CHAPTER III

Affected Environment

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This chapter describes the general setting, Colorado River system resource linkages, and resources in the study area that would be affected by any of the alternatives if implemented. The conditions described are those that existed in 1990, prior to the Glen Canyon Environmental Studies (GCES) research flows, under the water and power operating regimes that existed at that time. These conditions establish the baseline for analysis of effects, found in chapter IV. The resources presented are: water, sediment, fish, vegetation, wildlife and habitat, endangered and other special status species, cultural resources, air quality, recreation, hydropower, and non-use value.

SETTING

The affected environment includes two areas: (1) the immediate or Glen Canyon Dam area and (2) the region. The immediate area is the Colorado River corridor through Glen, Marble, and Grand Canyons in Coconino and Mohave Counties in northwestern Arizona. This area extends from Lake Powell downstream into Lake Mead. While the focus of the environmental impact statement (EIS) is on this river corridor, some alternatives may lead to regional impacts outside of the immediate geographic area. The following map shows the regional extent of the Colorado River Basin.

Immediate Area (see frontispiece)

Lake Powell and the first 15.5 miles of the Colorado River downstream of Glen Canyon Dam are part of Glen Canyon National Recreation Area (GLCA). The river flows another 278 miles through Grand Canyon National Park (GRCA) into Lake Mead, part of Lake Mead National Recreation Area. All of these areas are administered by the National Park Service (NPS). The Navajo Indian Reservation is adjacent to GRCA and GLCA. Kaibab National Forest, administered by the Forest Service of the U.S. Department of Agriculture, adjoins GRCA on the north and south. The Hualapai Reservation includes 108 miles of Grand Canyon south of the river from National Canyon (river mile[1] (RM) 166.5) to RM 273. The Havasupai Reservation adjoins GRCA south of the river and west of the Kaibab National Forest.

Between Glen Canyon Dam and Lake Mead, the Colorado River falls about 1,900 feet, or from approximately 3100 to 1200 feet above sea level. More than 100 rapids, some having drops of up to 40 feet, account for most of this elevation loss. Numerous tributaries enter this stretch of river, the principal ones being the Paria and Little Colorado Rivers, and Bright Angel, Tapeats, Kanab, Havasu, Diamond, and Spencer Creeks.

The Colorado River can be reached by two highways: U.S. 89 crosses the river immediately below Glen Canyon Dam, and U.S. 89 Alternate crosses about 20 miles downstream near the community of Marble Canyon (near RM 4). Year-round access to the south rim of Grand Canyon is provided by U.S. 180 and Arizona 64. Access to the north rim is provided by Arizona 67, but the part of that road between the GRCA boundary and the north rim is open only from about mid-May to mid-October.

Access to the south and north rims and the river at other locations is provided by a few unimproved roads and several trails. Some of the unimproved roads and trails access the canyon via the Navajo Indian Reservation, and permits for their use must

[1] River mile designates distance downstream from Lees Ferry (RM 0), which is located 15.5 miles downstream from Glen Canyon Dam. Negative numbers (i.e., RM -9) indicate distance upstream between Lees Ferry and the dam.

be obtained from the Navajo Nation in Cameron or Window Rock, Arizona. Access to the river is also available from Supai via a hiking trail through the Havasupai Reservation and from Peach Springs to Diamond Creek via the Hualapai Indian Reservation. An NPS road provides access to Lees Ferry from Marble Canyon.

Two cities in the area are Flagstaff, Arizona, about 80 miles south of the south rim of Grand Canyon, and Page, Arizona, about 2 miles southeast of Glen Canyon Dam. Commercial air service is available at both cities and near Grand Canyon Village on the south rim. Commercial boat trips on the Colorado River begin immediately below Glen Canyon Dam and at Lees Ferry (RM 0); private trips begin only at Lees Ferry. Also, the Hualapai Tribe provides commercial river trips from Diamond Creek to Lake Mead. Mule trips are conducted from Grand Canyon Village and the north rim.

Colorado River Region

The Colorado River has its headwaters in the mountains of Colorado and flows southwestward to its mouth at the Gulf of California. It drains an area of approximately 244,000 square miles, of which 242,000 are in the United States and 2,000 are in northern Mexico. The basin extends from the Wind River Mountains in Wyoming to south of the United States–Mexico border, a straight line distance of approximately 900 miles. Basin width varies from about 300 miles in the upper reaches to more than 500 miles in the lower reaches. It is bounded on the north and east by the Continental Divide in the Rocky Mountains, on the west by the Wasatch Mountains, and on the southwest by the San Jacinto Mountains. Colorado River tributaries drain parts of seven Western States: Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming.

The Upper Colorado River Basin drains an area of 108,000 square miles; its tributaries include the Upper Colorado, Green, Gunnison, San Juan, and Paria Rivers. The Lower Colorado River Basin drains an area of 136,000 square miles, and its tributary basins include the Lower Colorado, Little Colorado, Virgin, and Gila Rivers. The division between the two basins is at Lee Ferry, a reference point in the mainstream of the Colorado River 1 mile below the mouth of the Paria River (not to be confused with Lees Ferry, which is the site of the U.S. Geological Survey (USGS) stream gauge above the Paria River confluence).

Geology

For more than 5 million years, the Colorado River and its tributaries—along with geologic uplift and weathering—have carved the Grand Canyon. The canyon is about a mile deep and varies in width from a few hundred feet at river level to as much as 18 miles at the rim. The river cut only a narrow gorge; running water from the canyon walls, freezing and thawing, and abrasion of rock against rock excavated most of the canyon. The Colorado River is like a huge conveyor belt for transporting finer particles to the ocean, temporarily (geologically speaking) dropping its load into Lake Mead.

In cutting the canyon, the river has exposed rocks of all geologic eras, covering a span of nearly 2 billion years. The rocks of Grand Canyon are part of the Colorado Plateau, a 130,000-square-mile area covering most of the Colorado River Basin. The elevation of the canyon rim varies between about 5000 and 8000 feet above sea level, with the north rim about 1,000 feet higher than the south rim.

A river trip starting at Glen Canyon Dam is a trip backward through geologic time (Beus and Morales, 1990). Glen Canyon is cut through the massive Navajo Sandstone of the Mesozoic era—about 200 million years old. Downstream from Lees Ferry, the great sequence of nearly horizontal sedimentary rocks of the Paleozoic era appear at river level in descending order, beginning with the Kaibab Formation that caps much of the canyon rim. In Marble Canyon, river runners pass through the cavernous Redwall Limestone. The river is narrower here and in other places where the Paleozoic rocks are relatively hard and wider through more easily eroded formations. The shelves of the Tapeats Sandstone (more than 500 million years old) at the base of the Paleozoics appear near the mouth of the Little Colorado River (LCR). For the rest of the trip, the narrowest reaches are cut through the dense, dark-colored Vishnu Schist of the Proterozoic era (about 1.7 billion years old). In the Toroweap area, river runners are greeted with a spectacular display of the youngest rocks in the canyon—remnants of lava flows that poured over the north rim about 1 million years ago during the Cenozoic era. The hardened lava still clings to the canyon walls, and basalt boulders still affect riverflow—providing thrills for river runners at Lava Falls Rapid. The trip ends in Lake Mead at Grand Wash Cliffs, the southwestern edge of the Colorado Plateau and the mouth of Grand Canyon.

Climate

Climatic conditions in the area vary considerably with elevation. At Bright Angel Campground (elevation 2400 feet) near Phantom Ranch, the climate is characterized by mild winters, hot summers, and low rainfall. Average high temperatures range from about 59 degrees Fahrenheit (°F) in winter to 103 °F in summer. Low temperatures range from about 39 to 76 °F. Average annual precipitation—mostly in the form of rain—is about 11.2 inches. Precipitation occurs uniformly in summer, fall, and winter and is somewhat less in spring.

In contrast, the climate at the north rim (elevation 7800 to 8800 feet) is characterized by cold winters, cool summers, and abundant precipitation with snowfall. Average high temperatures range from 39 °F in winter to 75 °F in summer; low temperatures range from about 18 to 43 °F. Average annual precipitation is 33.6 inches. The south rim (elevation 7000 feet) receives about 16 inches of precipitation annually. Average high temperatures range from 41 °F in winter to 84 °F in summer; average low temperatures range from 18 °F in winter to 54 °F in summer.

The Upper Colorado River Basin can be generally classified as semiarid and the Lower Basin as arid. The climate varies from cold-humid at the headwaters in the high mountains of Colorado, New Mexico, Utah, and Wyoming to dry-temperate in the northern areas below the mountains and arid in the lower southern areas. Annual precipitation in the higher mountains occurs mostly as snow, which results in as much as 60 inches of precipitation per year. Thousands of square miles in the lower part of the basin are sparsely vegetated because of low rainfall and poor soil conditions. Rainfall in this area averages from 6 to 8 inches, mostly from cloudburst storms during the late summer and early fall.

COLORADO RIVER SYSTEM RESOURCE LINKAGES

Resources downstream from Glen Canyon Dam through Grand Canyon are interrelated, or linked, since virtually all of them are associated with or dependent on water and sediment. This section gives an overview of linkages to better illustrate the interdependence of processes and resources in the study area. A detailed description of resources follows this overview.

This resource linkage overview specifically responds to the EIS scoping process. Many comments from the public called for consideration of the "Grand Canyon ecosystem," showing public awareness of the interrelationships among resources. The term "ecosystem" refers to the system formed by interactions between communities of organisms and their environment. A "system" is based on the concept that resources and the processes that drive them are linked. In an ecosystem, changes in a single process can affect resources throughout the entire system.

This EIS emphasizes the holistic pattern of system behavior rather than impacts on separate elements. However, it cannot provide a complete, scientific study of the Grand Canyon ecosystem because such an approach is too technically detailed for the purpose and scope of this document. Also, all the linkages among resources of the Grand Canyon ecosystem are not fully understood at this time. As discussed in chapter II, a program of monitoring and adaptive management is required to expand our understanding of how changes in processes affect this system.

The Glen Canyon Dam EIS focuses on the following processes, resources, and their linkages:

Water release and sediment transport patterns
Aquatic and terrestrial "indicator resources" within the system

The system of concern in this study is the Colorado River corridor—from Glen Canyon Dam through Grand Canyon to Lake Mead—and includes resources located in the river channel and in a narrow band of adjacent land (figure III-1). Resources within this system depend on factors outside these operationally defined boundaries, including the physical and biological constraints of Lake Powell and, to a lesser extent, Lake Mead and tributaries such as the LCR.

The Grand Canyon ecosystem originally developed in a sediment-laden, seasonally fluctuating environment. The construction of Glen Canyon Dam altered the natural dynamics of the Colorado River. Today, the ecological resources of Grand Canyon depend on the water releases from the dam and variable sediment input from tributaries. The alternatives evaluated through this EIS must take into account not only the short-term needs of the environment but also the long-term requirements for maintaining and supporting the ecological elements of Grand Canyon.

Lake Powell traps water, sediment, and associated nutrients that previously traveled down the Colorado River. Interruption of riverflow and regulated release of lake water now support aquatic and terrestrial systems that did not exist before Glen Canyon Dam. Some changes are lamented while others are valued. The following discussion addresses the current systems, their resources, and how dam operations affect them either directly or through linkages among resources. The present interactions among water volume and release patterns, sediment transport, and downstream resources have created and support a complex system much different from predam conditions.

Water Volume and Pattern of Release

The major function of Glen Canyon Dam (and Lake Powell) is water storage. The dam is managed to release at least 8.23 million acre-feet (maf) of water annually to the Lower Basin. In this EIS, riverflows below the dam are referred to as releases or discharge. The measure of riverflow is in cubic feet per second (cfs). Annual and monthly volumes are measured in acre-feet. To put these relationships in perspective, Glen Canyon Dam would have to release approximately 11,400 cfs, 24 hours per day, every day of the year to release 8.23 maf. The amount of water and its pattern of release directly or indirectly affect physical, biological, cultural, and recreational resources within the river corridor.

Predam flows ranged seasonally from spring peaks sometimes greater than 100,000 cfs to winter lows of 1,000 to 3,000 cfs. During spring snowmelt periods and flash floods, significant daily and hourly flow fluctuations often occurred. While annual variability in water volume was high, a generally consistent pattern of high spring flows followed by lower summer flows provided an important environmental cue to plants and animals in the river and along its shoreline.

The frequency of daily and hourly fluctuations has increased since the dam was completed. Water is released to maximize the value of generated power by providing peaking power during high-demand periods. More power is produced by releasing more water through the dam's generators. Daily releases can range from 1,000 to 31,500 cfs, but actual daily fluctuations have been less than this maximum range. These fluctuations result in a downstream "fluctuating zone" between low and high river stages (water level associated with a given discharge) that is inundated and exposed on a daily basis. For purposes of this analysis, flows are defined as fluctuating if they both increase and decrease more than 2,000 cfs in a 24-hour period.

Hydropower conserves nonrenewable fuel resources and is cleaner, more flexible, and more responsive than other forms of electrical

Photo by Gary Ladd

Figure III-1.—Photograph of Colorado River corridor looking downstream from Nankoweap Creek.

generation. Glen Canyon Powerplant is an important component of the electrical power system of the Western United States. The powerplant has eight generating units with a maximum combined capacity of 1,356 megawatts. When possible, higher releases are scheduled in high-demand winter and summer months to generate more electricity. Glen Canyon Powerplant historically has produced about $55 million in revenue in a minimum water release (8.23-maf) year.

Glen Canyon Dam also affects downstream water temperature and clarity. Historically, the Colorado River and its larger tributaries were characterized by heavy sediment loads, variable water temperatures, large seasonal flow fluctuations, extreme turbulence, and a wide range of dissolved solids concentrations. The dam has altered these characteristics. Before the dam, water temperature varied on a seasonal basis from highs around 80 °F to lows near freezing. Now, water released from Glen Canyon Dam averages 46 °F year round. Very little warming occurs downstream. Lake Powell traps sediment that historically was transported downstream. The dam releases clear water, and the river becomes muddy only when downstream tributaries contribute sediment.

Sediment Transport and Its Effect on Other Resources

Sediment can be considered a basic resource, linked in some way to most of the resources within Glen and Grand Canyons. The discussions in this document deal mainly with sand-sized particles, although all sizes of sediment—from the smallest clays and silts to the largest boulders—are important system components. Sediment occurs both above and below the river's surface, and its transport and deposition are important considerations in many resource analyses.

Exposed and submerged sediment deposits throughout Glen and Grand Canyons are very important for cultural, recreational, and biological resources. Sediment is critical for stabilizing archeological sites and camping beaches, for developing and maintaining backwater fish habitats, for transporting nutrients, and for supporting vegetation that provides wildlife habitat.

Large annual floodflows—sometimes greater than 100,000 cfs—historically transported tremendous quantities of sediment that accumulated in high deposits and sometimes formed terraces. Wind and water eroded these deposits after the return to lower flows. Natural cycles of deposition and erosion generally prevented establishment of vegetation near the river.

Sediment supply and the river's capacity to transport sediment (especially sand and larger particles) both have been reduced. Maximum water releases (31,500 cfs) are much lower than the peak flows that occurred before Glen Canyon Dam. During normal operations, the riverbed and low elevation sandbars tend to build up (aggrade), and high elevation sandbars tend to erode. The only sources for resupplying sediment to the river below the dam are tributaries—primarily the Paria River, LCR, and Kanab Creek.

The 1983-86 floodflows (similar to predam spring peaks) transported sand stored within the river channel, eroded low elevation sandbars, and aggraded high elevation sandbars in wide reaches. In many places, vegetation that had developed since dam construction was scoured, drowned, or buried. Some archeological sites also were damaged. The high elevation sandbars eroded following the return to lower flows (as they did predam). Because floods of predam magnitude and sediment concentration can no longer occur, erosion of high terraces will continue.

