not surprising because historical reports make it clear that the endangered fishes seasonally occupied virtually all of the tributary streams in the upper basin (e.g., Quartarone 1993) . However, tributaries varied in the amount of habitat occupied by the fishes and the magnitude of indirect contributions. Most tributary streams are presently inhabited by one or more species of the four endangered fishes, especially in lower reaches. While few tributaries now support all of the life history needs for any of the fishes, collectively they contribute a great amount of habitat. On the other hand, some tributaries do not appear to support populations of the listed species, and some tributaries present obstacles such as barriers or populations of harmful nonnative fishes. The nonnative fish issue is complex: while many tributaries harbor predaceous or competitive nonnative fishes in shoreline habitat, larger channels are usually dominated by native fish species.

Larger tributaries that enter upstream portions of the mainstream rivers are important because benefits of flow contributions are sustained for a long distance downstream. These upstream areas, such as the tributary Colorado and Green rivers, Yampa River and Gunnison River historically supported endangered fishes. Almost without exclusion these rivers supported several species directly. However, of these rivers, only the Yampa River has not been blocked and/or dewatered by construction and operation of dams and diversions. Lower portions of these streams are consistently and heavily used by pikeminnow during some portion of the year, and provide spawning grounds in the Yampa and Gunnison rivers. Unblocked upper areas are used by pikeminnow as adult concentration areas.

The larger streams of intermediate position that enter in the midstream of the Green and Colorado Rivers generally function as adult habitat for Colorado pikeminnow and razorback sucker. Of these, the White River supports a relatively large and important spawning population of Colorado pikeminnow. Although blocked by Taylor Draw Dam near Rangely, Colorado, flows of the White River are near historic levels, and more than 100 miles of habitat are still accessible.

All streams that we evaluated that entered the downstream portions of the Green and Colorado Rivers functioned to provide habitat diversity at their confluence with the mainstream. Some of these reaches were occupied by adult pikeminnow and in one case it appears that larval razorback suckers found the habitat to their liking. A similar situation apparently occurs where rivers enter Lake Powell. Flow, sediment and nutrient inputs of tributary rivers provide a contrasting habitat to that of the open lake. As a result, these habitats are used by adult pikeminnow and razorback suckers.

The amount of indirect contributions was generally related to the size of the tributary. Largest tributaries, such as the Yampa and Gunnison rivers, contributed the most flow and sediment to the mainstream rivers. Conversely, very small tributaries like the

Escalante River contribute very little of either. The biggest exception to the pattern is the tributary portion of the Green River which contributes substantial flow to the system but virtually no sediment due to sediment storage in Flaming Gorge Reservoir.

In general, the potential for enhancing indirect contributions is relatively limited. The existing system of water management and flow depletions constrains flow in the system, although there may be opportunities for flow management. Sediment transport is also constrained by the flow regime and the presence of dams, which trap sediment. However, some opportunity exists for a managed hydrograph to deliver sediment on a schedule that is optimal for creation and maintenance of mainstream habitat.

Better management of flows in regulated tributaries may help mitigate habitat alteration on the mainstream. Deliveries of flow and sediment by tributaries play a role in the creation and maintenance of habitat in mainstream reaches. Until that linkage is better understood, the potential benefits of reservoir releases cannot be evaluated adequately.

Water quality issues are less well defined than those for flow and sediment. Perhaps the best studied water quality issue is temperature. Installation of large dams, especially Flaming Gorge, has generally led to lower temperatures in the vicinity of the dam, especially early in the season. Warmer temperatures below Flaming Gorge Reservoir would enhance physical habitat for Colorado pikeminnow and razorback sucker and improve prospects for establishing the humpback chub above the Yampa River confluence. It is unclear if other similar opportunities for enhancement exist below other reservoirs.

The connection between water quality and recovery of endangered species has been difficult to demonstrate. Certainly oil spills and accidental spills of other toxic materials must be minimized, and it is reasonable to be concerned about elevated concentrations of heavy metals. Also, there is concern that high levels of selenium may have hastened the decline of endangered fishes and may pose a threat to razorback sucker reproduction. Selenium has received considerable attention in the past, but relatively little effort has been devoted to metals.

Recent water quality studies from Utah indicate the mechanism by which metals concentrations could be elevated seasonally in certain tributaries. Elevated concentrations in these small tributaries may not be of much concern to life history stages occupying mainstem habitat, but the potential for harm increases where larval stages make use of habitat near the mouth of the tributaries. Metals released from the sediments of lakes in these tributaries could affect sensitive life history stages present near the mouth of each tributary. Concern is great enough to prompt studies of the concentrations of metals both in the lakes and in the tributaries downstream at a time when larvae may be present at the tributary mouths.

The Recovery Program has a vested interest in the outcome of TMDL development for basins within the recovery area. Issues related to protection of water quality are largely

the domain of state agencies, but the process for addressing water quality problems generally follows federally-mandated procedures. When water quality issues are identified within a basin, the state is obliged to list the parameter and the affected reach(es) and a timetable is set for developing a plan for managing the sources of water quality impairment. Each TMDL analysis is performed within a watershed, and stakeholders in that watershed participate in the process. There are two reasons for the Recovery Program to become involved: to promote awareness of recovery issues as they affect state agencies and other stakeholders, and to influence the priority that will be set on efforts to manage water quality problems. For example, if selenium were identified as a water quality problem in a particular basin, and neither the state water quality agency nor other stakeholders found the problem urgent, the Recovery Program could provide a compelling reason for advancing the timetable for managing that water quality problem.

There is a need for more information on linkages between indirect contributions from tributaries and the creation and maintenance of specific habitat within mainstream rivers. In particular, recovery may benefit from an improved understanding of the dynamics of Colorado pikeminnow nursery habitat. The linkage is almost certainly very dynamic because the timing of flow and sediment deliveries is different for each tributary in each year. Nevertheless, it would be very helpful to establish the principle source of sediment and the significance of timing for creation of suitable habitat for each nursery area. If the timing of sediment deliveries were altered for one or more of the tributaries, would suitable habitat still be maintained? Attention should also be given to the mechanisms responsible for degradation of nursery habitat; especially, what role does augmented baseflow play in altering habitat quantity or quality of these shallow backwater areas?

Tributaries differ greatly in their present capacity to support life history states of the endangered fishes. Only the Yampa River has the capacity today to support all life history stages of any one of the endangered fishes. A similar potential may exist in the tributary Colorado River, and reintroductions are occurring. It also may be possible to establish a population of humpback chub in the tributary Green River, but once again this is a potential that has not been realized. Management of tributaries must be closely linked with management of mainstream habitat if tributaries are to make contributions to the recovery effort.

Integrating the management of tributary and mainstream habitats is a means for increasing carrying capacity for populations of the endangered fishes, but is probably not a mechanism for increasing the number of populations with the exception of the three large tributaries mentioned above. This may have important implications for recovery goals that specify the number of populations required to de-list. Limiting factors that must be addressed to enhance the habitat available in tributaries include access to more habitat through removal or circumvention of barriers, reduction of the abundance of nonnative fishes, and improvements to water quality.

Reintroduction is the most promising approach for increasing the number of populations in the Yampa, tributary Colorado, and tributary Green rivers. The Recovery Program is

making an ambitious effort to recover bonytail by reintroducing them to the Green and Colorado rivers, and plans also exist for reintroductions elsewhere. These are important actions that may need to be coupled with additional efforts that address obstacles to recovery. In the upper Green River basin, this probably means warming the water to at least 18-20 ^{0} C before there is a reasonable chance of successful expansion of the humpback chub. In the upper Colorado River, the removal or circumvention of barriers is probably a necessary complement to reintroduction efforts.

From a system-wide perspective, the Yampa River is the most important tributary for recovering the endangered fishes. The Yampa River basin (including the Little Snake River) has escaped much of the water development activity that has greatly altered most other tributaries. The river is largely unregulated and there are no significant barriers to fish movement. Furthermore, the Yampa River supports populations of the three listed fishes that still have wild populations, and it is the site of a major reintroduction effort for the bonytail. No other tributary offers comparable assets for recovery.

The Yampa River also has a great influence on endangered fish habitats in the downstream Green River. Its effect on the hydrograph and on sediment transport in the Green River has been discussed in detail in earlier sections of this report. In particular, the Yampa produces nearly the entire runoff pulse observed in the Green River below their confluence, and it delivers a substantial portion of sediment. In this sense, the Yampa offsets some of the deleterious effects of Flaming Gorge Reservoir. This role should not be underestimated. Re-operation of Flaming Gorge Dam to meet recommended flows for the endangered fishes is constrained by the physical capabilities of the dam design, and cannot replace the valuable role played by the unconstrained Yampa River.

Because of the importance of the Yampa, special care should be exercised when water development projects are proposed for that basin. In particular, the Recovery Program should be very cautious of future water development projects. The ecologically beneficial attributes of the stream may be slowly eroded by this process in which the incremental changes due to individual development projects may be very difficult to measure or predict, but the aggregate effects may be undesirable.

The Recovery Program has initiated a series of management plans that have the capacity to facilitate recovery efforts. A plan is in progress for the Yampa River basin (Hamill 1997) and the next one is slated for the Gunnison River. Subsequent plans could be scheduled in a sequence corresponding to the relative importance of the tributary basins. Hopefully, this document will aid in identifying those higher priority tributaries.

In the following section these conclusions are used to provide recommendations to the Recovery Program. The relative importance of the tributaries and the nature of the major limiting factors were used to prepare recommendations for addressing limiting factors in geographical areas that offer the greatest potential for enhancing recovery.