The future existence of Grand Canyon sandbars depends on sand supplied from tributaries, daily water release patterns, and the long-term frequency and magnitude of flood releases from the dam. Cycles of sediment deposition and erosion are a natural process for rivers in the Southwestern United States. High flows—whether daily or annual—are necessary to replenish sand deposits, but high flows occurring too frequently in the dam-altered river will lead to long-term net erosion.

Flows, Sediment, and Downstream Resources

The Colorado River is the main influence in this dynamic ecosystem: changes in its flow ripple outward to affect both aquatic (water) and terrestrial (land) resources downstream. The system now contains a mixture of native and non-native plant and animal communities that began developing prior to the dam, with the introduction of non-native fish and vegetation. Dam construction and operation further modified this mixture and created the current system that is supported by postdam conditions. The river is forever changed. That change—brought about by Glen Canyon Dam—permitted this ecosystem to develop and establish itself.

Aquatic Resources

The predam aquatic system supported an array of native and non-native fish. Non-native carp and channel catfish have probably been present since the late 1800's. Channel catfish comprised 90 percent of fish captures in Glen Canyon in the late 1950's. At the time of the dam closure in 1963, at least eight species of non-native fish also were present in the system. During the 4 years following dam closure, when water temperature still varied seasonally from 45 to 70 °F, relative abundance of native fish increased over non-natives in the Glen Canyon area. By 1968, non-native fish once again became more abundant than natives, with trout dominating the now cold water system immediately below the dam.

The biological foundation of the aquatic system in the postdam Colorado River below Glen Canyon Dam is *Cladophora glomerata*, a filamentous green alga. River conditions created by the dam—low temperatures, nutrients from Lake Powell, and clear water—make possible the abundant growth of *Cladophora*. *Cladophora* filaments provide attachment sites for diatoms and hiding places for insect larvae. The non-native small crustacean, *Gammarus lacustris*, feeds on diatoms and uses *Cladophora* as a refuge. Together, *Cladophora*, diatoms, and associated invertebrates (*Gammarus* and insects) provide an important food source for other organisms in the aquatic food chain.

Several species of fish, including trout, were stocked in the Colorado River and some of its tributaries before construction of Glen Canyon Dam. Trout could not survive in the seasonally warm, muddy river. The postdam conditions described above, including the *Cladophora*-diatom-*Gammarus* food chain, now support a blue ribbon rainbow trout fishery in the Glen Canyon reach below the dam. However, water quality changes with distance from the dam, and aquatic communities change in response. While water temperature increases only slightly downstream, sediment from tributaries accumulates, turbidity increases, and the abundance of food-chain organisms decreases. The sediment particles' abrasive action also decreases the abundance of food organisms. As their food supply decreases downstream, trout decrease in abundance and condition (figure III-2).

Before the dam, eight native and several non-native fish species inhabited the river. Today, three native species have been extirpated, two are listed as endangered, and one is a candidate for listing under the Endangered Species Act. Two natives remain relatively common in tributaries and certain sections of the river. Non-native carp and channel catfish also have declined, while trout have increased. The reasons for extirpations or declines are undoubtedly complex, but principal known factors are competition and predation by

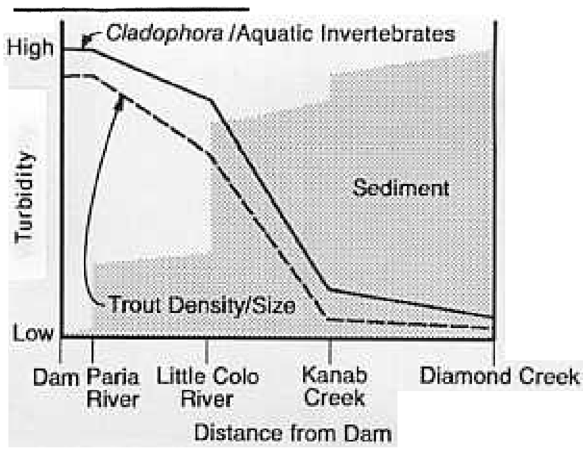


Figure III-2.—As the river's sediment load increases downstream, the abundance of Cladophora, aquatic macroinvertebrates, and rainbow trout decreases.

non-native fish and habitat changes brought about by construction and operation of Glen Canyon Dam. The following linkages are believed related to changes in water quality.

- Low water temperature prevents mainstem spawning and threatens survival of young fish.
- Low water temperature may affect food consumed during certain fish life stages.
- Increased water clarity may make some native fish more vulnerable to competition and predation from non-native fish.

Because of cold water temperatures, suitable habitats for young native and non-native fish in Grand Canyon are confined to tributaries, tributary mouths, and backwaters. Reproduction of warmwater fish species is restricted to within the tributaries, which are mostly outside the influence of the dam.

The slow-moving water in backwaters and nearshore areas protects young fish from the stress and dangers of the main channel. Under the proper conditions, backwaters have higher water temperatures than the main channel and better food conditions for young fish.

Those native fish populations that remain in Grand Canyon may derive some indirect protection from cold water releases. Year-round releases of uniformly cold water may discourage further invasion and reproduction of warmwater non-native fish that prey on native fish or compete with them for food or other resources.

Not only do the physical characteristics of water affect aquatic resources, but how water is released from the dam also affects them. For example, periods of exposure can adversely affect *Cladophora* and its associated invertebrates through drying, freezing, or ultraviolet light. Fluctuating discharges may dislodge segments of *Cladophora* and temporarily increase drifting clumps of this important food-bearing resource downstream for trout and other organisms. The fluctuating zone supports fewer aquatic invertebrates than those sites that remain continuously inundated. Insect larvae are uncommon in the fluctuating zone.

Flow fluctuations affect the spawning attempts of all fish. Although the trout fishery is maintained by stocking, mature trout attempt to spawn at suitable river sites and in certain tributaries. Rapid decreases in discharge can strand spawning trout, and low river stages can expose their nests and limit their access to tributaries. Fluctuating releases also may affect fish access to tributaries and backwater habitat. Flow fluctuations destabilize backwaters and nearshore areas and may force fish out of these more favorable habitats into the harsher conditions of the mainstem.

Bald eagles—which only passed through Grand Canyon before the dam—now stop during winter at sites along the river to feed on spawning trout and fish stranded by fluctuating flows (figure III-3).

Water release patterns also affect recreation. Three groups account for almost all recreational use of the Colorado River corridor: anglers, day

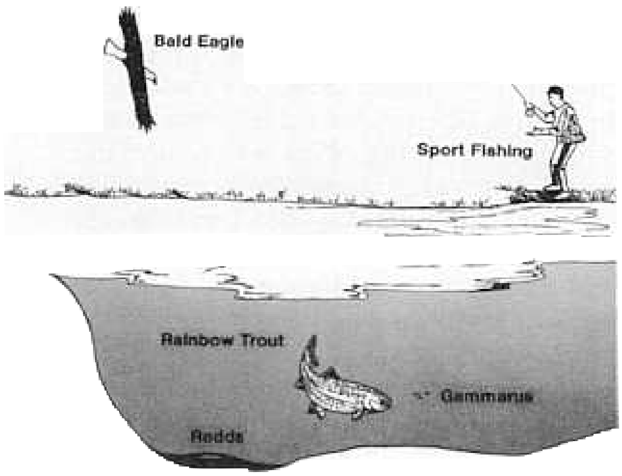


Figure III-3.—The effects of dam operations on linkages between aquatic and terrestrial resources are exemplified by the trout fishery. Fluctuating flows can affect food abundance, trout spawning in the river and tributaries, the availability of trout as prey for eagles, and the sport fishery. These resources were not found in the Colorado River corridor through Grand Canyon before construction of Glen Canyon Dam.

rafters, and white-water boaters. Most trout fishing occurs in the 15-mile Glen Canyon reach below the dam. While some bank fishing occurs, most anglers are also boaters who motor upstream from Lees Ferry. Low flows can expose submerged cobble bars and make navigation difficult.

Terrestrial Resources

Riparian (near water) vegetation is a major terrestrial "indicator resource" below the dam. Before Glen Canyon Dam, seasonally high riverflows reworked sediment deposits and scoured most vegetation from the river corridor below the 100,000- to 125,000-cfs river stage elevation. The only riparian vegetation present along the river developed above this scour zone in what is known as the old high water zone (OHWZ). Dominant plants in the OHWZ include acacia, mesquite, and hackberry.

Following dam construction, protection from annual high flows permitted riparian vegetation to develop below the OHWZ in what has become known as the new high water zone (NHWZ). Today, this new zone of vegetation provides over 1,000 acres of additional habitat for native wildlife. A mixture of native and non-native plant species provides habitat for numerous species of mammals, birds, amphibians and reptiles, and terrestrial invertebrates. Many of these plants and animals have cultural significance to Native Americans.

Riparian vegetation reflects water flow patterns and sediment dynamics and is an excellent example of how system processes affect linked resources. High flows transport available sediments. Some sediments are deposited and become sandbars after flows recede, while other sediments are carried out of the system to become part of Lake Mead's delta. Before the dam, annual high flows carried large sediment loads through Glen and Grand Canyons, scouring or burying any vegetation below the OHWZ. With the dam, flows are regulated, sediment supplies are limited, and riparian vegetation has established in the NHWZ.

Riparian vegetation in the NHWZ grows on sediment deposits. While high flows can rapidly and dramatically restructure sandbars and associated riparian vegetation, daily dam release patterns influence the distribution of plants on sediment deposits. Below the level of maximum flow, sediment deposits are unstable and generally unsuitable for the establishment of woody vegetation. NHWZ plants grow in the area between the river's maximum stage and the level where limited ground water no longer supports growth.

Emergent marsh vegetation, such as cattails, often develops in areas with low water velocity, high concentrations of silt and clay, and a reliable water supply—typically backwaters. Under fluctuating dam releases, these important sites are periodically flooded and dewatered, allowing patches of emergent marsh plants to become established. Marshes probably did not occur in Glen and Grand Canyons before dam construction. Even though emergent marsh vegetation now makes up less than 2 percent of the total riparian vegetation, it greatly enhances plant diversity in the river corridor.

While riparian vegetation supports its own insect populations, it also provides habitat for insects emerging from the river. Structural diversity of the riparian plant communities and abundant invertebrates make the riparian zone—especially the NHWZ vegetation resulting from dam-regulated flows—valuable wildlife habitat. The riparian zone is attractive to mammals because it provides them with cover and food, and some mammals—like bats—eat the abundant insects in the river corridor.

Birds are more dependent than mammals on riparian vegetation for cover, specifically nesting cover. Over half of the bird species nesting along the river corridor nest in riparian vegetation. Many birds eat insects or feed insects to their young, relying on the river and riparian vegetation for this important food. Some breeding bird densities in the riparian zone are among the highest recorded for their species. One of the highest known densities of peregrine falcons in North

America resides in Grand Canyon, feeding on the swallows, swifts, and bats there (figure III-4).

The importance of riparian zone resources as wildlife habitat is easily demonstrated by the distribution of four common lizards. These species are most abundant near the shoreline where invertebrates, including insects, are common. Densities of lizards in some Colorado River corridor locations are higher than anywhere else in the Southwest.

Summary

As described above, the processes (water releases and sediment transport) that control downstream resources and the resources themselves (water, sediment, fish, vegetation, and wildlife and their habitat) are interconnected within a system operationally defined as the Grand Canyon ecosystem.

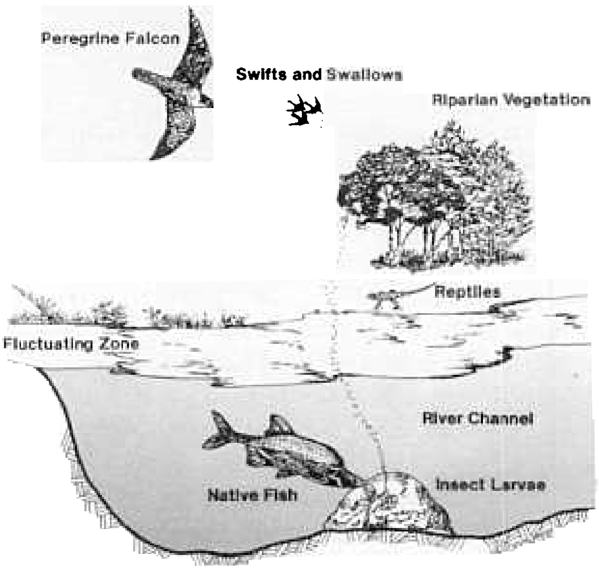


Figure III-4.—Insects are an important linkage between aquatic and terrestrial systems in Grand Canyon. Some insects emerge from the river as adults and become food for various wildlife species using the river corridor. For example, swallows, swifts, and bats feed on emerging insects; peregrine falcons, an endangered species, feed on these foraging species.

The reader should keep in mind that this system exists within the boundaries of conditions dictated by Glen Canyon Dam. None of the alternatives considered in this EIS has the potential to return the system to predam conditions. Well-defined volumes of cold, clear water annually pass through Glen and Grand Canyons. Native and non-native fish that could not tolerate these conditions have declined or disappeared from the canyon. Other species and communities that were rare or nonexistent before the dam are now abundant: *Cladophora*, *Gammarus*, trout, bald eagles, peregrine falcons, and riparian vegetation and its wildlife in the NHWZ. The following discussions present the details surrounding the affected resources necessary to understand and evaluate the effects of each alternative.

WATER

Most of the Colorado River water flowing into Lake Powell and ultimately released into Glen Canyon originates in the Rocky Mountains. Runoff from spring snowmelt in the Rockies is high during April through July, and flow in the Colorado River above Lake Powell reaches its annual maximum, then recedes for the remainder of the year. During the summer and fall, thunderstorms cause flooding in tributaries originating on the Colorado Plateau, producing additional peaks in the river, but usually smaller than the snowmelt peaks and of much shorter duration. Since Glen Canyon Dam was completed in 1963, flows immediately below the dam have consisted almost entirely of water released from Lake Powell. Downstream, the river gains additional water from the few perennial tributaries, ground-water discharge, and occasional flash floods from side canyons.

Flow regulation by the dam has resulted in a slight increase in median flows and a large decrease in the magnitude and frequency of major floods in the Colorado River, although flash floods in tributaries continue to produce temporary uncontrolled peak flows in the river. Because demands for hydroelectric power determine the hourly schedule of discharges, water releases vary over a 24-hour cycle. The peak daily discharge below the dam generally occurs in the daytime, and the minimum discharge occurs at night. The times at which the peak and minimum occur downstream vary with distance from the dam.

In addition to reservoir capacity, annual runoff, and discharge capacity, Glen Canyon Dam operations also are affected by legal and institutional constraints specified in various Federal laws, interstate compacts, international treaties, and Supreme Court decisions—the "Law of the River."

Section 602 of the Colorado River Basin Project Act (Public Law 90-537) directed the Secretary of the Interior to develop operating criteria to comply with and carry out the provisions of the Colorado River Compact, the Upper Colorado River Basin Compact, and the Mexican Water Treaty. This resulted in the 1970 Criteria for Coordinated Long-Range Operation of Colorado River Reservoirs (Long-Range Operating Criteria). These Long-Range Operating Criteria cover the coordinated operations of the Upper Basin reservoirs and Lake Mead and are reproduced in attachment C.

The Long-Range Operating Criteria are subject to review at least every 5 years. The most recent review was completed in 1993. As part of the review process, comments are invited and received from numerous individuals and groups.

In 1985, the Colorado River Management Work Group was formed to "seek consensus regarding operating flexibility available in the existing operating criteria and to develop procedures and analytical tools to be used for formulating future annual operating plans" (Bureau of Reclamation, 1986). Since formation, the work group has met several times each year to develop annual operating plans and to conduct studies with the objective of improving overall operations. Until recently, the work group has consisted principally of representatives of the Basin States, Bureau of Reclamation (Reclamation), and the Western Area Power Administration (Western). In 1991, additional resource management agencies and organizations were invited and became involved.