RECOMMENDATIONS

Recovery of the big river fishes will rely on remedies addressing those factors thought to limit the endangered fish populations. Consequently, recommendations should be cast primarily in terms of the major limiting factors. From a practical perspective, recommendations should be directed at particular geographic locations where relief from limiting factors will presumably have the greatest effect on recovering the fish populations. The ranking of tributary streams in terms of direct and indirect contributions to recovery is therefore a precondition for formulating useful recommendations, because it helps demonstrate where greatest potentials reside. Rankings of tributaries on the basis of direct and indirect contributions to recovery have been presented in preceding sections of this report.

The following recommendations have been developed on the basis of three goals: to exploit existing potential, to clarify connections, and to improve management framework. The eight recommendations listed below are grouped according to those goals, but without ranking them. The list of recommendations has been kept short deliberately with the idea that implementation could proceed simultaneously on all recommendations that are adopted.

The potential for aiding the recovery effort by management action in tributary streams includes expanding the size or numbers of existing endangered fish populations. Removal of barriers to migration can allow existing populations to expand into habitat that is not now accessible. Reintroduction has potential to increase the number of populations in the basin. The potential benefits of removing barriers and reintroducing populations will be jeopardized unless steps are taken to control the abundance of nonnative fishes.

In some instances, there is a perception that specific limiting factors are at play but the importance of the factor, or perhaps the mechanism of operation, may require clarification. Studies are therefore recommended for clarifying the importance of tributaries for reintroduction of one or more of the listed fishes by understanding limiting factors. These include determining the importance of tributary mouths for support of larval fishes, the role of individual sediment sources in shaping nursery habitat, and the potential for harm through release of metals from anoxic reservoirs. Each topic holds potential for revealing information that may be used to promote recovery. However, until these factors are better understood, the basis for recovery action is insufficient.

We have addressed two institutional issues that have bearing on recovery. The first concerns interactions between the Recovery Program and state water quality agencies regarding the management of suspended sediment in streams. The second issue involves setting priorities for management plans being developed for tributary basins . Neither issue has direct bearing on recovery, but both are potentially significant for facilitating future recovery actions.

Finally, the conclusions that we have reached are based on existing knowledge of the fish and factors that influence their recovery. We recognize that the relative importance of our findings may change in the future as more knowledge is obtained. However, we do not believe that implementation of the following recommendations should be delayed:

– The Recovery Program should expand efforts to circumvent or eliminate barriers to fish movement, especially in high priority tributary streams.

One of the more conspicuous alterations to physical habitat in the upper Colorado River basin has been the installation of structures, such as impoundments and diversion dams, that block the movements of the endangered fish and limit recovery prospects. We applaud the Recovery Program for giving serious consideration to the removal of barriers. It is evident that Colorado pikeminnow, a highly migratory species, has been greatly affected by physical barriers that now prevent some populations from reaching the full range of habitat once occupied in the upper Colorado River basin. In particular, access to habitat preferred by adults is greatly restricted in the White River and the tributary portion of the upper Colorado River. In the White River, the recovery effort for Colorado pikeminnow would benefit by providing access around Taylor Draw dam, or by removing the dam. There is good habitat upstream to Meeker, Colorado, that adult Colorado pikeminnow occupied before the dam was closed and recent studies show that the fish will utilize this area if access is provided. Taylor Draw Dam is not well-suited for installation of a passageway, and costs associated with such construction would presumably be very high. Finally, Kenney Reservoir is filling rapidly with sediment, which will limit its usefulness. In the tributary Colorado River, there is little doubt that adult pikeminnow will move into upstream reaches if given the opportunity. A fish passage structure at the Redlands Diversion in the Gunnison River has demonstrated that the fish can negotiate such passageways and will use habitat upstream. At present, however, it is not known if the number of migrants using the passageway is a large or small proportion of those fish seeking to move upstream. Our ranking of tributaries in terms of the significance of barriers to movement is as follows: (1) Colorado River above Grand Junction, (2) White River, and (3) Gunnison River. Passageways are already in place or being designed for some, but not all facilities in these areas.

– The Recovery Program should reevaluate alternatives for providing fish access to upstream areas. Endangered fish populations in tributary reaches provide the best opportunities for range expansion, but a comprehensive system is needed to evaluate recovery success.

Reintroduction offers hope for expanding the numbers of individuals and populations more quickly than could be expected with the stock present today. Moreover, reintroduction offers the only possibility for recovering the bonytail. In addition, placing individuals in habitat that is perceived to be suitable will provide a serious test of the present state of knowledge concerning ecological requirements of the endangered fishes. The Recovery Program already has made a major commitment to reintroduction. This recommendation supports those efforts and indicates priorities among the tributaries. Of present

reintroductions, the Recovery Program has stocked bonytail in promising locations in the tributary Green and Yampa rivers. Strong potential for reestablishing fish populations also exists in the Colorado River above Palisade, Colorado where historical information and present habitat conditions suggest that it may be possible to reintroduce Colorado pikeminnow, humpback chub, and razorback sucker. Success may depend in part on action taken to circumvent or remove existing barriers to fish movement. Finally, there may be potential for reintroducing razorback suckers in the lower White River using insights gained from reintroducing the species elsewhere. It is unclear why razorback sucker do not utilize the White River more heavily and more effort is needed to determine the factors that may limit their use of that system.

The recovery program should develop a comprehensive system to evaluate recovery success for the endangered fishes among the different tributaries. Stocking of the endangered fishes will meet with varying levels of success. It will be important to determine why the fish do well in some areas but not in others. A greater understanding of factors limiting the success of introductions can be applied throughout the recovery program, especially to improve stocking protocols and to provide for habitat requirements.

– The Recovery Program should develop and implement plans for removing nonnative fishes from tributaries and controlling nonnative fish movement into the mainstream rivers from tributary source areas.

Nonnative fishes are having a significant impact on recruitment of endangered fishes. Tributary streams present recovery obstacles by supporting large populations of nonnative fishes, especially in altered habitats. Many of the nonnative predators, especially centrarchids, enter mainstem reaches from source areas such as small ponds and reservoirs in the Duchesne, White, Yampa, and Colorado river basins. In addition, nonnative fishes present in tributary mouths may be competing with, or preying on, larval fishes. The issue has been studied extensively and limited action has been taken. The draft Yampa River Management plan contains the right elements, and presumably it can be successfully implemented. One impediment appears to be the requirement for translocation of northern pike, because few suitable sites are available. Perhaps a better solution would be to eradicate northern pike, if possible. Also, we encourage the program to monitor closely the efforts proposed in the Yampa basin to remove channel catfish, which are a serious problem throughout the basin. In general, a significant reduction in the number of nonnative predators should lead to improved recruitment of the listed fishes.

– The Recovery Program should determine the environmental attributes of the mouths of tributary streams that promote utilization by larval razorback suckers

Recent studies suggest that the mouths of some tributary streams provide important habitat for endangered fishes (e.g., mouth of the San Rafael as habitat for larval razorback suckers). These findings merit further investigation to assess the spatial and temporal dimensions of the habitat, as well as a thorough assessment of ecological significance. Some relevant questions include: (1) Are all tributary mouths providing important habitat?, (2) What are the species and life history stages that benefit from the habitat?, and (3) Does this habitat offer ecological characteristic not available in backwaters or eddies that are more common physical features of the riverine environment? It will be difficult to protect this habitat if the beneficial characteristics have not been identified.

– The Recovery Program should establish which tributaries are primary sediment sources for each Colorado pikeminnow nursery habitat.

Nursery habitat for the Colorado pikeminnow appears to be restricted to a few reaches in which there is an abundance of sandy backwaters, such as the Colorado River near Moab and the Green River near Ouray and Mineral Bottom. The flow conditions that shape these habitat features are not adequately understood. Little is known about which tributaries are the predominant sediment sources and whether the importance of these might change according to annual flow regimes. In a broad context, the investigation should establish the optimal timing of flow and sediment deliveries from individual tributaries. It should also define the flow or sediment delivery conditions that are most detrimental to the habitat. A better understanding of mechanisms shaping nursery habitat will facilitate decisions about flows needed for recovery and will help ensure that ample nursery habitat is available. In addition, specific knowledge regarding sediment sources will be important if the recovery program is to participate effectively in the development of sediment TMDLs, which in some cases may require Section 7 consultation by USFWS. This recommendation addresses one (tractable) facet of a much broader issue concerning the potential for mitigating the effects of habitat alteration in the mainstem by manipulating flows in the tributaries.

– The Recovery Program should initiate a study to measure the release of metals from selected reservoirs in Utah that are known to experience seasonal depletion of dissolved oxygen.

Water quality in the Duchesne, Price, and San Rafael rivers may be jeopardized by conditions that promote seasonal release of metals from the sediments of lakes. If metals are released in sufficient quantity, larvae inhabiting the mouths of these rivers may be at risk. The state of Utah has identified numerous reservoirs in the Green River basin that experience chronic loss of dissolved oxygen in deep water. The loss of oxygen from lake water above the sediment creates redox conditions that release metals from the sediment. Depletion of dissolved oxygen is most likely to occur in late winter (March-April) or summer (July-September).

There is insufficient information to judge the potential for metals to impair water quality in stream reaches occupied by the endangered fishes. More data are needed assessing concentrations during periods of oxygen depletion. Water samples should be taken near the bottom of each lake and, if conditions are anoxic, the samples should be assayed for metals. If concentrations are high, then simple mass balance calculations should be employed to predict concentrations near the mouth of the tributary. If the mass balance study indicates that there is a reasonable potential for metals to degrade water quality in river reaches used by the endangered fishes, proposals should be developed for reducing the release of metals (e.g., through aeration or destratification) from the most potent sources.

As mentioned previously, the State of Utah detected oxygen problems in many reservoirs. These reservoirs have been added to the 303d list, indicating that TMDLs will be established. However, the assignment of low priority to TMDL development means that years will pass before action is taken. Furthermore, the focus will be on oxygen rather than on metals. Consequently, it makes sense for the Recovery Program to evaluate the extent of the problem and, if warranted, suggest action for the State.

– **The Recovery Program should participate actively in the development of TMDLs for suspended sediment in any tributary for which a TMDL has been proposed by state water quality agencies.**

Suspended sediment is a potentially difficult water quality issue, because the transport of sediment may be both good and bad for fish. Nationwide, suspended sediment is regarded as one of the most common causes of water quality impairment, and the typical motivation for controlling sediment is based on concern about degradation of aquatic habitat. Consequently, the prevailing mindset in state water quality agencies seeks to control downstream sediment transport. At the same time, a supply of sediment is important for the creation and maintenance of nursery areas used by the Colorado pikeminnow. Furthermore, suspended sediment creates the turbidity that can shelter endangered fish larvae from sight-feeding predators, such as introduced centrarchids. Although participants in the program are cognizant of these two views of suspended sediment, most individuals in state water quality agencies are not.

State water quality agencies are obliged to identify water quality concerns for all streams in their respective jurisdictions. When water quality is shown to be impaired in a particular stream reach, that stream must be added to a 303d list as required by the U.S. EPA. Once a stream is placed on the 303d list, a TMDL (total maximum daily load) evaluation is required, although the time line for implementing the TMDL is flexible. Each TMDL determines the maximum amount of a pollutant that a stream can receive and still meet water quality standards. Stakeholders in the affected watershed participate in the TMDL process.

The Recovery Program is one of the few entities with an understanding of the positive role that suspended sediment can play in promoting Recovery. This perspective must be

represented in the TMDL process. The Recovery program should address its concerns to the water quality agency in each state and make it clear that the program wants stakeholder status in the development of any sediment TMDLs. In practice, most sediment TMDLs will have little effect on the Recovery process, but participation in TMDL development will serve a useful purpose. The Recovery Program can broaden the perspective of state agencies regarding water quality issues that have bearing on Recovery of endangered fishes in the upper Colorado River basin.

– The Recovery Program should develop management plans for tributaries in accordance with their perceived importance to Recovery.

The Recovery Program is in the process of developing management plans for individual river basins. A plan is in progress for the Yampa River basin (due to be completed in November), and it will be followed by a plan for the Gunnison River basin. Comparable work for the upper Colorado has already been completed in connection with studies of the 15-Mile Reach. The sequence for these plans is in agreement with priorities we have indicated in Table 12. Four subsequent plans could be developed in the following sequence: 1) White River, 2) Duchesne and tributary Green (above Yampa) rivers, 3) Dolores River, and 4) Price and San Rafael rivers. We do not feel there is a need to develop comparable plans for the Dirty Devil River, Escalante River, or Plateau Creek watersheds. After management plans are completed for the more important tributaries, the Recovery Program should consider integrating them in an ecosystem or multispecies recovery plan to provide an integrated approach within the upper basin.

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FIGURES

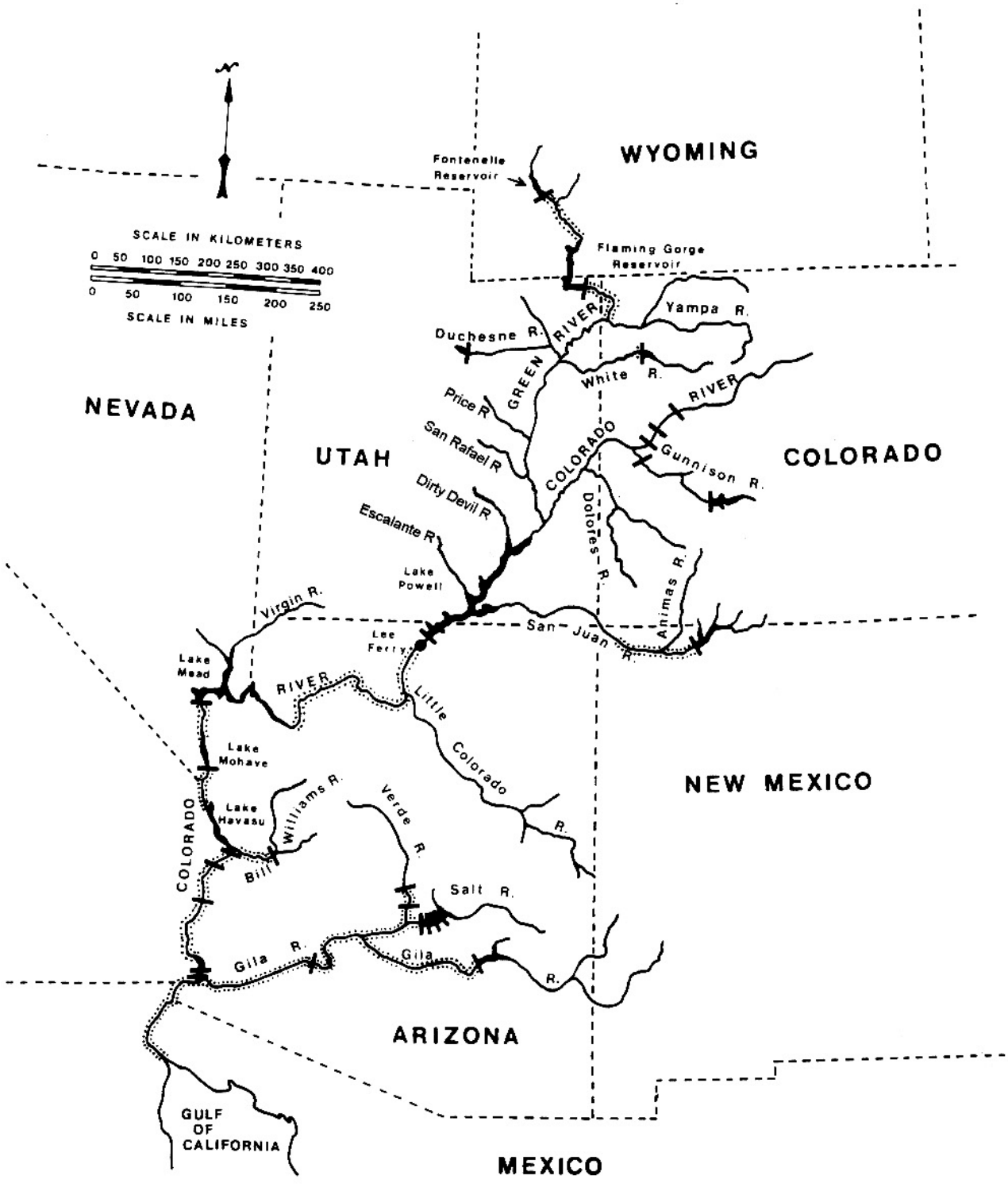

Figure 1. Mainstream barriers and their impacts in the Colorado River basin. Solid bars perpendicular to channel indicate barriers, darkened sections above barriers show impoundments, and stippling indicates downstream impact. (after Tyus 1984)