This section provides historic perspectives on the following water issues:

- Streamflows
- Floodflows and other spills
- Reservoir storage
- Water allocation deliveries
- Upper Basin yield determination
- Water quality

Streamflows

The closure and water release management of Glen Canyon Dam have affected Colorado River flows in Glen and Grand Canyons. Figure III-5 illustrates the changes in the pattern of annual flows at Lees Ferry for the predam period (from 1922, when continuous records began, through 1962) and postdam period (1963-89).

Predam Streamflows

Predam flows were characterized by large year-to-year and seasonal variability (figure III-6). Melting of the mountain snowpack typically produced high runoff of long duration during the late spring and early summer. Spring flows often were characterized by double peaks. Annual maximum daily flows greater than 80,000 cfs were not uncommon; in some years they exceeded 100,000 cfs. In contrast, flows less than 3,000 cfs were typical throughout late summer, fall, and winter. Figure III-7 illustrates the occurrence of predam and postdam daily flows for 4 representative months (the higher flows are shaded darker) and shows that spring flows were much higher and winter flows much lower predam than postdam.

Throughout most years, an additional variability pattern was superimposed on the general seasonal pattern of predam flows, particularly during the summer-fall monsoon season. Increases and decreases of short duration, but occasionally very high magnitude, commonly occurred (and still do) at intervals of a few days or less due to floods from tributaries—perennial tributaries such as the Paria River and LCR and hundreds of usually dry side canyons. Thus, while predam flow did not resemble the daily fluctuations of dam operations, neither was it steady, as shown in figure III-6.

Before closure of Glen Canyon Dam, flows below the damsite typically exceeded 33,200 cfs (powerplant capacity) during April through July. Occasionally, flows exceeded 33,200 cfs in August and into the fall in response to floods from tributaries—mainly the Paria River and LCR (a few of the largest floods in the LCR have occurred in mid-winter). Table III-1 summarizes maximum predam and postdam flows and the frequency with which powerplant capacity was exceeded. These data show that high flows were larger and more frequent before the dam was built.

Table III-1.—High predam and postdam Colorado River flows below Glen Canyon Dam (daily values)

	Percent of days 33,200 cfs exceeded		Maximum flows (cfs)	
Month	Predam (1922-62)	Postdam (1963-89)	Predam (1922-62)	Postdam (1963-89)
April	16	0	75,000	
May	61	9	119,000	48,000
June	77	13	124,000	93,000
July	17	7	119,000	88,000
August	3	2	65,000	45,000

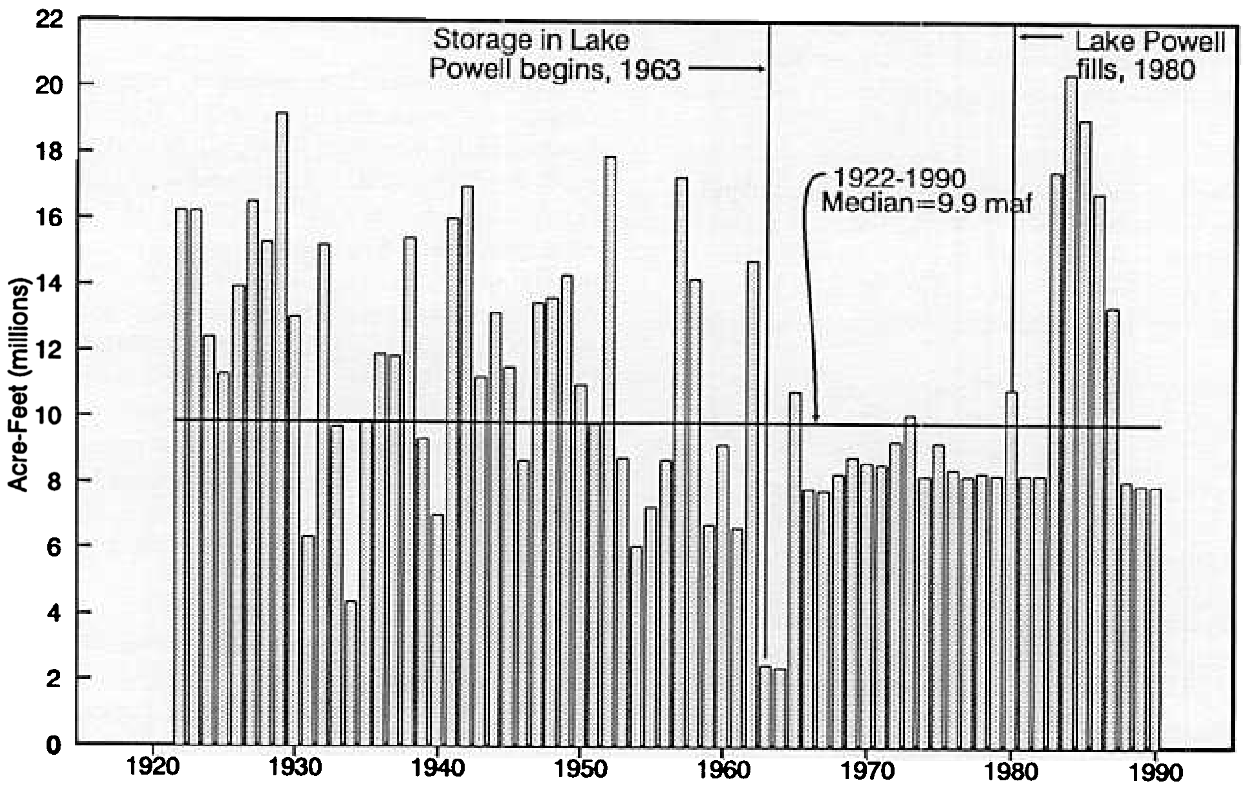


Figure III-5.—The pattern of annual flows at Lees Ferry changed with completion of Glen Canyon Dam in 1963.

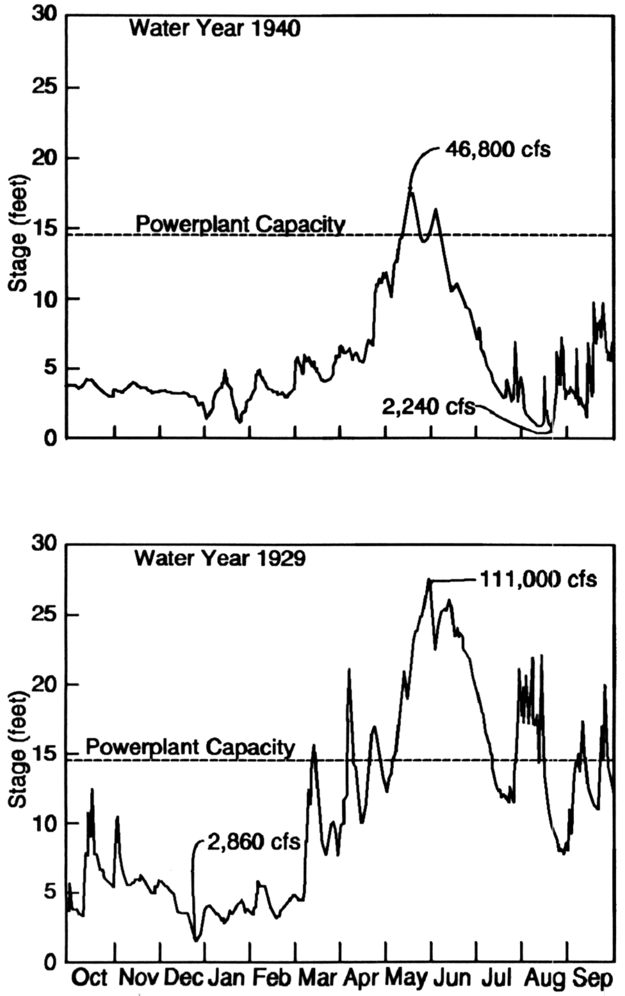


Figure III-6.—Predam stage hydrographs at Phantom Ranch. Day-to-day variations caused by tributary floods are superimposed on the seasonal variation caused by snowmelt in the Rocky Mountains.

Postdam Streamflows

Historic operations (prior to existing interim flows) are described under the No Action Alternative, chapter II. Additional historical perspective on monthly and hourly releases is provided here.

Lake Powell began storing water in March 1963 and filled in June 1980. Very little water was released through Grand Canyon for the first 2 years after dam closure (about 2.5 maf each year). In 1964, Lake Powell achieved the minimum elevation necessary for power production (3490 feet). Since 1965, the minimum annual release from Glen Canyon Dam has been about 8.23 maf, and variability in annual releases has been reduced. Figure III-7 compares the postdam daily flows with predam flows. Of particular note is the substantial reduction of high spring flows in the postdam period.

Monthly Streamflow. Predam monthly flow volumes reflect high spring flows and low winter flows. Table III-2 presents predam and postdam median monthly volumes for representative months of the four seasons. Postdam volumes have been much less extreme than predam volumes.

Table III-2.—Median predam and postdam monthly flows at Lees Ferry (1,000 acre-feet)

	Predam (1922-62)	Postdam (1963-89)
Fall (October)	412	609
Winter (January)	319	745
Spring (May)	2,805	845
Summer (July)	1,357	827

Hourly Streamflow. Figure III-8 shows the daily range in flows for low, moderate, and high water release years. The range is represented by a plotting of the lowest and highest hourly releases for each day of the water year. Greater fluctuations occur in years with low and moderate release volumes. See chapter II (figure II-4) for typical daily fluctuations during 24-hour periods with high, moderate, and low daily release volumes.

Daily flow maximums, minimums, and fluctuations are important when comparing EIS alternatives. Figure II-5 in chapter II shows postdam daily occurrences of these parameters by month. Table III-3 provides such postdam daily occurrences by season.

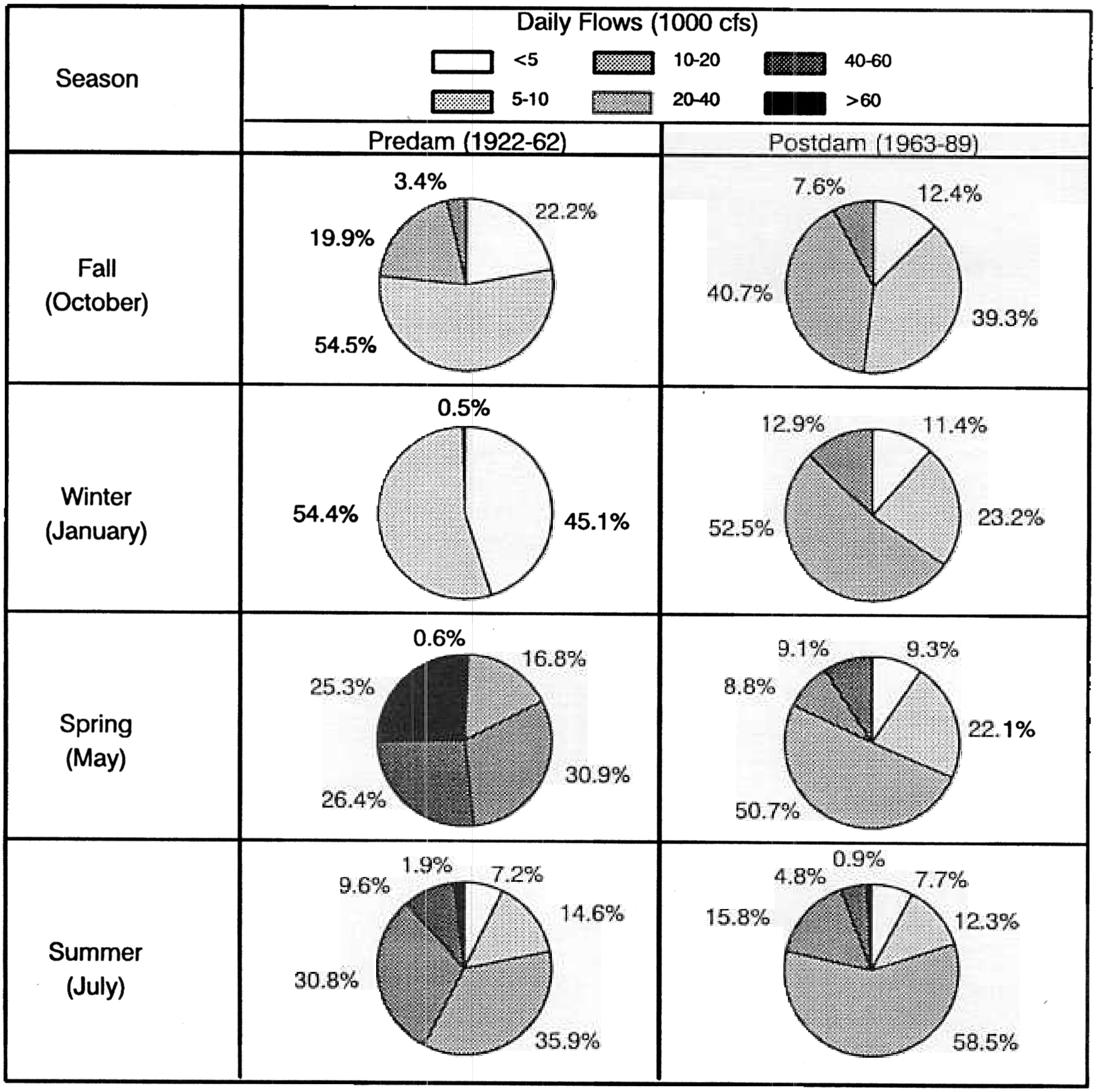


Figure III-7.—Predam and postdam daily flows at Lees Ferry (percent of days that the specified flows occurred).

Rate of Change in Streamflow (Ramp Rate). The ramp rate is the rate of change in instantaneous discharge to achieve either higher or lower releases in responding to electrical load. The principal times of change are in the morning, when the releases are ramped upward to respond to the peak daytime demand, and at night, when releases are ramped downward as the electrical demand diminishes. Ramp rates are of concern because of their effects on sediment, aquatic resources, rafting, and fishing downstream of the dam. The historic down and up ramp rates are shown in chapter II (figure II-6).

Table III-3.—Historic minimum and maximum hourly releases and daily fluctuations, 1965-89 (percent of days)

Minimum hourly releases			
	<5,000 cfs	<8,000 cfs	
Fall (October)	70	81	
Winter (January)	54	76	
Spring (May)	44	64	
Summer (July)	49	66	
Maximum hourly releases			
	>20,000 cfs	>25,000 cfs	
Fall (October)	32	11	
Winter (January)	64	39	
Spring (May)	99	96	
Summer (July)	70	47	
Daily fluctuations			
	>8,000 cfs	>12,000 cfs	>20,000 cfs
Fall (October)	77	49	7
Winter (January)	83	69	23
Spring (May)	74	49	10
Summer (July)	83	67	22

Downstream Transformation of Fluctuating Releases

Daily fluctuations in releases from Glen Canyon Dam produce long waves that travel the length of the canyon. To an observer at a fixed location, these waves resemble ocean tides. The waves produced by fluctuating releases transfer the energy of the released water downstream by continuously displacing an equivalent amount of water. As a wave passes a fixed location, an observer sees displaced water, not the released water that initially formed the wave.

The size and shape of the waves change as the waves travel downstream. Minimum flows at wave troughs increase with distance below the dam, and the range in flow fluctuation (wave height) decreases. The rising limb of the flow fluctuation, or wave, becomes steeper, and the falling limb becomes flatter. Such changes are important considerations for determining impacts on sediment resources, fish habitat, riparian habitat, and recreation. See Appendix B, Hydrology, for additional information about wave transformation.

Travel Time of Water

Information about travel time of water released from the dam to sites of interest downstream is important for assessing water quality and sediment transport. Travel time is determined by water velocity, which varies with discharge. Dissolved materials, such as oxygen or a tracer dye, travel at the same velocities as the water in which they are mixed. Suspended materials, such as silt, tend to travel at slightly lower velocities, and floating materials—when not trapped in an eddy—travel at the highest water velocities at the water surface. The energy waves produced by fluctuating releases from the dam, however, travel at substantially greater velocities than the water that initially forms them, so wave travel times through a given reach are much shorter than travel times of the released water. Additional information about travel time of water is provided in appendix B.