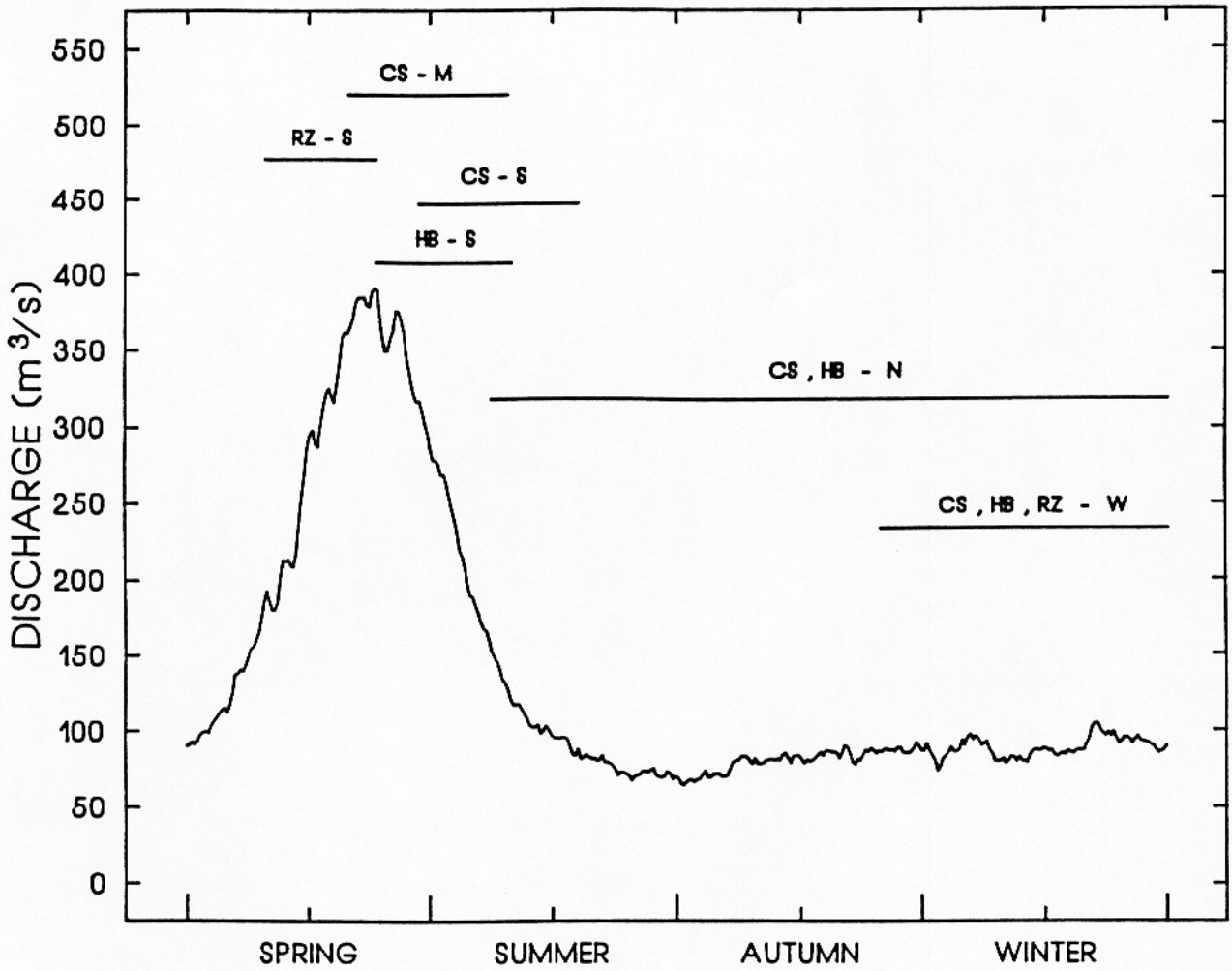

Figure 2. Conceptual relationship between the natural hydrograph and the timing of events (M=migration, S=spawning, N=nursery, W=winter) in the life history of Colorado pikeminnow (CS), razorback sucker (RZ), and humpback chub (HB). (After Tyus and Karp 1989).

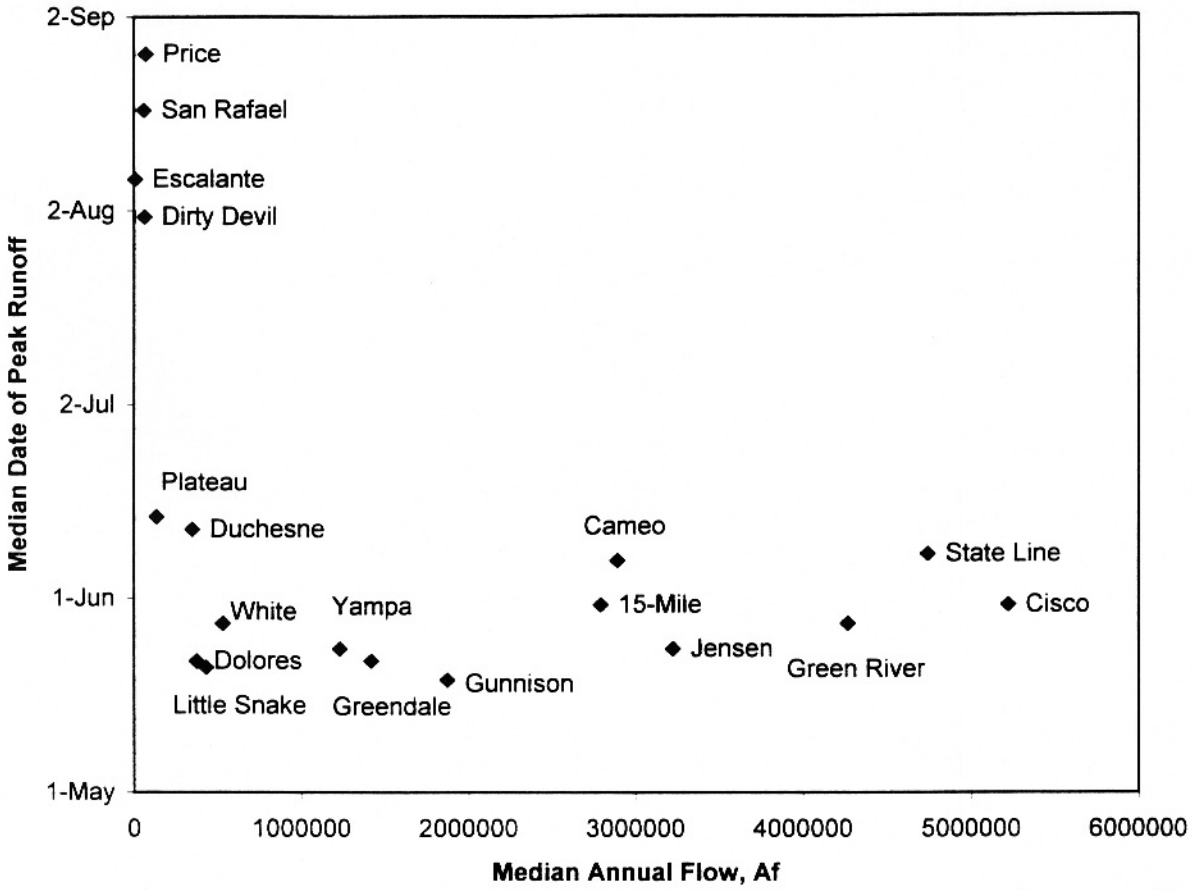

Figure 3. Relationship between median date of annual peak runoff and the size of watersheds as indicated by median annual flow.

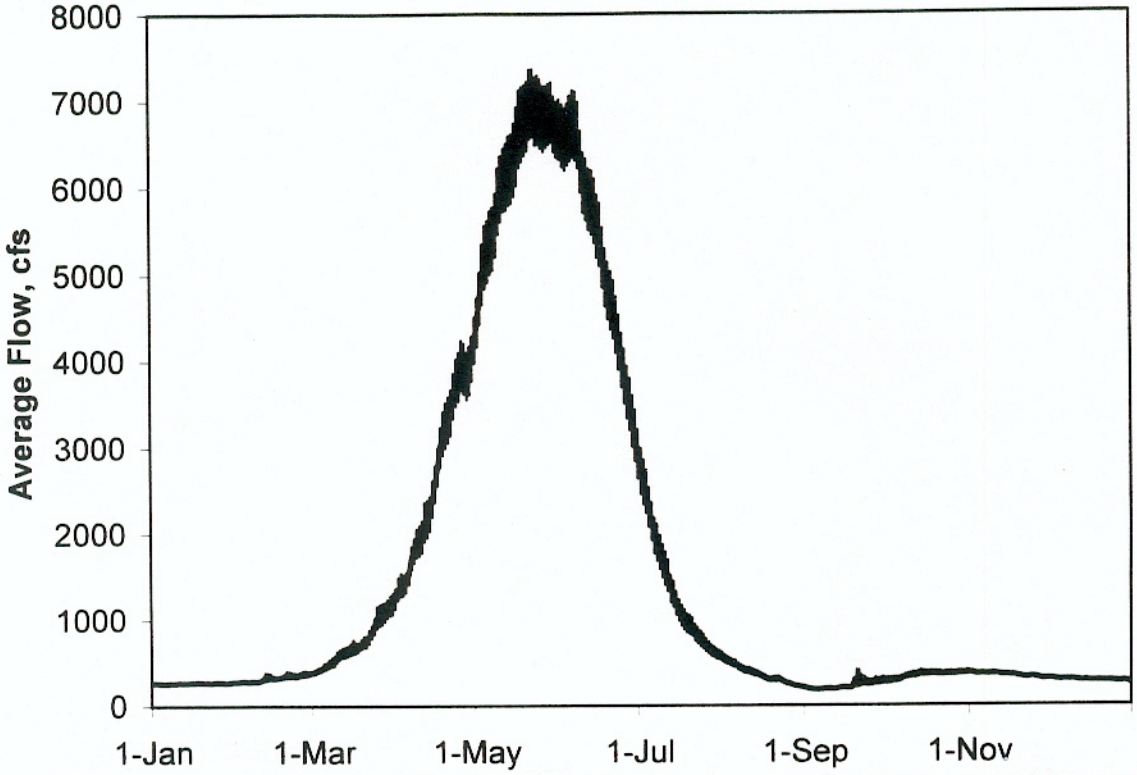

Figure 4. Typical flows in the Yampa River. For each day of the year, the average flow and standard error are shown based on data for Water Years 1939-1998.