Tributary Flows

Principal tributaries to the Colorado River below Glen Canyon Dam are the Paria and Little Colorado Rivers, and Bright Angel, Tapeats, Kanab, and Havasu Creeks. Streamflow records are available for the Paria River (at Lees Ferry), the LCR (near Cameron, Arizona), and Bright Angel Creek (near Grand Canyon). Table III-4 presents USGS water records for maximum and minimum flows by day, month, and year for each of these tributaries.

Floodflows and Other Spills

Floodflows are defined in this EIS as flows in excess of the powerplant capacity of 33,200 cfs.

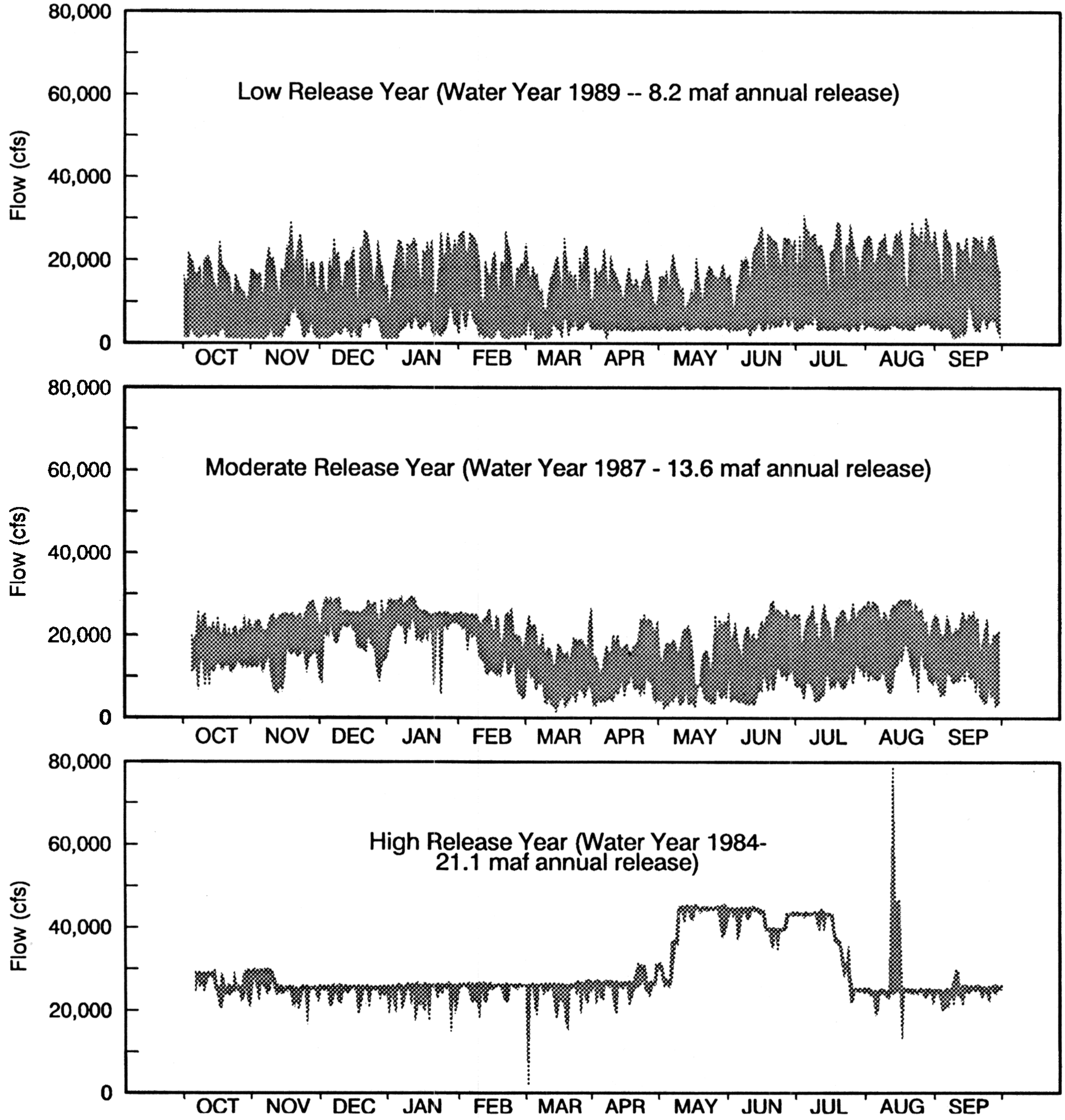


Figure III-8.—The magnitude of daily fluctuations has been greater for low to moderate release years than for high release years.

Spills other than floodflows are excess annual release volumes greater than legally required owing to scheduling difficulties.

The ideal operating plan would enable Lake Powell to fill each year without risking floodflows. Floodflows are undesirable because they move sediment out of the system, they bypass the powerplant, and they exceed diversion capacities (often causing loss of downstream water uses). Unfortunately, inflow forecasts have a large degree of uncertainty, which increases the risks of

Table III-4.—Recorded flows of principal tributaries to the Colorado River in Grand Canyon through 1990

	Paria River (1924-90)	Little Colorado River (1947-90)	Bright Angel Creek (1923-74)
Minimum day (cfs)		0	10
Maximum day (cfs)	6,750	18,400	2,500
Minimum month (acre-feet)	119	0	795
Maximum month (acre-feet)	24,596	257,766	30,019
Minimum year (acre-feet)	8,280	16,873	10,562
Maximum year (acre-feet)	45,900	815,855	62,845

either flood releases or not filling the reservoir. Since the closure of Glen Canyon Dam, floodflows (releases in excess of powerplant capacity—33,200 cfs) have occurred almost exclusively in the months of May, June, July, and August.

The present methods of scheduling releases to avoid floodflows are discussed under the No Action Alternative in chapter II. These operating measures are thought to provide protection against floodflows for all years except those with extreme inflows compounded with a high forecast error. If the reservoir was near full when such hydrologic events occurred, floodflows would be difficult, if not impossible, to avoid.

Reservoir Storage

If monthly release volumes were altered, storage patterns at Lake Powell within the year could be affected. Further, if annual release volumes were changed (such as by increasing or decreasing spills), carryover storage from one year to the next could be affected. Storage amounts in Lakes Powell and Mead are operationally tied together because the Long-Range Operating Criteria require storage equalization between the two reservoirs under certain conditions. Figure III-9 presents the end-of-month storage in the two reservoirs since 1963.

Since first reaching storage equalization with Lake Mead in 1974, Lake Powell has had two significant periods of drawdown due to drought—one beginning in 1976 and a more recent one that started in 1988. Lake Powell first filled in 1980 and, under historic and present operations, is not allowed to exceed 22.6 maf on January 1 to allow receiving spring inflows. A typical storage pattern is to draw the reservoir down beginning in July or August through February or March of the next water year. With spring inflow beginning in March or April, Lake Powell begins to rise to its maximum storage in June or July. During drought periods, its annual increase in storage is very slight or nonexistent.

Lake Mead is somewhat insulated against dramatic drawdowns due to drought because of the minimum annual release requirement from Lake Powell under the Long-Range Operating Criteria. Also, annual fluctuations at Lake Mead are smaller than those at Lake Powell. Storage in Lake Mead rises and falls as a result of scheduled releases from Lake Powell and Lake Mead to meet downstream demands or to comply with flood control regulations.

Water Allocation Deliveries

Water allocation deliveries are the deliveries of Colorado River water to entities in the seven Colorado River Basin States and Mexico, in accordance with the "Law of the River."

In recent years, Lower Basin water demands have approached their 7.5-maf entitlement, thus requiring rationing and innovative solutions to

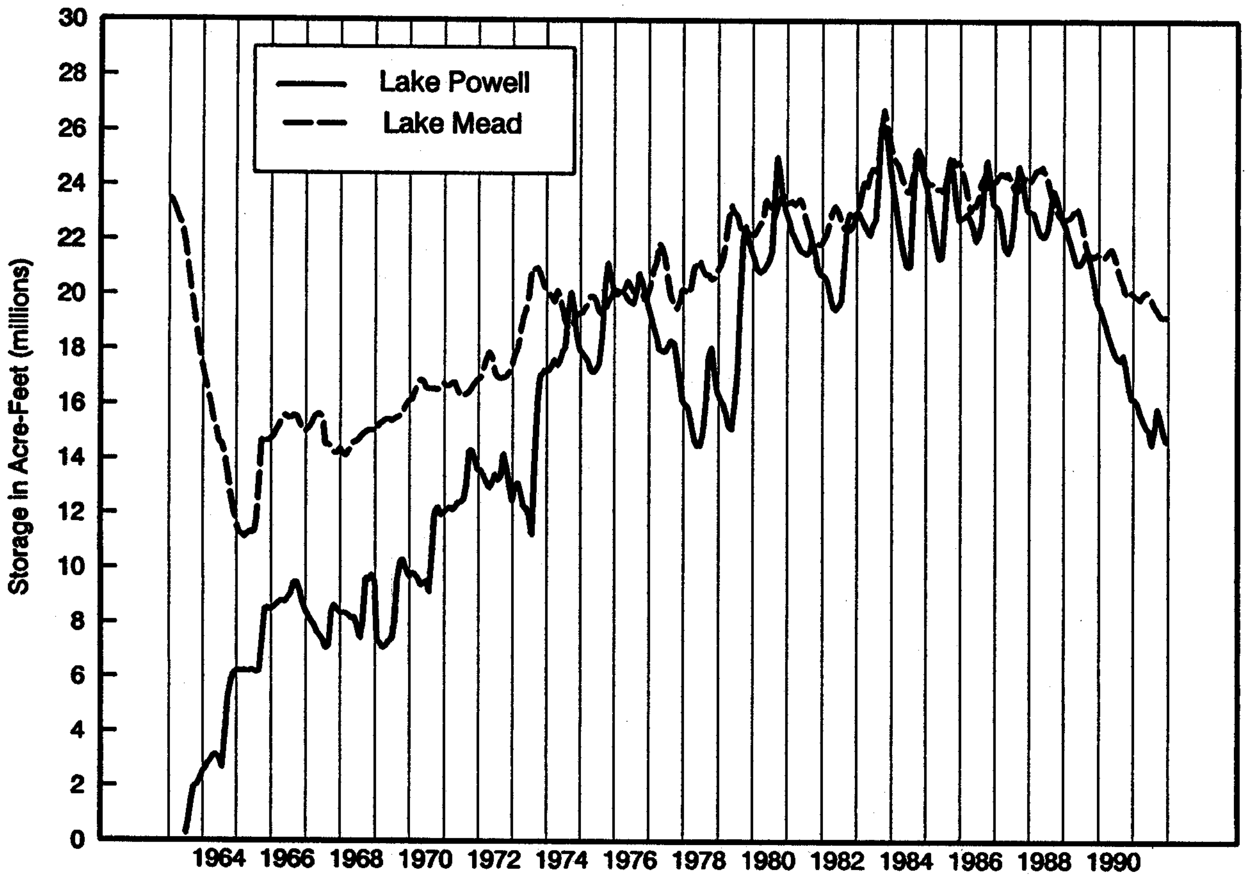


Figure III-9.—End-of-month storage in Lakes Powell and Mead since 1963.

anticipated future shortages. California's water use has been exceeding its 4.4-maf entitlement, until Arizona's capability to use its full 2.8 maf is developed. Lower Basin consumptive water uses and deliveries to Mexico for 1986 through 1991 are shown in table III-5.

The most recent official records of Upper Basin consumptive water use are contained in *Colorado River System Consumptive Uses and Losses Report, 1981-85* (Bureau of Reclamation, 1991e). The estimated uses in that document are presented in table III-6.

These historic and projected consumptive water uses are considered in the chapter IV analysis of alternatives. In that analysis, projected future water deliveries under each action alternative are analyzed and compared with projected future deliveries under historic operations.

Upper Basin Yield Determination

In 1988, a determination was made of water availability under long-term contracts for municipal and industrial uses from Navajo Reservoir on the San Juan River in New Mexico. This hydrologic determination required an assessment of the total water depletion that can ultimately be allowed in the Upper Basin. The analysis is summarized in *Hydrologic Determination, 1988: Water Availability from Navajo Reservoir and the Upper Colorado River Basin for Use in New Mexico* (U.S. Department of the Interior, 1989).

Table III-5. -Historic Colorado River consumptive water use, Lower Basin[1]
(in 1,000 acre-feet)

Year	Arizona	California	Nevada	Total	Mexico Basic	Mexico Excess[2]
Basic apportionment	2,800	4,400	300	7,500	1,500	
1986	1,357	4,804	112	6,273	1,700	9,224
1987	1,734	4,891	109	6,734	1,700	3,044
1988	1,923	5,040	129	7,092	1,700	759
1989	2,230	5,144	156	7,530	1,500	228
1990	2,260	5,219	178	7,657	1,542	134
1991	1,864	5,006	180	7,050	1,521	141

[1] Published in accordance with the Supreme Court decree in *Arizona* v. *California*.
[2] Includes amounts ranging from 98,000 to 148,000 acre-feet per year pursuant to minute No. 242 of the Mexican Water Treaty.

Table III-6.—Colorado River consumptive water use, Upper Basin
(in 1,000 acre-feet)

Year	Arizona	Colorado	New Mexico	Utah	Wyoming	Total
Basic apportionment[1]	50	3,079.5	669.5	1,368	833	6,000
1981	42	2,086	342	782	341	3,551
1982	40	2,106	425	746	330	3,607
1983	42	1,920	426	718	346	3,410
1984	44	1,865	417	762	307	3,351
1985	44	1,994	401	879	336	3,610

[1] In accordance with 1988 hydrologic determination.

The determination concluded that annual water depletion for the Upper Basin reasonably can be allowed to increase to 6 maf. The determination further certifies the availability of interim excess supplies of 69,000 acre-feet annually through year 2039 for marketing in New Mexico. Subsection (b) of article II of the Upper Colorado River Basin Compact permits New Mexico (or any other Upper Basin State) to use water in excess of its percentage allotment, provided such excess does not prohibit any of the remaining States from using their allotment.

Any reduction in the 6-maf determination (as a result of implementation of an alternative or otherwise) would cause a corresponding reduction in the 69,000 acre-feet determined to be available to New Mexico through 2039.

Water Quality

The study area for evaluation of water quality includes Lake Powell and the Colorado River and its tributaries between Glen Canyon Dam and the inflow area of Lake Mead. This section describes chemical, physical, and biological characteristics of the study area and their influence on river system water quality. More detailed information can be found in Appendix C, Water Quality.

Lake Powell

Lake Powell limnology—or water quality and aquatic ecology—is a story of change, both over years and seasons. Changes include:

- The reservoir's stages of development, from initial filling to a full reservoir, and subsequent stages of drawdown and refilling
- Seasonal changes in climate
- Variable quality and quantity of inflow

Lake Powell was filling nearly continuously from 1963 until 1980. Through 1982, the reservoir periodically stratified into chemical layers through most of the year and thermal layers from spring through early fall. The depth of stratification was to about the penstocks. The reservoir completely filled and spilled for the first time in 1980 and remained full through 1987. Releases through the river outlets and spillways during the 1983-84 high flows helped flush out the reservoir and mix the layers, forestalling stratification for over a year. The major drought in the Southwest that began in 1987 caused the elevation of Lake Powell to drop over 80 feet from full pool between 1988 to 1992. Lake Powell has reestablished its stratifications, but winter vertical mixing has not been strong enough to mix as thoroughly.

Long-term hydrologic cycles cause large changes in reservoir depth and volume which influence vertical mixing, nutrient distribution, sedimentation patterns, and circulation in the reservoir.

Inflows. The Colorado River is the major tributary to Lake Powell, followed by the Green River—which joins the Colorado River upstream of Lake Powell—and the San Juan River. Together, the three tributaries contribute about 95 percent of the total reservoir inflow. Each tributary has a unique chemical, physical, and biological composition stemming from diverse basin geology, development, and seasonal and annual hydrologic variations, among other factors.