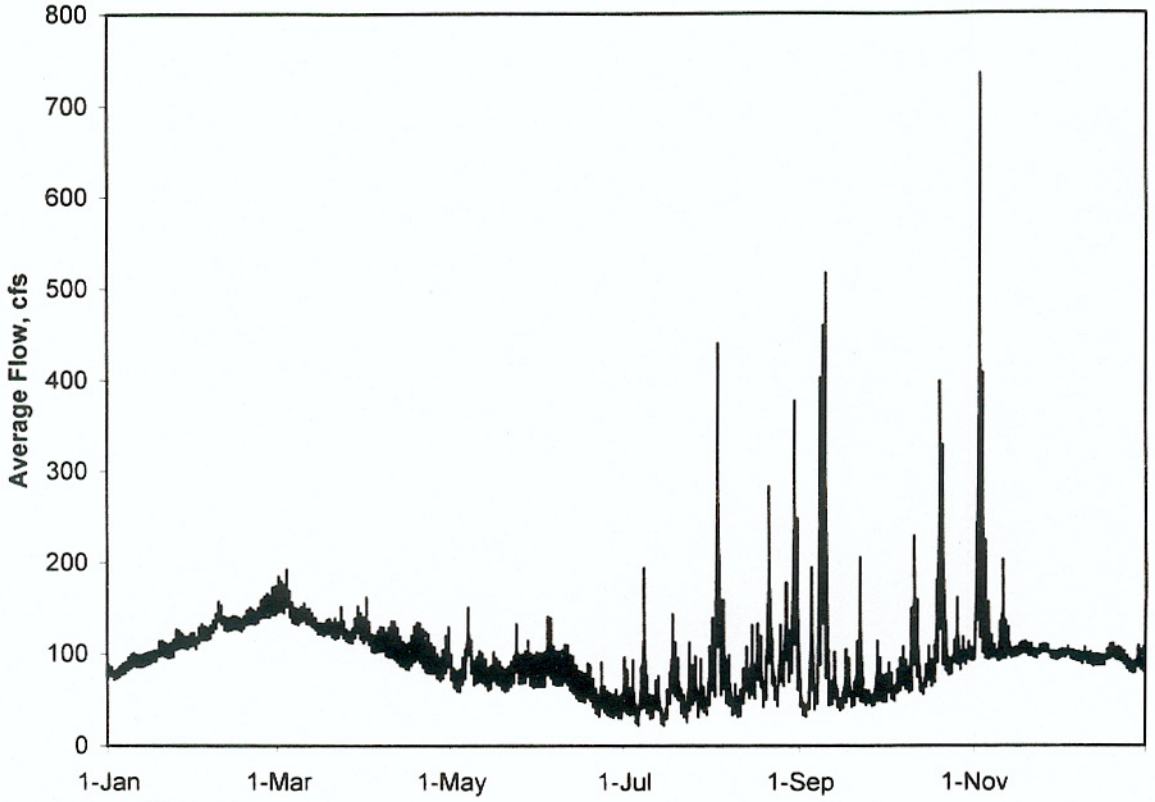

Figure 5. Typical flows in the Dirty Devil River. For each day of the year, the average flow and standard error are shown based on data for WY1949-1993.

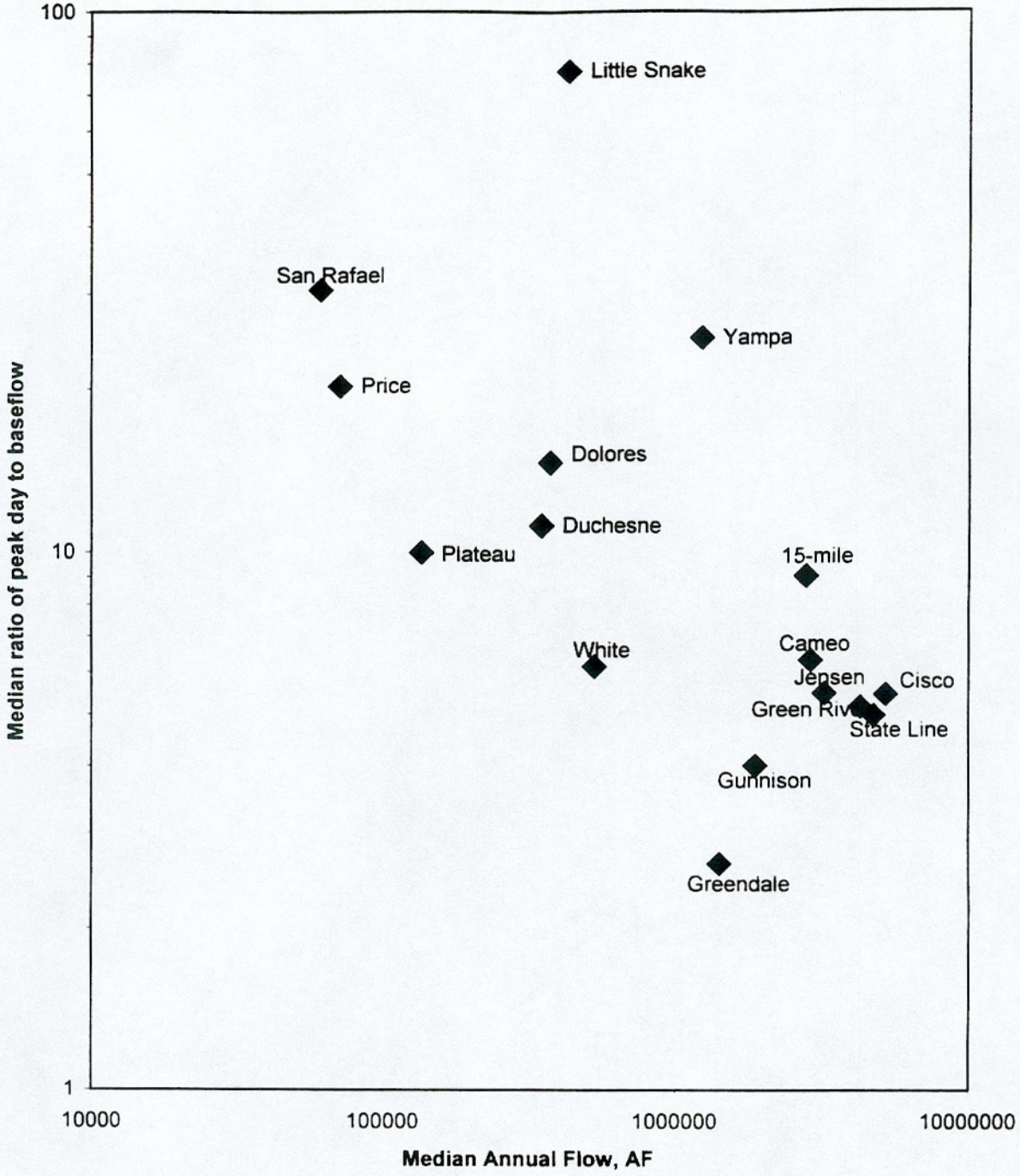

Figure 6. Relationship between ratio of peak daily flows to base flow and median annual flow for tributary and mainstem sites.

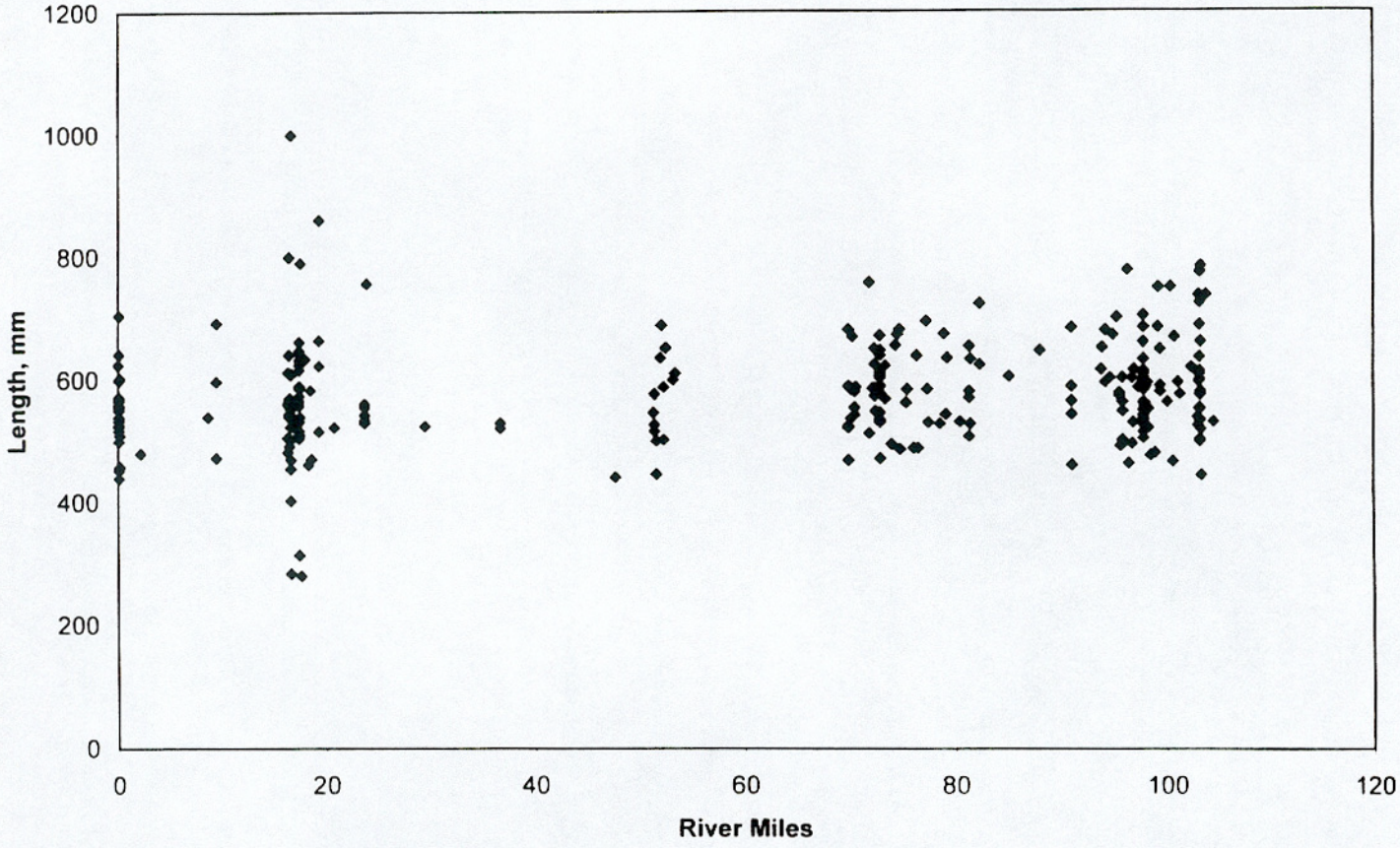

Figure 7. Recent captures of adult Colorado pikeminnow (n = 274) in the Yampa River, Colorado, 1990 -1997. River mile 0 = river mouth. Length is total length. Data courtesy of the U.S. Fish and Wildlife Service.

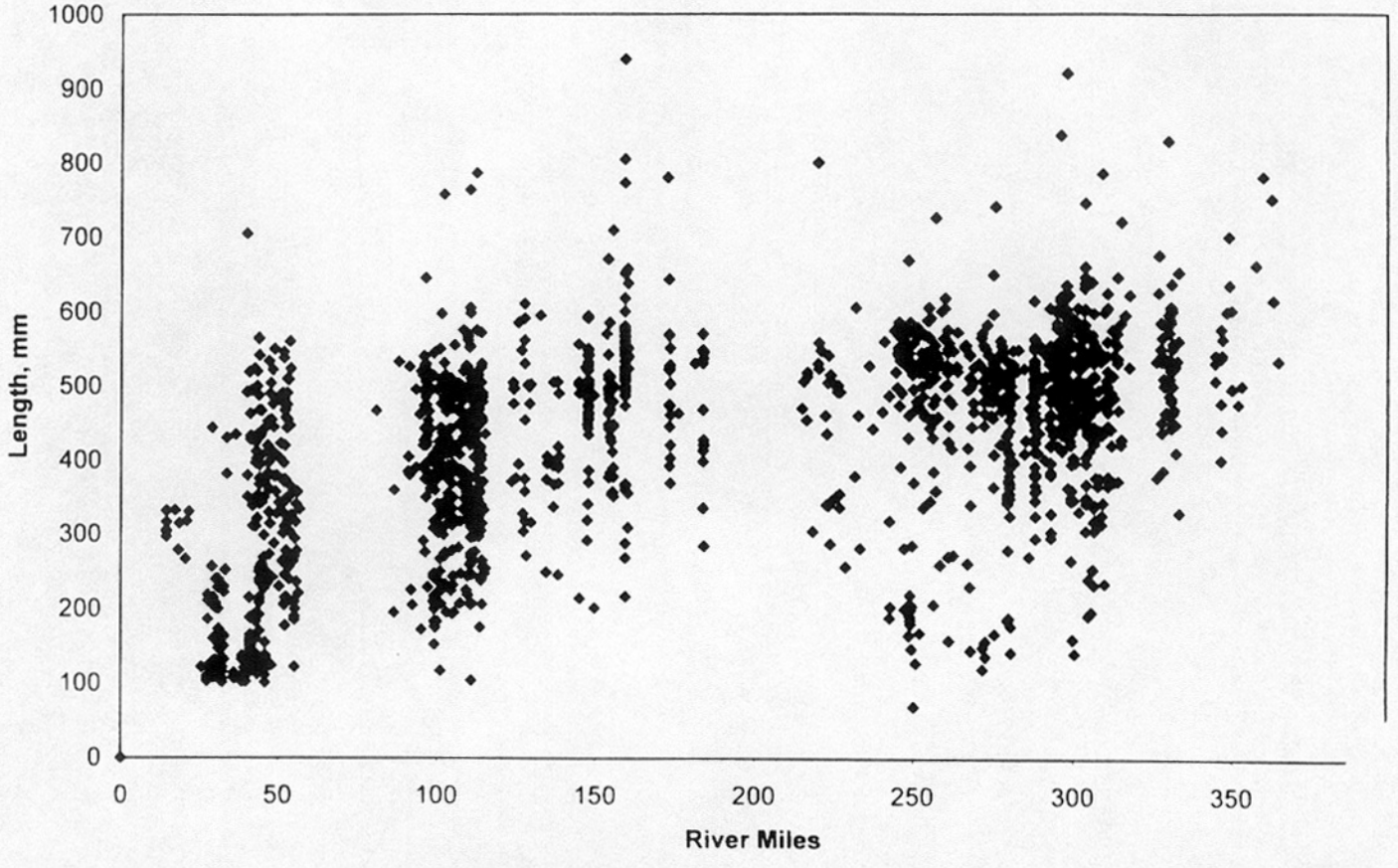

Figure 8. Recent captures of adult Colorado pikeminnow (n = 1,624) in the Green River, Utah, 1990 -1997. River mile 0 = river mouth. Length is total length. Data courtesy of the U.S. Fish and Wildlife Service.

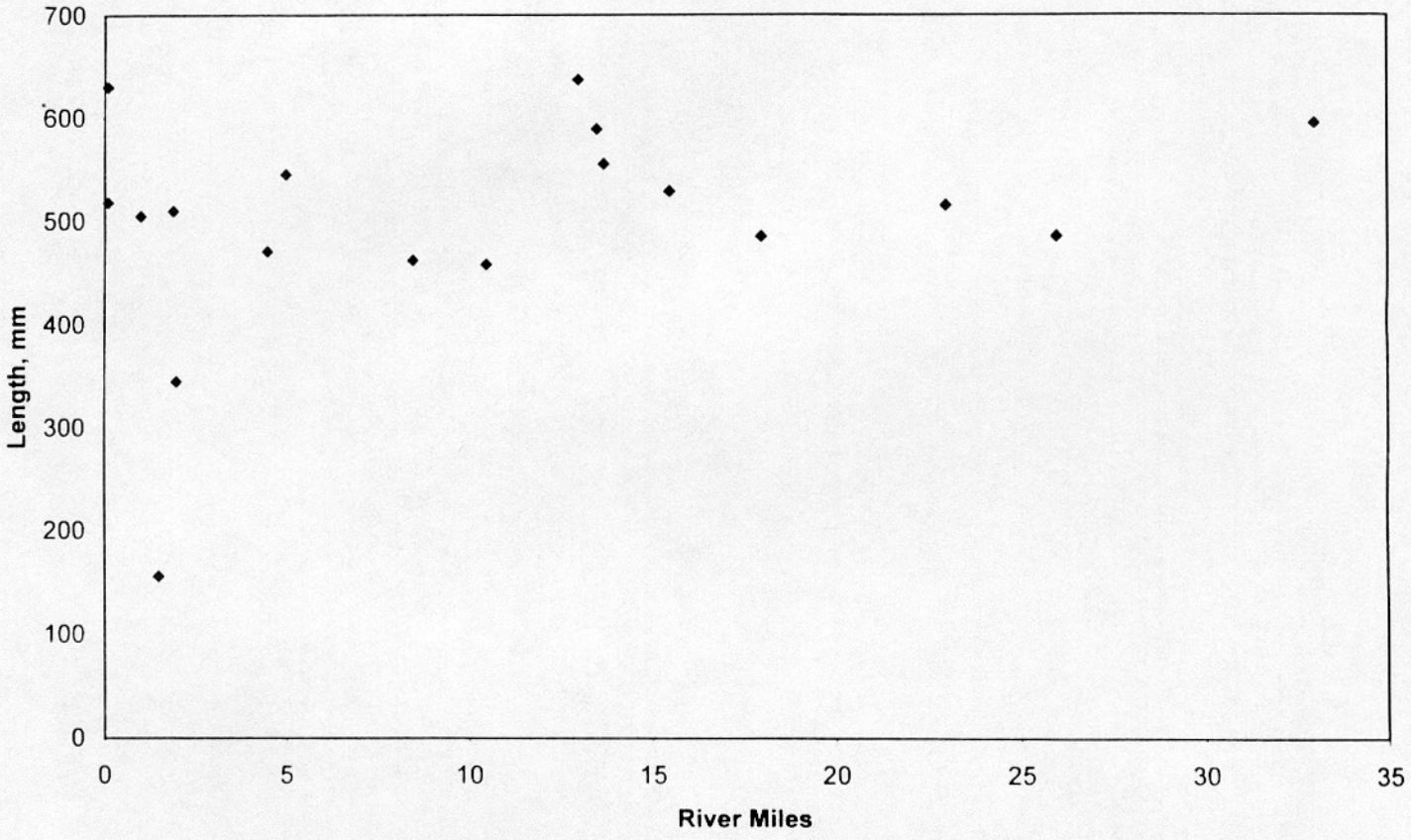

Figure 9. Recent captures of adult Colorado pikeminnow (n = 18) in the Duchesne River, Utah, 1990 -1997. River mile 0 = river mouth. Length is total length. Data courtesy of the U.S. Fish and Wildlife Service.