Three distinct seasonal inflows from the Colorado River form currents which travel in different ways through Lake Powell. Spring inflows are warm and less dense than the cold reservoir water, allowing the inflow to flow over the top of the reservoir surface. These inflows may reach the dam in 2 to 7 months, depending on the volume of water in the reservoir and amount of spring inflow. In contrast, winter inflows are cold and saline, so they are denser than reservoir water. Thus, winter inflows travel primarily along the bottom of Lake Powell, pushing oxygen-poor, saline water up toward the penstock intakes. Late summer inflows are intermediate in density and travel about mid-depth in Lake Powell. Figure III-10 illustrates these general current patterns.

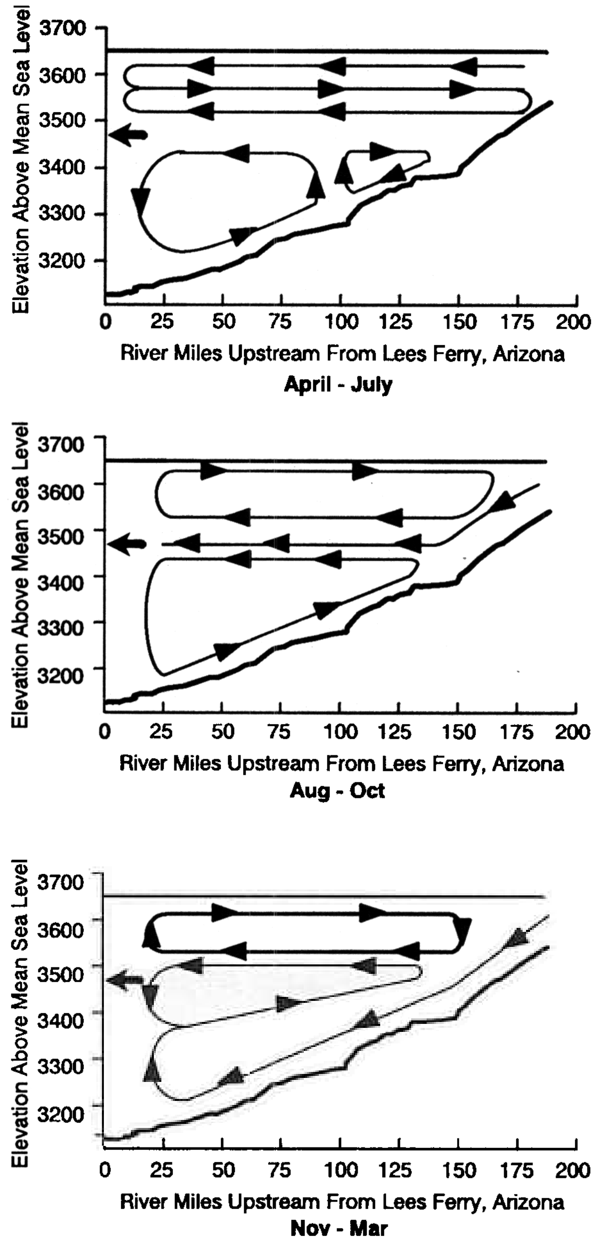


Figure III-10.—Generalized seasonal circulation patterns in Lake Powell (modified from Merritt and Johnson, 1977).

When reservoir water is drawn through the penstock intakes at elevation 3470 feet—or about 230 feet below full pool—a withdrawal current forms, which further influences other currents in Lake Powell. The vertical extent of the withdrawal current increases with the amount of discharge and reaches a maximum of about 100 feet above and below the intakes (Johnson and Merritt, 1979). The intakes usually withdraw water from within the bottom layer of the lake, the hypolimnion, which is discussed later in greater detail.

Studies. Lake Powell limnology has been studied at various levels of detail since about 1968, providing a basic background of some limnological components and processes at particular stages of reservoir development. Reservoir fisheries have been studied in greatest detail. Since about 1972, Reclamation's water quality data collection program has focused on salinity and temperature; dissolved oxygen (DO), circulation, and other data also were collected. Recently, the Lake Powell Monitoring Program has been gathering data at more regular intervals. Short-term and single-event studies, often not conducted reservoir wide, have provided additional information on nutrients, plankton, sediment chemistry, pH, and trace elements such as mercury, selenium, and lead. The U.S. Fish and Wildlife Service (FWS) also has collected fish samples for trace chemical analysis, and NPS conducts bacteriological studies in recreation areas for human health concerns.

Since data was not collected at regular intervals, limited comparisons may be made between seasons and years. Accordingly, general statements characterizing all components and processes of reservoir limnology and quantitative predictions of future changes cannot be made with confidence. In the absence of a complete data history, alternate means were used to assess past and future conditions, such as comparing the characteristics of Lake Powell with other reservoirs and lakes.

Temperature. Most of Lake Powell is extremely clear; sunlight penetrates to depths of 82 to 113 feet. Sunlight's ability to warm water decreases with depth, so Lake Powell is thermally stratified through much of the year. The epilimnion is the topmost and warmest layer, ranging from 30 to as much as 80 feet in depth (Johnson and Merritt, 1979). However, the thickness varies with seasons and location (Hammer and MacKichan, 1981). Although temperatures within this layer vary slightly with depth, summer temperatures reach about 80 °F, and winter temperatures may drop to 45 °F. Temperatures of 45 °F or less can be lethal to the threadfin shad, which comprise much of the prey base for the Lake Powell sport fishery. The metalimnion, or the middle layer, often ranges from 30 to as much as 80 feet in depth. Here sunlight is limited, and water temperatures decrease with depth. The hypolimnion, or bottom layer, is too deep for sunlight to reach, and water temperatures remain nearly constant at about 46 °F. This uneven heat distribution also creates circulation in the reservoir.

Nutrients. Most of the incoming nutrients to Lake Powell are associated with or attached to sediments, and essentially all sediment settles to the reservoir bottom. Lake Powell retains over 97 percent of the inflowing phosphorus, primarily with sediments (Miller et al., 1983). Algae cannot readily consume nutrients attached to sediments. Nutrient concentrations near the surface are highest during June and July, stimulating growth of plankton. As plankton populations grow, the nutrient supply diminishes. Typically, planktonic algal blooms occur in the summer, mainly in shallow, sunny inflow areas where tributaries enter the reservoir carrying nutrient-rich sediments.

Other Characteristics. Other water quality characteristics also vary with reservoir depth. Atmospheric reaeration and wind-induced mixing of reservoir water is limited to the epilimnion, thus restricting reaeration of deeper water throughout the summer. The shallow epilimnion is generally well oxygenated, averaging over 8 milligrams per liter (mg/L). DO concentrations in the metalimnion may range from 5 to 10 mg/L, except when associated with the summer development of the minimum DO layer, described below. Concentrations of DO deep in the hypolimnion can be as low as 2 to 3 mg/L, and overall water quality remains nearly constant in this layer. Salinity, nutrients, selenium, and mercury concentrations are highest in the hypolimnion and lowest in the epilimnion.

A DO minimum layer periodically develops in the metalimnion between 45 and 60 feet below the reservoir surface during the summer with concentrations as low as 2 mg/L (Johnson and Page, 1981). Its formation results from DO consumption by algae, bacteria, zooplankton, fish respiration, and the chemical processes of organic decay. The DO minimum layer typically begins forming in tributary inflow bays and may extend over most of the reservoir by September.

A water quality inventory conducted for Lake Powell analyzed tributary delta sediments and surface and bottom waters for lead, mercury, selenium, and other trace elements primarily associated with sediments (Kidd and Potter, 1978). This study concluded that Lake Powell traps most of the elements investigated, except lead. More dissolved lead left the reservoir than came in, attributable to gas spills from boating. Mercury and selenium occur naturally in the Colorado River Basin and accumulate in tissues of living organisms in the lake (Wood and Kimball, 1987).

Lake Powell also traps sediment. It is estimated that within about 300 to 500 years, sediment will fill the reservoir to near the elevation of the penstocks. As the lake fills with sediment, the reservoir will shrink—affecting changes in temperature distribution, DO and nutrient content, circulation, plankton communities, and other reservoir components.

Colorado River Below Glen Canyon Dam

Two major influences on Lake Powell and downstream water quality are:

- Reservoir elevation (the amount of water in Lake Powell)
- The intake level where water is withdrawn

The intakes withdraw water mostly from the hypolimnion when Lake Powell's elevation is above about 3590 feet. As Lake Powell is drawn down (below 3590 feet), the reservoir surface drops, and water may be withdrawn from the metalimnion and epilimnion, where reservoir water differs in quality.

Most of Lake Powell's influences on the Colorado River below the dam center on flow, sediment, and water quality. Reservoir releases have changed variation and magnitude of downstream riverflow, turbidity, temperature, salinity, nutrients, and other water quality characteristics. Below the dam, both temperature and salinity change little with the seasons. Salinity fluctuations downstream now vary less over several years than the predam cycles changed in months. Downstream salinity is of major economic significance to water users in the Lower Colorado River Basin because high salinity causes problems, such as damage to irrigated crops and municipal water systems.

River temperatures at Lees Ferry are inversely related to Lake Powell water surface elevations. Releases from Glen Canyon Dam have ranged from 43 to 54 °F and average about 46 °F. River temperatures increase slowly downstream of the dam but seldom exceed 60 °F at Diamond Creek, about 240 miles downstream (Sartoris, 1990). The greatest warming occurs during June through August. The average annual downstream river temperature is about 55 °F (48 to 62 °F), and actual river temperatures have deviated very little in recent years (Sartoris, 1990). As the reservoir surface elevation falls below 3590 feet, release temperatures, and thus river temperatures, begin to rise measurably.

Releases from Glen Canyon Dam are relatively clear, lacking nutrient-rich sediments or any algae, and are resultingly low in nutrients. The clear water allows greater sunlight penetration, enhancing productivity in spite of low nutrient concentrations. Tributaries below the dam have somewhat higher nutrient concentrations than the mainstem, yet contribute little to overall mainstem nutrient concentrations.

DO concentrations below Glen Canyon Dam range from approximately 6 mg/L in the winter to 9 mg/L in the summer. Concentrations generally increase slightly with distance downstream, depending on the season.

SEDIMENT

Sediment is literally the foundation of the riparian environment and recreation along the Colorado River in Grand Canyon National Park. (U.S. Department of the Interior, 1988, page A-7.)

In this EIS, sediment is defined as unconsolidated material derived from weathering of rock and transported and deposited by water or wind. Although occasionally used synonymously with "sand," the term "sediment" generally refers to the full range of sediment sizes found in Grand Canyon.

Glen Canyon Dam has caused three major changes related to sediment resources downstream in Glen and Grand Canyons. The first is reduced sediment supply. Because the dam traps virtually all of the incoming sediment in Lake Powell, the Colorado River—which once flowed red from high concentrations of sediment from the Upper Basin—is now released as clear water from Glen Canyon Dam. The second major change caused by the dam is reduced capacity of the Colorado River to transport sand and other sediment. The natural peak flows that occurred annually prior to dam construction had a tremendous capacity to transport sediment. Maximum releases from the dam are substantially less than those historic annual peak flows. The third major change is the reduction in the high water zone from the level of predam annual floods to the level of powerplant releases. Thus, the height of annual deposition and erosion of sediment has been reduced.

Through the scoping process, the public identified sediment and beaches as major issues of concern. The following categories of sediment resources are affected in some way by the dam and its operation; some also are affected by natural processes or human use:

- Riverbed sand
- Sandbars (beaches and backwaters)
- High terraces
- Debris fans and rapids
- Lake deltas

Background

Sediment along the Colorado River below Glen Canyon Dam is an important and dynamic resource. Many of the other resources discussed in this EIS depend on sediment to varying degrees.

Although some sediment is derived from the canyon walls, most sediment enters the regulated Colorado River from the tributaries downstream from Lake Powell. Through complex processes, sediment in the river is transported, deposited, and eroded again for further transport. The quantity of sediment in motion at a given time and location depends on the amount and particle size of sediment available, the dimensions and slope of the channel, and the magnitude of flow.

Sediment-dependent resources in Grand Canyon can be related to four general size classes of sediment particles:

- Silts and clays (finer than 0.062 millimeter (mm))
- Sand (0.062 mm to 2 mm)
- Gravels and cobbles (2 mm to 256 mm)
- Boulders (greater than 256 mm)

Sediment transport and deposition varies with particle size. Silts and clays are easily transported and generally pass through the system in a relatively short time, although some may be deposited in low velocity areas on sandbars and in backwaters. Silt- and clay-sized particles provide important nutrients for vegetation, and clay also provides cohesion for deposits of coarser sediment.

The most abundant sediment size class found along the river is sand. Many sandbars are used as campsites by boaters and are substrate for vegetation and wildlife habitat. Next in size are the gravels and cobbles, which—together with small boulders—armor the streambed in some places. Some fish species use shallow gravel beds for spawning.

The largest particles are boulders, some larger than automobiles, which fall from the canyon walls or reach the river in debris flows from steep tributary canyons. Boulders create and modify most of the major rapids and are a major factor in the creation of sandbars. Although its riverbed is bedrock in some places, the Colorado River generally is a cobble- and gravel-bed stream, through which sand is transported. Sand is stored throughout Grand Canyon in "patches" on the riverbed and in eddies (Graf et al., 1993).

The river's capacity to transport sediment increases exponentially with the amount of water flowing in the river. All sediment particles weigh more than water, so they tend to settle to the bottom. The turbulence of flowing water is the uplifting force that causes sediment particles to be carried in suspension or roll along the streambed. The greater the river's flow, the greater the velocity and the greater the turbulence. Clay and silt particles commonly are carried in suspension by nearly all dam releases. Flows in the river often are large enough to carry sand grains in suspension or to roll them along the riverbed, depositing the grains temporarily in areas where water velocity is insufficient to move them. Even larger flows and velocities are needed to move gravel and cobbles. The largest boulders remain in place for decades or more, awaiting the rare flood large enough to move them short distances along the riverbed.

Riverbed Sand

The decreased annual peak flows reduced the river's capacity to transport sand (figure III-11). Measured suspended sediment loads (sand, silt, and clay) at Phantom Ranch averaged 85.9 million tons per year during 1941-57. Since construction of Glen Canyon Dam, this average has been reduced to an estimated 11 million tons per year, approximately 70 percent of which comes from the Paria River and the LCR. Together these rivers have delivered an average of 12 million tons per year of sediment to Grand Canyon since 1941 (Andrews, 1991a).

Most of the sediment delivered to and transported by the Colorado River is silt and clay. Because these finer particles can be carried in suspension by most dam releases, the quantity of silt and clay transported depends mainly on tributary supply. Although sandbars along the banks of the Colorado River contain some silt and clay, their existence primarily depends on the transport of sand.

As bed-material load (mainly sand and gravel) enters the Colorado River from the tributaries, it begins the long and slow journey to Lake Mead. During the course of this journey, sand particles may go through numerous cycles of temporary transport and deposition. The riverbed is made up of bedrock, boulders, cobbles, gravel, and sand. The location of these materials depends on the local geology, river velocity, and the supply of incoming sediment. The riverbed is highly irregular and contains many deep pools, rapids, and eddies, where sands, gravels, and cobbles are stored during periods of low discharge (Graf et al., 1993).

Because of reduced capacity to transport sand, the Colorado River now can store more sand and larger-sized sediments in low velocity areas. The amount of sand stored within the riverbed each year depends on the tributary sand supply (which is highly variable), the pattern of water release, and the amount stored at the beginning of the year. Sand stored on the riverbed is the principal source for building sandbars during periods of high releases. The probability of net increase in sand stored in the river channel is used as an indicator of impacts of the alternatives.

Delivery to the Colorado River

The quantity of sand stored in a given reach—and thus available for deposition on sandbars—depends upon the supply of sand from the upstream channel and tributaries and the rate at which sand is removed from the reach by transport downstream.

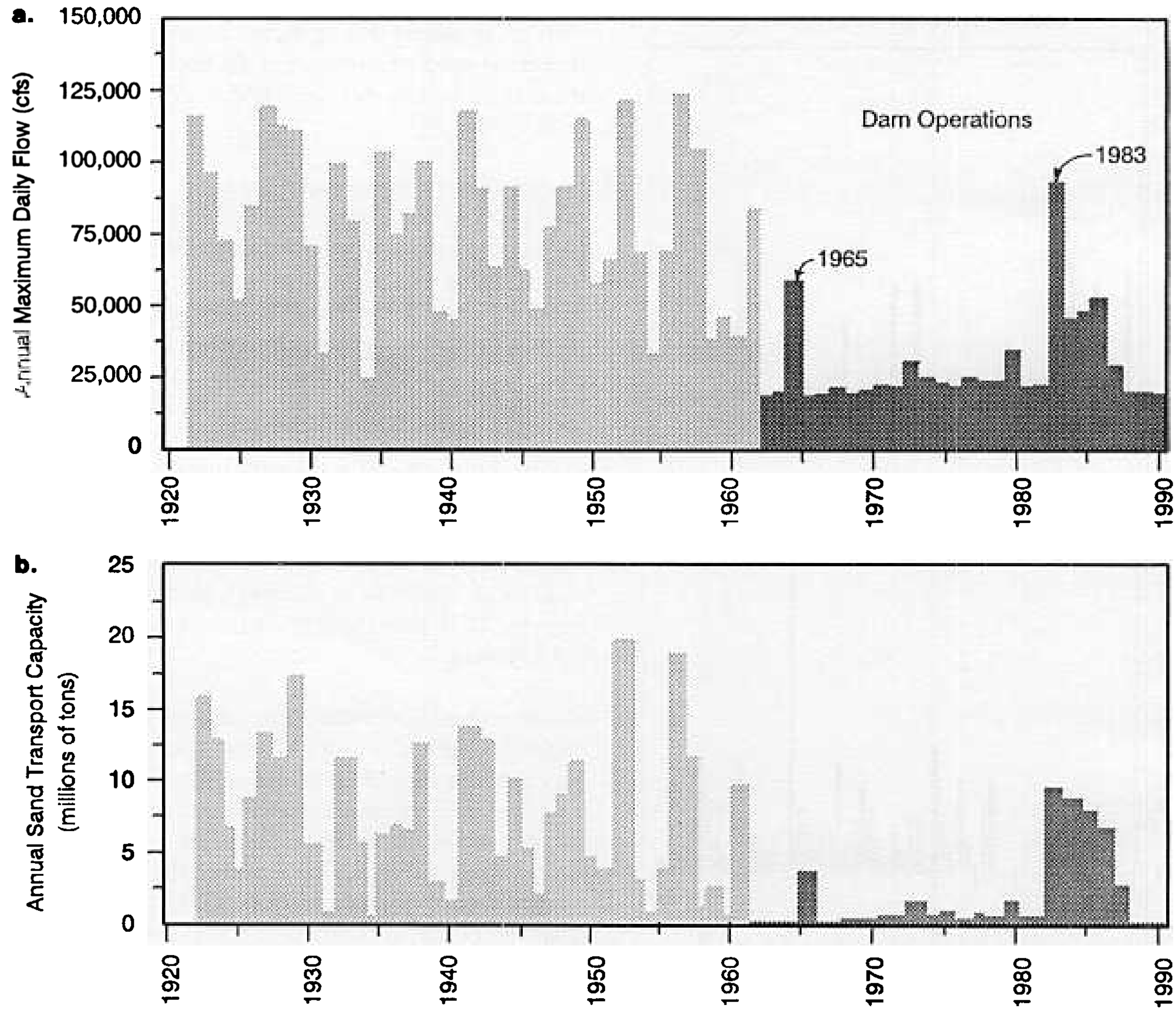


Figure III-11.—Annual peak flows (a) and estimated sand transport capacity (b) for the Colorado River at Lees Ferry from 1922 to 1990, both of which have been substantially reduced since dam closure. Sand transport capacity was estimated from an accumulation of daily sand loads. Daily loads (both predam and postdam) were determined from mean daily flow at Lees Ferry, using the Pemberton (1987) sand load equation for Phantom Ranch. Actual predam loads may have been greater than those computed, and actual postdam loads much smaller than computed. Postdam transport capacity at Lees Ferry is much greater than sand supply.

Many tributaries supply sediment, including sand, to the Colorado River downstream from Glen Canyon Dam. The Paria and LCR are estimated to supply over 70 percent of the total sediment (sand, silt, and clay) entering Grand Canyon. Other tributaries typically deliver sediment during flash floods or debris flows. There are no tributaries that deliver substantial quantities of sediment between the dam and the Paria River, although sediment occasionally is delivered to that reach by side-canyon flash floods.

Gauged Tributaries. Sand contribution from the Paria and Little Colorado Rivers and Kanab Creek, estimated at USGS gauging stations, varies greatly from year to year (see figure III-12) but

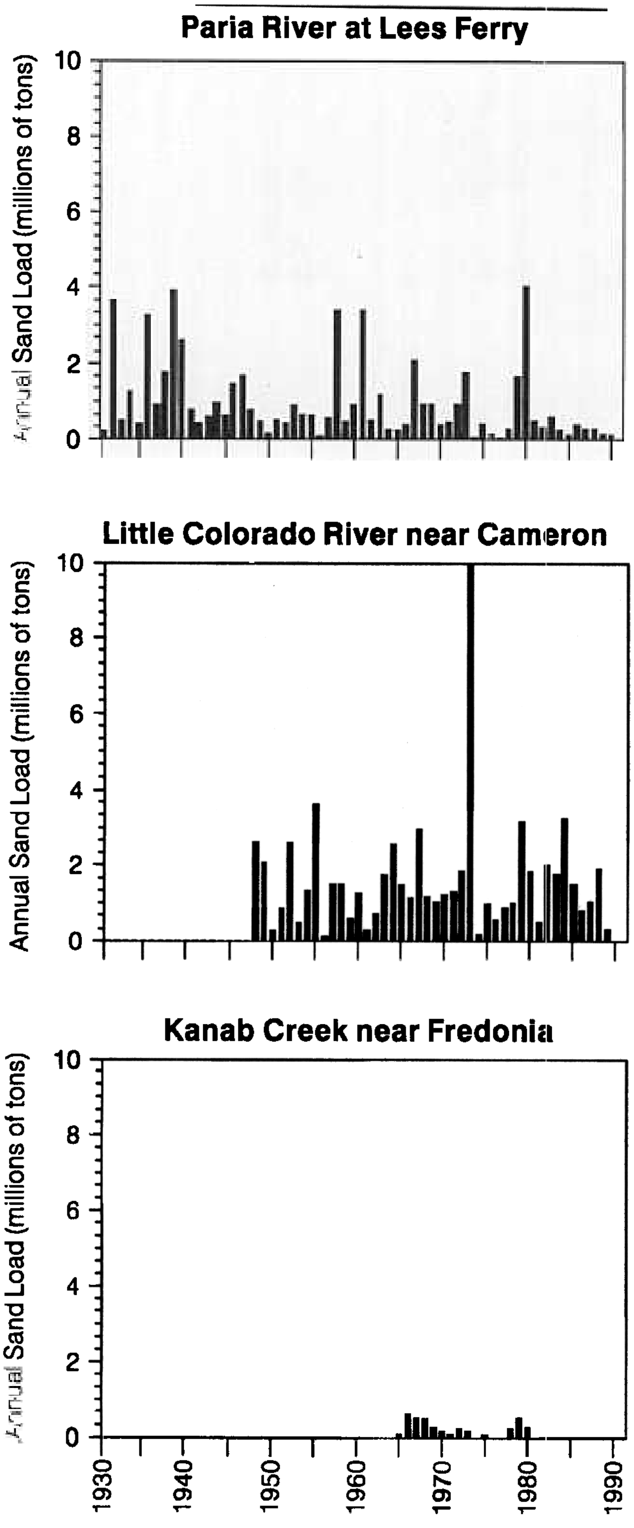


Figure III-12.—Annual sand contributions from the Paria River, LCR, and Kanab Creek. Computed from mean daily flows using sand load equations of Randle and Pemberton (1987).

generally has decreased in the 20th century. Sand delivery is subject to long-term climate variations that affect sediment storage in the flood plains of these streams (Hereford and Webb, 1992; Graf et al., 1991).

In spite of the reduced sand-transport capacity of the Colorado River, there has been a net decrease in sand storage between the dam (RM -15.5) and the LCR (RM 61) since closure of the dam. Most of the decrease has occurred since the floods of 1983-86. Also, annual sand deliveries from the Paria River (RM 1) have been below average since 1980 (figure III-12; also see Graf et al., 1991); however, Topping and Smith (1993) are reevaluating the flood history and transport capacity of the Paria. A well-documented large flood on the LCR during interim flows delivered large quantities of sand and silt to the river (Beus et al., 1993; Hazel et al., 1993; Kaplinski et al., 1994). Downstream from the LCR, there has been a net increase in sand storage.

Under normal fluctuating flows, a long-term sand balance is likely downstream from the LCR but may not be achieved upstream. However, future long-term changes in the sand supply from tributaries could alter this conclusion. Smilie, Jackson, and Tucker (1993) analyzed the frequency of annual sand delivery from the Paria River (1949-76) in relation to Colorado River transport capacity. Their results for a minimum release year (8.23 maf) suggest that, when the range in daily flow fluctuations exceeds about 18,000 cfs on an annual basis, transport capacity exceeds the long-term supply from the Paria River (about 790,000 tons) in the reach between the Paria River and LCR . Even when transport capacity and long-term sand supply are in balance, however, there would be periods of fairly substantial short-term losses and gains in sand storage between the Paria River and LCR.

Ungauged Tributaries. Smaller tributary canyons typically form along faults or joints in the rocks (Dolan et al., 1978). Much of the sand and coarser debris (gravel, cobbles, and boulders) from these ephemeral tributaries is delivered to the river by debris flows and flash floods.

The quantity of sand supplied from ungauged tributaries is not well known and is difficult to estimate due to the variability of debris flows and flash floods. However, Randle and Pemberton (1987) made a rough estimate of 0.7 million tons per year based on the relationship between drainage area and sediment yield derived for the semiarid States. The long-term cumulative average annual sand delivery from all tributaries, gauged and ungauged, is shown in figure III-13. The amounts are listed by reach in appendix D, table D-1.

The occurrence and size of both debris flows and flash floods are influenced by geologic and geomorphic conditions within the watershed and prior history of flows, as well as by rainfall amount and intensity. For example, Havasu Creek has not had a debris flow in recent geologic time, but it had a spectacularly destructive flash flood in September 1990. Slope failures in the steep tributary valleys commonly trigger debris flows. Geologic conditions favorable for debris flows from side canyons vary throughout Grand Canyon. Therefore, the potential for sand delivery from these tributaries to the river also varies throughout the canyon (Webb et al., 1989).

The major points concerning sediment delivered to the Colorado River by ungauged tributaries are summarized below (Melis and Webb, 1993; Webb et al., 1989, 1991).

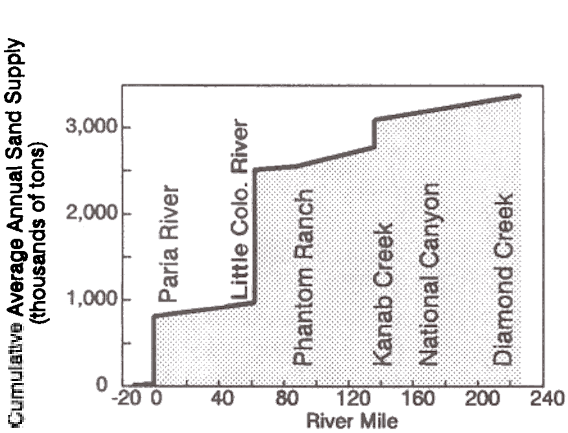


Figure III-13.—Cumulative sand supply increases with river mile, with large increases at the confluences of the Paria and Little Colorado Rivers.

- Flash floods, including debris flows, periodically occur in about 525 tributaries of the Colorado River in Grand Canyon.
- The 525 tributaries are potential sources of sand to replenish sandbars in Grand Canyon.
- On the average, debris flows occur one to four times per 100 years in any given tributary. The frequency of occurrence varies with the geologic formations of the side canyons.
- Debris flows are initiated by high-intensity precipitation and failure of either bedrock or rock fragments that accumulate on steep slopes or at the foot of cliffs.
- Debris flows in Grand Canyon are high-magnitude, short duration events. They contain about 10 to 40 percent sand and are capable of transporting extremely large boulders into the Colorado River.
- Debris flows create and maintain the rapids that are the hydraulic controls of the Colorado River. They also control the sizes and locations of eddies.
- Tributary flash floods, including debris flows, can erode sandbars. Some debris flows may cover sandbars with gravel, cobbles, and boulders.

Main Channel Transport and Storage

Sand transport capacity of the Colorado River is the amount of sand that the river could transport if sufficient sand were available. The amount of sand actually transported (sand load), therefore, may be less than the transport capacity, which mainly depends on the velocity of the water. Velocity, in turn, varies with riverflow and local channel characteristics. For a given riverflow, velocities—therefore, transport capacities—are greater in narrower, steeper reaches than in wider, flatter reaches. Narrow and wide reaches alternate throughout the length of the canyon (table III-7 and figure III-14). Where the rocks are very resistant to erosion, the river flows between the rock walls of a narrow gorge. Where the rocks are more easily eroded, the river has a relatively wide channel bounded by deposits of sand, gravel, and cobbles.

Table III-7.—Hydraulic characteristics of geologic reaches within Grand Canyon (modified from Schmidt and Graf, 1990)

Reach number	River miles[1]	Reach name	Width type	Average channel width[2] (feet)	Average depth[2] (feet)	Channel slope[3] (feet per mile)	Percentage of bed composed of bedrock and boulders[4]
0				450	27	1.4	>80
1				280	24	5.2	42
				210	27	7.4	81
				220	24	7.9	72
4				350	18	5.3	36
5	61.5–77.4		Wide	390	15	11.1	30
6	77.4–117.8		Narrow	190	27	12.1	62
7	117.8–125.5		Narrow	230	21	9.0	48
8	125.5–140		Narrow	210	26	10.6	68
9	140–160		Narrow	180	23	6.3	78
10	160–213.8		Wide	310	19	6.9	32
11	[5]213.8–236		Narrow	240	30	8.4	58
12	236–278				[No data]		

1 See figure III-14.
2 Average of cross-section data at about 1-mile intervals at 24,000 cfs (Randle and Pemberton, 1987).
3 Based on predicted water-surface elevations at 24,000 cfs (Randle and Pemberton, 1987).
4 From channel-bed material maps (Wilson, written communication,1987).
5 Results from miles 213.9–225.

The narrowest, steepest, and shallowest places of all are the rapids, which account for about 90 percent of the river elevation drop through the canyon but only about 10 percent of the length (Leopold, 1969). Water velocities typically are 10 times greater in the largest rapids than in the long pools that extend upstream from the rapids (Kieffer, 1988, 1990). Thus, while nearly all sediment particles but the largest boulders can be transported quickly through high velocity rapids, much of the sand is stored temporarily in low velocity pools and eddies.

Essentially all sand in the main channel between Glen Canyon Dam and Lees Ferry was deposited before the dam was closed. Since closure, the channel has degraded (Pemberton, 1976; Burkham, 1987). Loss of sand from this reach is irreversible without artificial resupply of sand because contribution from tributaries is very small, and transport capacity of the river is large.