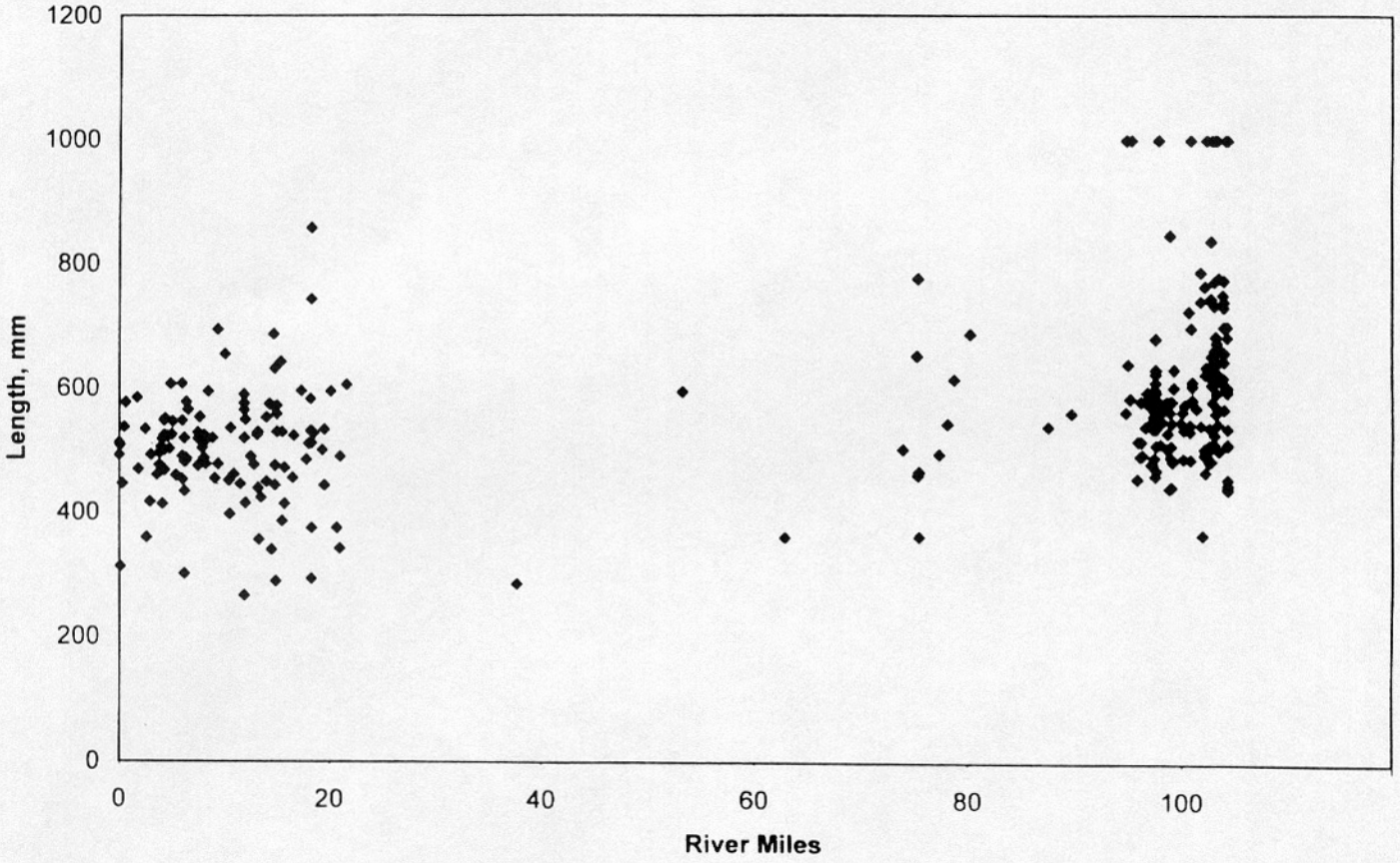

Figure 10. Recent captures of adult Colorado pikeminnow (n = 289) in the White River, Colorado and Utah, 1990 -1997. River mile 0 = river mouth. Length is total length. Data courtesy of the U.S. Fish and Wildlife Service.

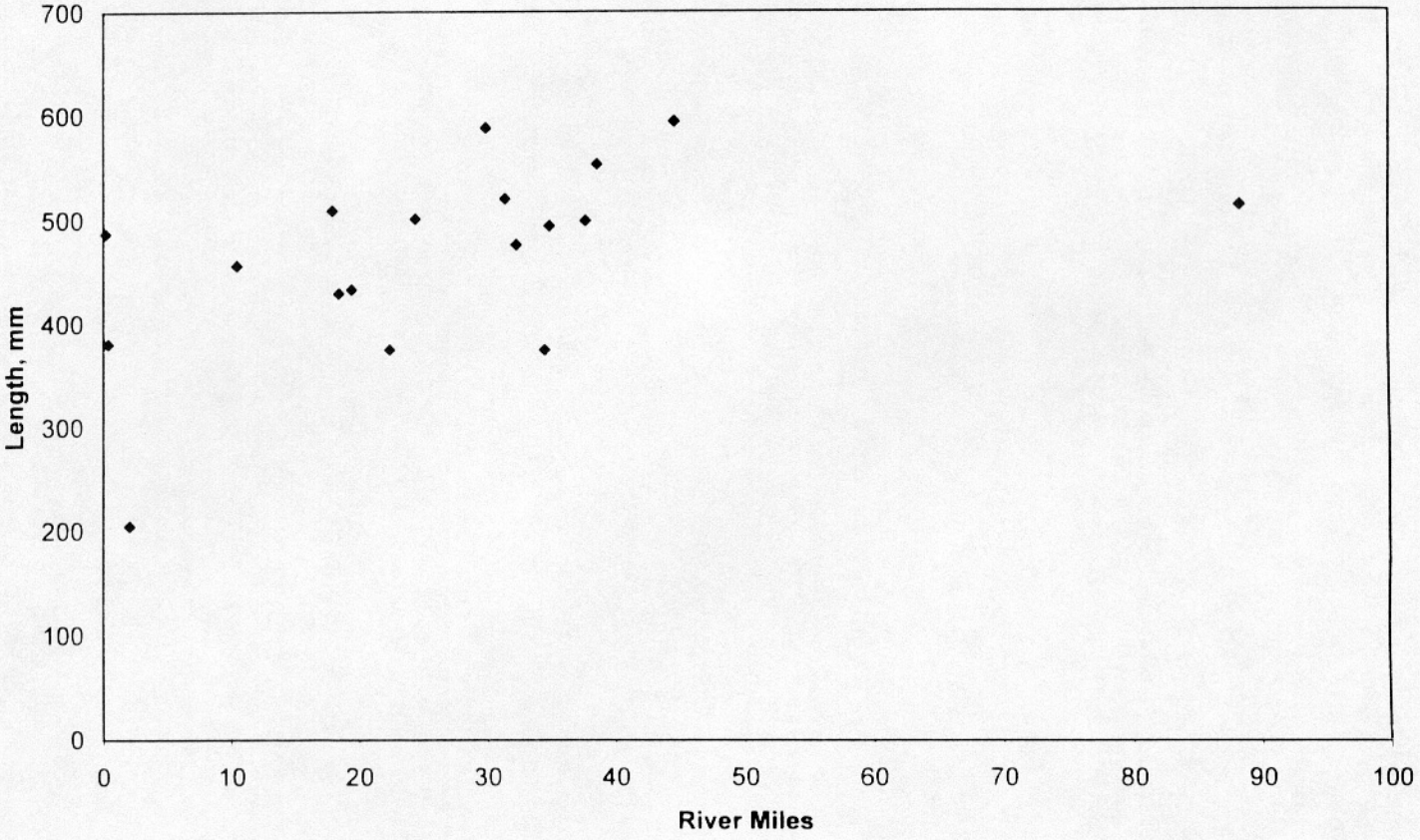

Figure 11. Recent captures of adult Colorado pikeminnow (n = 18) in the Price River, Utah, 1990 -1997. River mile 0 = river mouth. Length is total length. Data courtesy of the U.S. Fish and Wildlife Service.

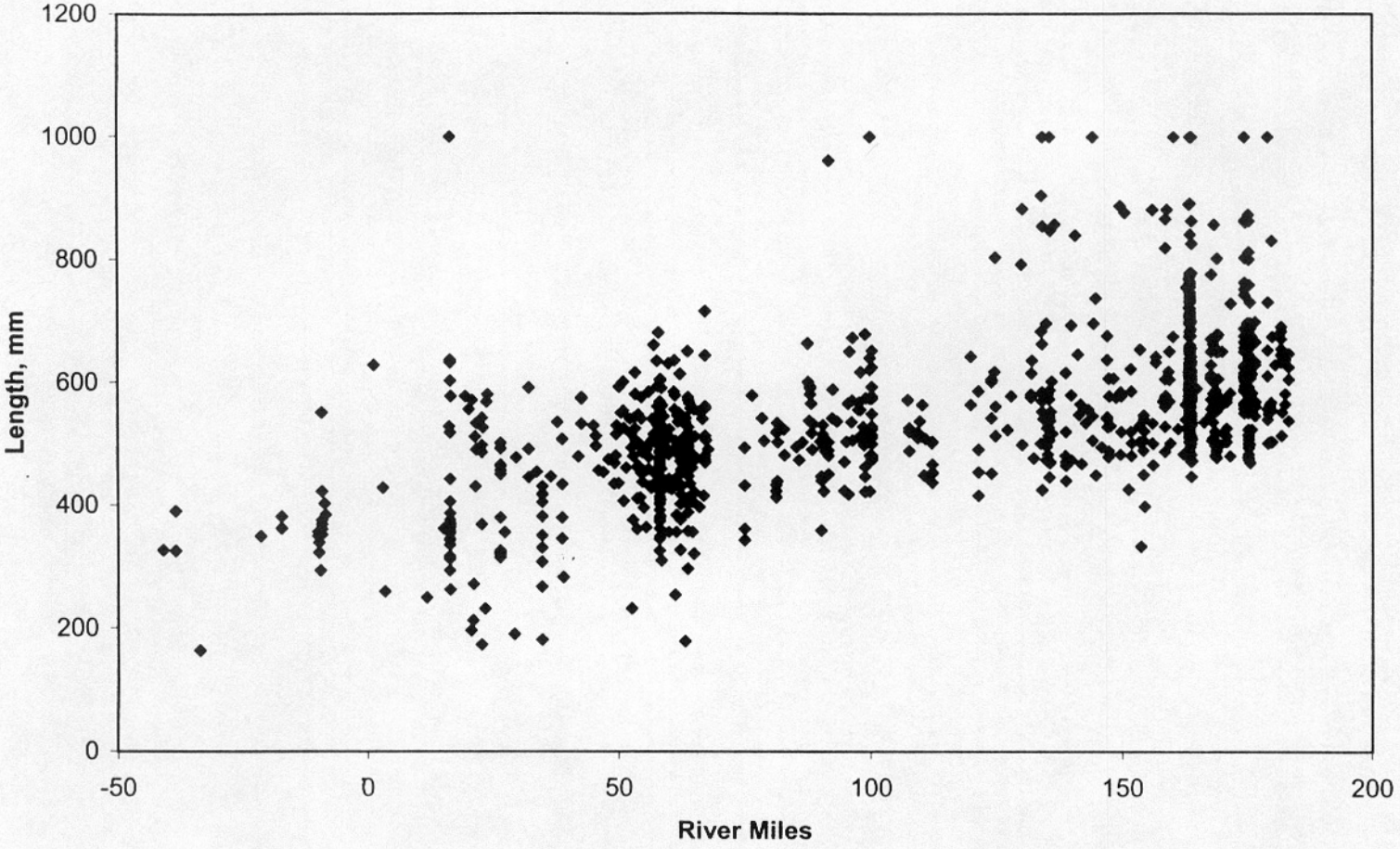

Figure 12. Recent captures of adult Colorado pikeminnow (n = 1,082) in the Colorado River, Colorado, 1990 -1997. River mile 0 = river mouth. Length is total length. Data courtesy of the U.S. Fish and Wildlife Service.