During the initial filling of Lake Powell, sand scoured upstream from Lees Ferry and sand contributed by tributaries downstream from Lees Ferry accumulated in the river channel. The

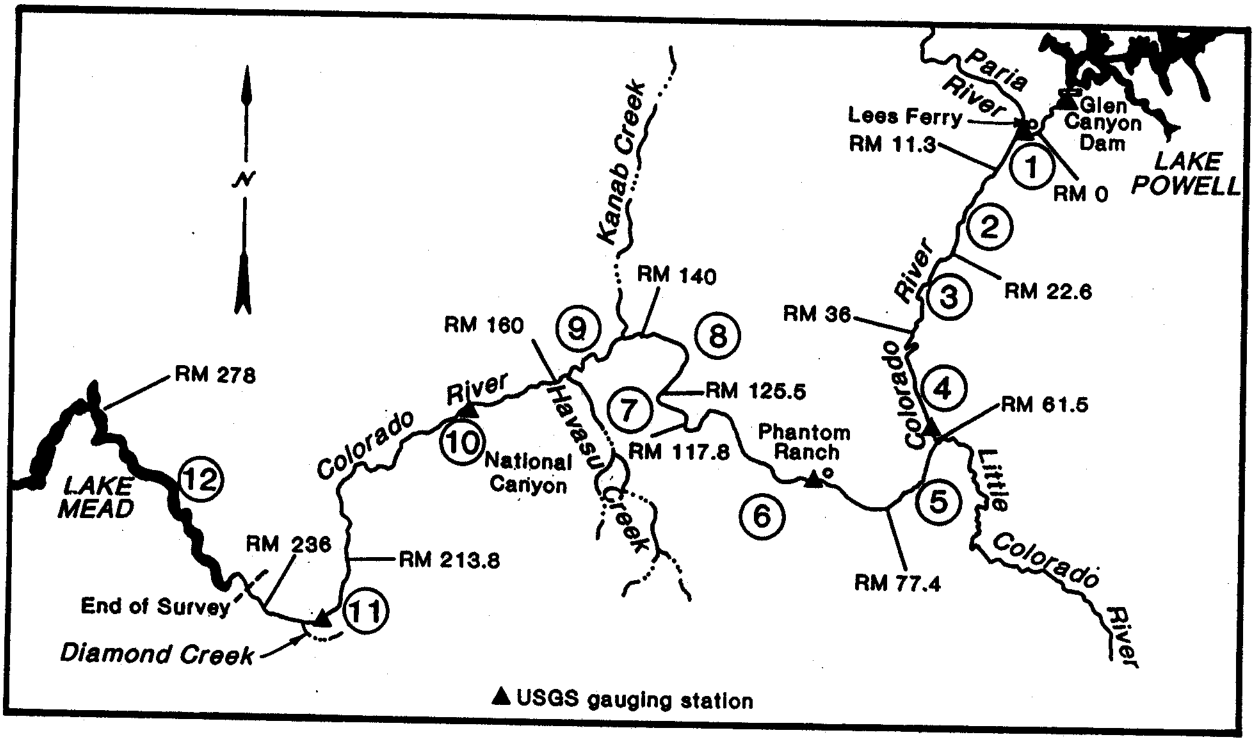


Figure III-14.—Geologic reaches within Grand Canyon (modified from Schmidt and Graf, 1990). Reach characteristics are listed in table III-7.

cumulative storage of sand between Lees Ferry and Phantom Ranch, shown in figure III-15, was calculated as the sum of computed inputs from the Paria and Little Colorado Rivers minus the computed transport past the Phantom Ranch gauge. The sand transport equations of Randle and Pemberton (1987) and Pemberton (1987) were used for these computations. The high flows of 1983-86 removed most of the sand that had accumulated during Lake Powell filling. Most of this sand was transported downstream to Lake Mead. Some sandbars within Grand Canyon aggraded as much as 10 feet, while others eroded—some substantially.

The amount of stored sand available for transport, therefore, depends on both preceding flow and sand delivery, as indicated by bed elevation. Before Glen Canyon Dam was constructed, bed elevation in pools decreased as sand and gravel were scoured from the bed during annual snowmelt runoff. Sand and gravel were deposited during lower flows at other times of the year, increasing bed elevation (Burkham, 1987). Burkham reported that bed elevation in pools before flow regulation changed as much as 30 feet annually at the USGS gauging station at Lees Ferry and as much as 8 feet at the gauge near Phantom Ranch. Daily discharges of 40,000 to 60,000 cfs for more than 40 days in 1965 degraded the bed at Lees Ferry about 27 feet. Because there is essentially no supply of sand and gravel from upstream, the bed has not aggraded since then. It would take an estimated 70,000-cfs flow to initiate further degradation at this site (U.S. Department of the Interior, 1988).

Degradation (scouring) of the riverbed in some places, such as at the Lees Ferry gauging station, is self-limiting by a progressive decrease in velocity and a corresponding increase in the size of bed material (Burkham, 1987). As degradation progresses and velocity decreases, bed material coarsens (Randle and Pemberton, 1987). Eventually, the bed material may become so coarse that flow is no longer capable of moving it,

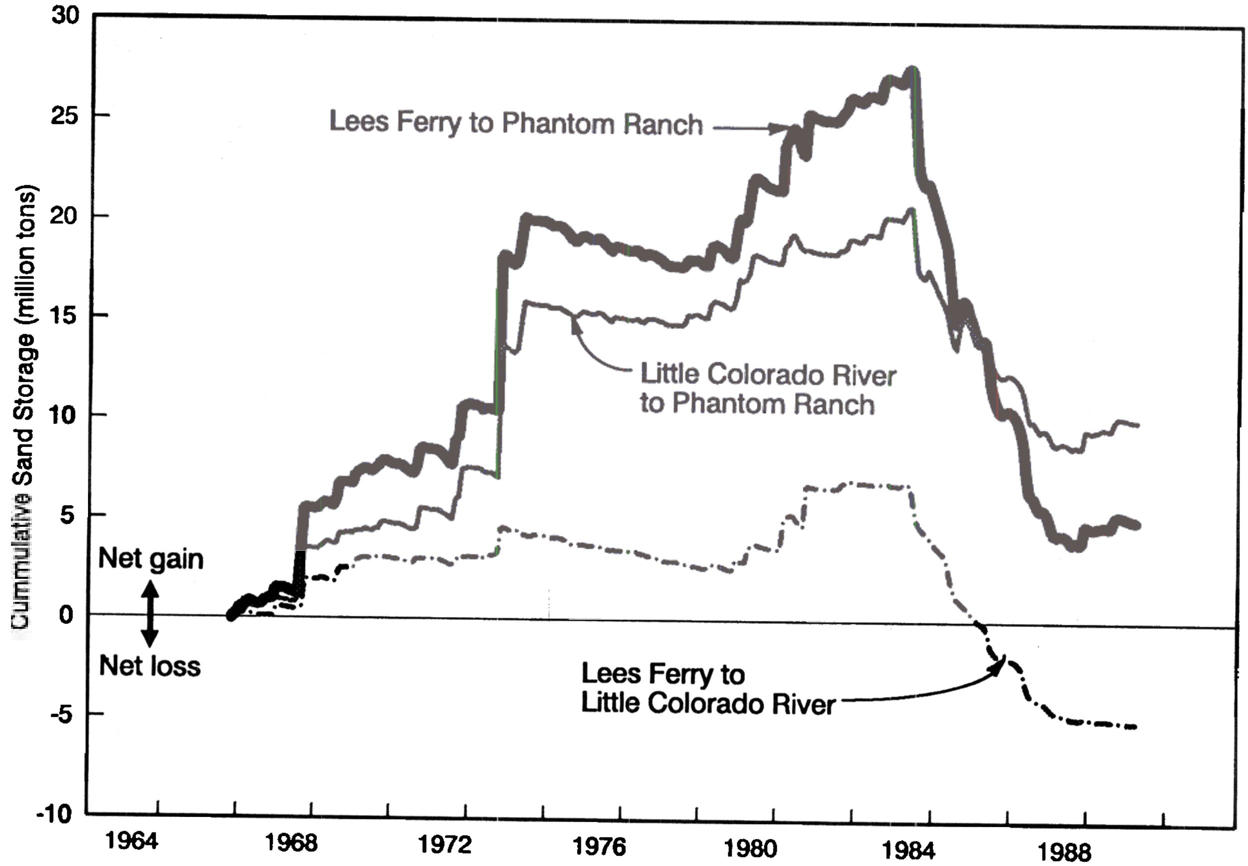


Figure III-15.—Cumulative sand storage between Lees Ferry and Phantom Ranch. Sand accumulated in the river during the relatively low releases while Lake Powell was filling, coupled with large sand contributions from the Paria and Little Colorado Rivers in 1972, 1979, and 1980. Sand was eroded from the channel during the 1983-86 high water years. Computation method is described in text.

so degradation stops. This process, called armoring, has happened in the Glen Canyon reach (Pemberton, 1976).

If the supply of sand is sufficient, the amount transported by the river is exponentially proportional to the riverflow (i.e., the rate of increase in sand load is much greater than the rate of increase in flow). Fluctuating flows, therefore, will transport more sediment than steady flows of the same volume because the fluctuating flows are higher than steady flows during part of each day. As the wave shape changes downstream (see WATER in this chapter), sediment transport capacity is reduced.

Computed sand loads at the gauge above the LCR for steady and fluctuating water releases of the same volume for 1 day are compared in figure III-16. Computed sand loads are based on the river's transport capacity. Actual sand loads may be smaller than computed loads when the tributary supply is less than transport capacity. As the bed elevation continues to increase, the annual transport through Grand Canyon will approach the amount delivered annually by tributaries. The sand that accumulates during low release years may be available to build sandbars during periods of sufficiently high discharge.

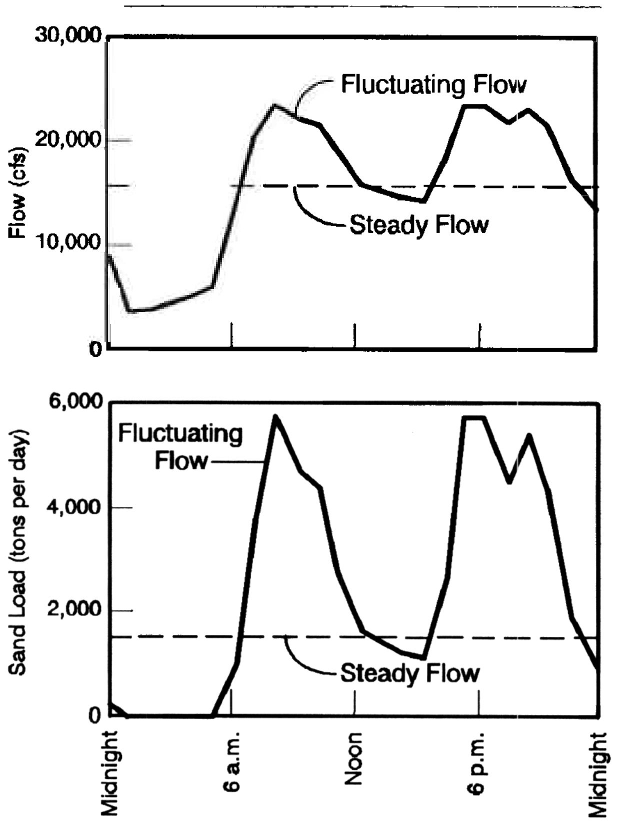


Figure III-16.—Comparison of riverflow and computed sand load at the gauge above the LCR under steady and fluctuating flows within a 24-hour period. Cumulative sand loads in this example are 1,500 tons for the steady flow and 2,500 tons for the fluctuating flow. At Phantom Ranch, the cumulative loads increased to 3,100 tons for the steady flow and 5,100 tons for the fluctuating flow.

Sandbars (Beaches and Backwaters)

Sandbars commonly found along the banks of the Colorado River in Grand Canyon are dynamic. Sandbars are derived from sand transported by the river and exchange sand with the river. These bars are composed mainly of sand; however, they may contain some silt, clay, or gravel. In this EIS, the term "sandbar" is used to mean any of the fine-grained alluvial deposits that intermittently form the banks of this otherwise talus- and bedrock-lined river (at low flows, some sandbars may appear to be separated from the main riverbank). There are more sandbars used as campsites in wider reaches than in narrower reaches (U.S. Department of the Interior, 1988; Kearsley and Warren, 1993). Sandbars are important for vegetation, riparian habitat for fish and wildlife, and recreation. Beaches are sandbars that have recreational value. Backwaters are low velocity areas formed by low elevation sandbars (see FISH, this chapter).

Sandbar deposition and erosion, both predam and postdam, are natural processes. Rates and amounts of deposition and erosion vary with:

- Flow magnitude and duration
- Tributary sediment supply
- Amount of sand stored in river channel pools and in eddies
- Local channel hydraulics

The pattern of sandbar deposition and erosion has been altered by Glen Canyon Dam. Before completion of the dam in 1963, sandbars in Glen and Grand Canyons were aggraded and eroded cyclically by seasonal and long-term variation in flow and sand transport (U.S. Department of the Interior, 1988; Howard and Dolan, 1981). During 1965-82 (following the flood release of 1965), high elevation sandbars generally eroded and low elevation sandbars generally aggraded; erosion rates decreased with time (Schmidt, 1992). During the floods and prolonged high releases of 1983-86, sand was deposited on higher sandbars but removed from lower sandbars. Generally, high rates of erosion were observed during the nearly steady high releases and during the return to normal fluctuating releases between October 1985 and January 1986 (Schmidt and Graf, 1990). Between 1987 and 1991, aggradation and erosion patterns were similar to those of 1965-82, but erosion rates were greater (Schmidt, 1992).

Since implementation of interim flows, sandbars have cyclically aggraded and eroded, with negligible net change overall (Beus and Avery, 1992). Also, sandbars between the 20,000- and 30,000-cfs levels have eroded and not been rebuilt, riparian vegetation is encroaching into the 20,000 to 30,000-cfs zone, and backwater habitats have filled with silt (Patten, written communication, 1993). Floods in the LCR during January-February 1993 added much sand to the system and substantially aggraded many sandbars downstream; however, postflood erosion removed much of the newly deposited sand from higher to lower elevations (Hazel et al., 1993; Kaplinski et al., 1994).

Recirculation Zones (Eddies)

Nearly all sandbars in Grand Canyon are associated with recirculation zones that consist of one or more eddies. As the river flows around an obstruction, such as protruding bedrock or a debris fan, the flow becomes constricted, and the downstream-directed current becomes separated from the riverbank (figure III-17). Downstream from the constriction, the channel is wider, the main current reattaches to the riverbank, and some of the water is redirected upstream. This change in flow direction forms a zone of recirculating water and sand between the points of separation and reattachment and between the main channel and the riverbank. The location of the reattachment point and length of the recirculation zone vary with riverflow. The recirculation zone lengthens with increasing discharge and shortens with decreasing discharge.