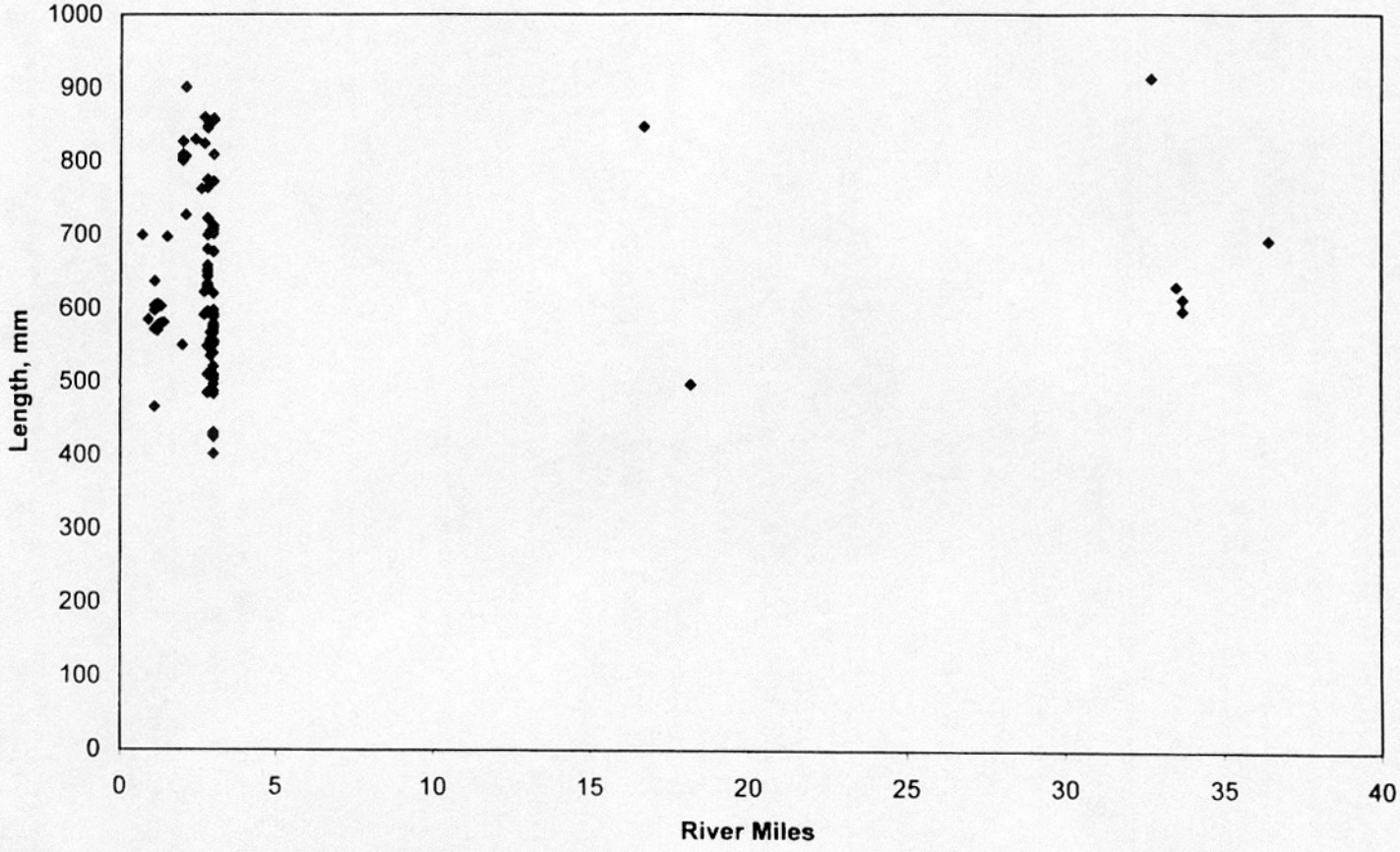

Figure 13. Recent captures of adult Colorado pikeminnow (n = 102) in the Gunnison River, Colorado, 1990 -1997. River mile 0 = river mouth. Length is total length. Data courtesy of the U.S. Fish and Wildlife Service.

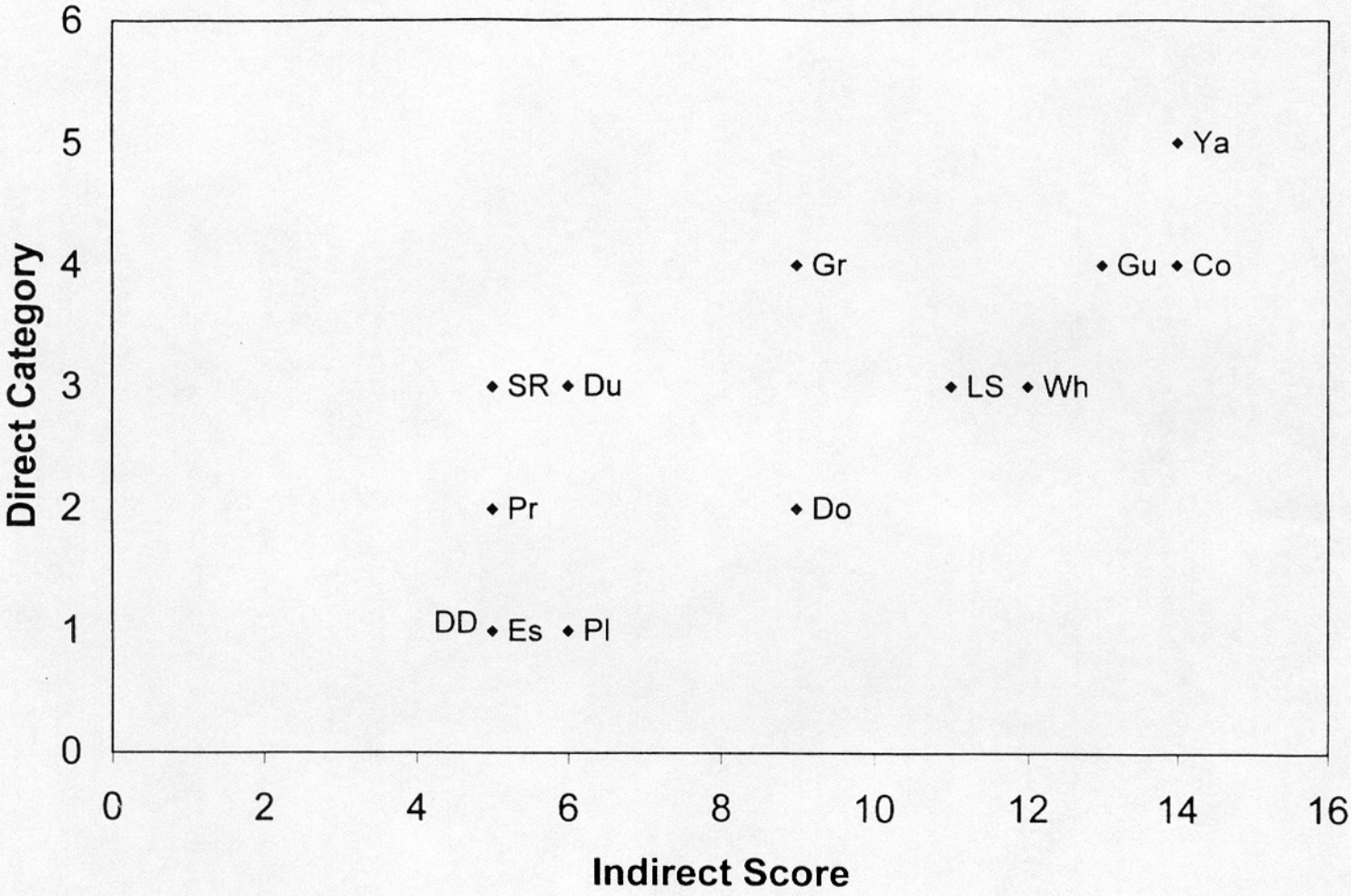

Figure 14. Relationships between potential direct contributions and present indirect contributions of tributaries in the upper Colorado River basin. CO= Tributary Colorado River, DD= Dirty Devil River, Do= Dolores River, Du= Duchesne River, Gr= Tributary Green River, Gu= Gunnison River, Es= Escalante River, LS= Little Snake River, Pl=Plateau Creek, Pr= Price River, SR= San Rafael River, Wh = White River, Ya= Yampa River.