There is great potential for deposition of sand, silt, and clay within a recirculation zone, where water velocities are much lower than velocities in the main channel (Schmidt, 1990). Figure III-18 shows that water with relatively high sand concentration moves into the eddy near the streambed, and water with relatively low sand concentration moves out of the eddy near the surface (Nelson, 1991). Sandbars form in low velocity areas at the downstream and upstream ends of the recirculation zone. These sandbars usually are continuous deposits, although the return-current channel connecting them may be submerged at most riverflows. Sand deposition and erosion in

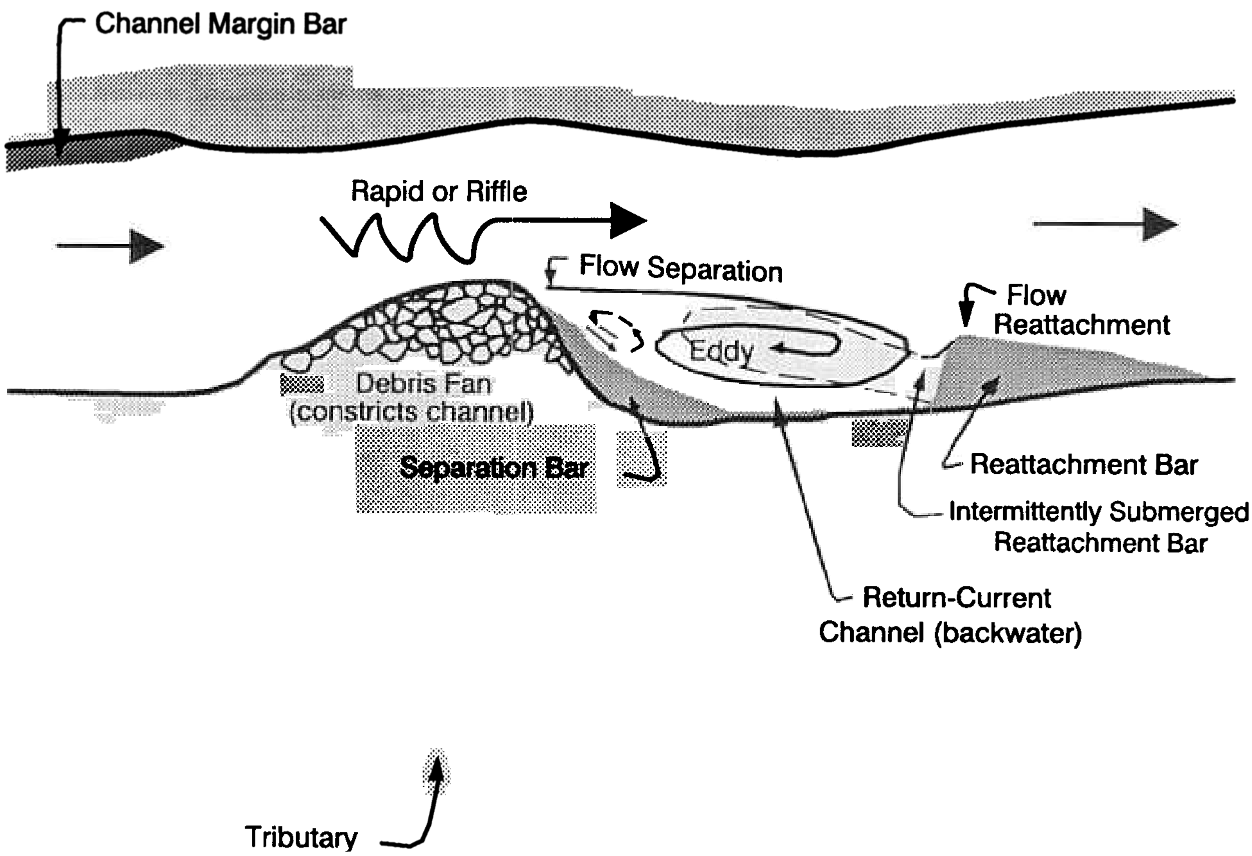


Figure III-17.—Relationship of sandbars and flow patterns. Riverflow is constricted in a rapid, causing an eddy downstream. Sand is suspended in the highly turbulent currents of the rapid and deposited on sandbars associated with the relatively tranquil eddy currents.

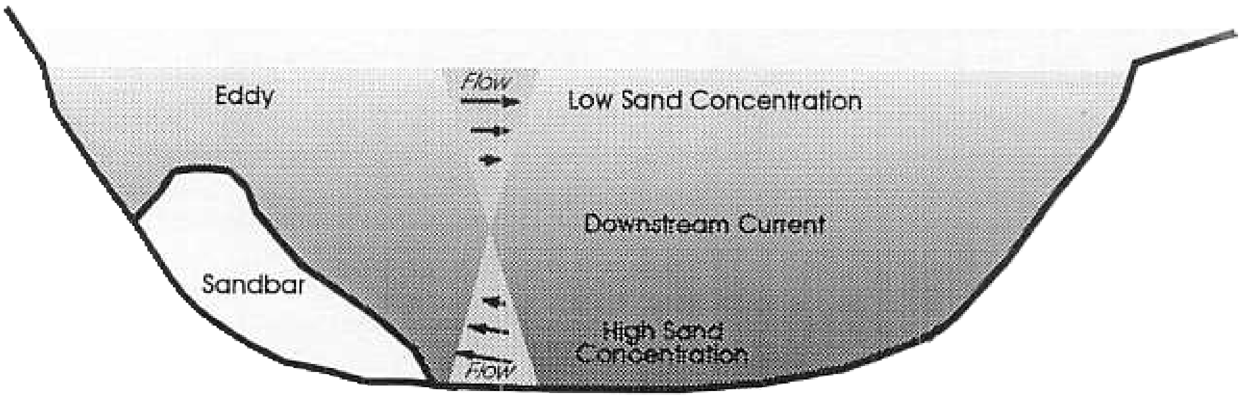


Figure III-18.—Cross section of the Colorado River. Eddies are very efficient sediment traps. Water with relatively high sand concentration (near the streambed) moves toward the eddy and builds a sandbar. Water with relatively low sand concentration (near the surface) moves from the eddy back to the main channel.

recirculation zones is dynamic, varying with changes in riverflows and the dimensions of debris fans.

Sandbars are classified as reattachment bars, separation bars, or channel margin bars, according to their position in a recirculation zone or location along the river (Schmidt, 1990; Schmidt and Graf, 1990).

Reattachment bars, formed in low velocity areas near the downstream end of recirculation zones, extend upstream from the point of flow reattachment and typically are broader but lower than the other types of sandbars (figure III-17). They are inundated more frequently and have been subjected to a greater range of aggradation and degradation (Schmidt and Graf, 1990). Reattachment bars and the return-current channels directly associated with them are important for backwaters and emergent marshes. Boaters use these sandbars for campsites where they are high enough to avoid inundation—mostly in wide reaches. In the narrowest gorges, reattachment bars may be submerged by all but the lowest flows.

Return-current channels, whether submerged or exposed, are components of reattachment bars. Return-current channels are excavated when the velocity of recirculating flow is strong enough to transport more sand from behind the reattachment bar than is being transported across the bar face. Responses of return-current channels to various flow-release patterns are not well understood; however, there is general agreement that they are destined to fill with sand and silt unless flushed occasionally by high flows—probably greater than powerplant capacity.

Backwaters are open return-current channels connected to the river that have little or no velocity and have potential for warming by exposure to the sun (see FISH in this chapter). The channel must be inundated, but the crest of the reattachment bar must be above water. Suitable backwaters are formed within certain ranges of riverflow; higher flows inundate the reattachment bar, and lower flows may leave the channel dry or disconnected from the river. According to Schmidt (verbal communication, 1992), floods increase the number of backwaters by removing vegetation and scouring the return-current channels; the number of backwaters decreases between floods as they fill with sediment (figure III-19). The effects of a flood of given magnitude and duration could vary considerably, depending on antecedent conditions—especially riverbed sand storage.

Deposition of silt and other fine sediment is important for establishment and maintenance of marshes (see VEGETATION in this chapter). Marshes became established along wide reaches of the Colorado River in Grand Canyon after flow regulation began in 1963, developing where large reattachment bars became overgrown by cattails and other marsh vegetation. The 1983-86 floods scoured the marsh vegetation and probably eroded several vertical feet of sand from these reattachment bars (Stevens et al., 1991). Since that time, emergent marsh vegetation has reestablished on many new reattachment bars. Vegetation becomes established on stable sandbars; however, the vegetation apparently does not prevent erosion (Stevens and Ayers, 1993).

Separation bars (typically high elevation bars) are formed in the low velocity areas near the upstream ends of recirculation zones and commonly mantle the downstream surface of debris fans

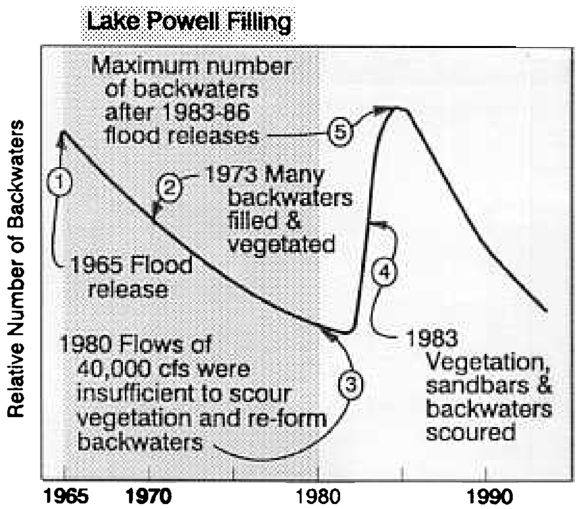


Figure III-19.—Conceptual change in relative number of backwaters (open return-current channels) during low flow seasons since the 1965 flood release, based on interpretation of aerial photographs (source: Schmidt, verbal communication, 1992).

(figure III-17). They generally are steeper and higher than reattachment bars; many extend above the level of 30,000 cfs. Usually associated with eddies, separation bars are built with sand transported upstream from the reattachment point. Therefore, separation bars are composed of finer-grained sand than reattachment bars. They are preferred as campsites because they are less likely to be inundated by rising river levels, and because the low velocities in the upper ends of eddies make it easier to moor boats (see RECREATION in this chapter).

Channel margin bars are elongated sand deposits along the margins of the Colorado River that have the form of terraces. Channel margin bars are not directly associated with large eddies; instead, they typically form in small eddies related to some sort of flow obstruction, such as a large boulder (Schmidt and Graf, 1990). Typically, channel margin bars cover bedrock or talus. In some reaches, particularly where the channel is wide, these bars line the channel from a few hundred feet to nearly a mile and often are heavily vegetated.

Downstream from RM 236, riverflow and deposition and erosion of sand and silt are affected by the level of Lake Mead (see discussion of Lake Mead delta later in this section).

Silt and Clay

Although most of the silt and clay delivered to the river is transported directly through the canyon, an important fraction is carried by currents into low velocity areas such as return-current channels, where silt and clay are deposited. Silt and clay add nutrients to the slackwater environment. Clay contributes to cohesion of sand on sandbars. The presence of silt and clay in sandbars can reduce permeability and make them more susceptible to seepage-induced erosion. Like that of sand, the only source of silt and clay in the canyon is the tributaries. Unlike sand, however, transport of silt and clay is not a function of the magnitude of dam releases. Silt and clay particles are readily transported by almost any discharge in the Colorado River, but the height of deposition in eddies depends on river stage—a result of both dam release and tributary inflow.

Little silt or clay would be deposited, however, when the riverflow is high and the supply of silt/clay entering from tributaries is small. In fact, previously deposited silt and clay are susceptible to being washed out of an eddy by any high, turbulent flow. Thus, the likelihood of deposition of fine sediment in the eddies would be greatest during the tributary flood season, coupled with higher-than-average dam releases.

Sandbar Deposition and Erosion

Deposition requires high flows, whether annual or daily; erosion occurs following the return to lower flows (Schmidt and Graf, 1990; Schmidt, 1992; Hazel et al., 1993; Kaplinski et al., 1994). Without occasional periods of sustained high releases (above powerplant capacity), high elevation sandbars eventually will erode and not rebuild (Andrews, 1991a). Sandbars typically were not vegetated prior to the dam. Unvegetated sandbars are dependent on cycles of deposition and erosion. Active erosion is a part of this natural process.

Comparison of photographs taken of the same sites in 1890 and in 1990 provides some information about the long-term change of sandbars (Webb, in press). In eastern Grand Canyon (RM 0-126), a relatively high percentage of sandbars had eroded between 1890 and 1990. In western Grand Canyon (downstream from RM 126), more sandbars were about the same size or had aggraded than had eroded. This comparison, however, does not take into account the short-term variability of sandbars, which could affect the conclusions.

Short-term changes in sandbars have been documented since completion of the dam. During periods of low releases (1966-82 and 1987-90), channel banks in wide reaches aggraded while high elevation sandbars used as campsites eroded. Erosion rates decreased with time. During periods of relatively high discharge (1983-86), reattachment bars eroded, but high elevation sandbars aggraded. Aggradation rates during 1987-91 were equivalent to those of 1966-82, but erosion rates during 1987-91 were about twice as great as those of 1966-82 (Schmidt, 1992).

Normal Operations. Sandbars experience cycles of deposition and subsequent erosion during normal operations. Generally, net erosion decreases downstream, with the attenuation of the daily extremes in river stage and the addition of sand from tributaries.

Sandbar erosion can result from any of three mechanisms: main-current erosion, seepage-induced erosion, and wave-induced erosion. At a particular sandbar and at a particular time, one of these mechanisms may be predominant. Up ramp rates have not been linked to sandbar erosion.

Main-current erosion is caused when the main channel current is in direct contact with part of a sandbar. Exposure of sandbars to this type of erosion may be increased by the contraction of the recirculating zones during periods of low discharge or when debris fans are overtopped during periods of high flow. Main-current erosion is believed to cause greater net loss of sand from recirculation zones to the river than the other types of erosion, but this has not been documented quantitatively.

Seepage-induced erosion affects most sandbars in Grand Canyon and is responsible for rivulet formation, slope failures, bank cuts, and piping and tunneling (Budhu, 1992). Seepage-induced erosion is affected by fluctuations in river stage, down ramp rates, and the duration of minimum flow. Erosion caused by rapid upramping has not been documented.

Wave-induced erosion is caused by turbulence in nearby rapids, wakes from motor boats, and wind. At each sandbar, effects of wave-induced erosion are concentrated at a specific river stage under steady flow but are distributed over the range of river stages under fluctuating flow. There is some evidence that waves agitate bottom sediments, enhancing the possibility of sand transport (Bauer and Schmidt, 1991, 1993).

During increasing flow, eddies expand downstream, and sand deposition rates within the eddy systems increase (Andrews, 1991b). During decreasing flow, the downstream areas of eddies shift upstream (contract), and sand deposition rates within the eddy system decrease. Sand deposited near the reattachment point during higher flows is subjected to main-current erosion by the river. Water stored within the sandbars begins to flow toward the river.

Ground-water processes occur on every sandbar during daily and hourly fluctuations. Ground-water levels within exposed sandbars rise and fall with increases and decreases in river stage (Werrell et al., 1993; Carpenter et al., 1991; Budhu, 1992). If river stage decreases rapidly, seepage-induced erosion may occur. Water table fluctuations within sandbars attached to the bank are greatest near the river and decrease with distance from the river. When river stage declines faster than ground water can drain from the sandbar, the exposed barface becomes saturated. Water seeping from the saturated barface forms rills that move sand particles toward the river (Werrell et al., 1993). When the rate of river stage decline is equal to or less than the rate at which ground water naturally drains from the barface, a seepage face will not form.

The sandbar slope stability model of Budhu (1992) is applied in this EIS (see figure III-20). Sandbars are initially deposited at angles ranging from 20 to 45 degrees with an average of 26 degrees. As the river stage recedes, this slope may be unstable. Seepage-induced erosion tends to reduce the slope of new deposited sands to about 11 degrees. On some sandbars, a rapid decrease in river stage sets up conditions for bar failure. The next rising river stage (at almost any ramp rate) could easily cause a failure to occur.

Sandbar height and active width for the range of daily and annual flow fluctuations are used as indicators of impacts of the alternatives. These are the height and width of the inundated zone (figure III-20).

Unanticipated Floods. Large unanticipated floods of sediment-free water generally have a much greater effect on sandbars than releases under normal operations. The magnitude and extent of the effects depend on the magnitude and duration of the flood and the supply of sand in eddies and the main channel prior to the flood. Floods may be beneficial to backwaters by removing vegetation and re-forming return-current channels.

Floods occurring when sand storage in the main channel is low probably would cause more extensive loss of sand-dependent resources than when pools and eddies are relatively full of sand. The 1983 flood, with plenty of stored sand available, aggraded many sandbars. However, Schmidt and Graf (1990) reported evidence that the floods of 1984-86 did not deposit as much as the flood of 1983 and caused greater erosion. If sand contribution from tributaries is sufficient to balance the sand removed from Grand Canyon over the long term, the net change in sandbars would be small.

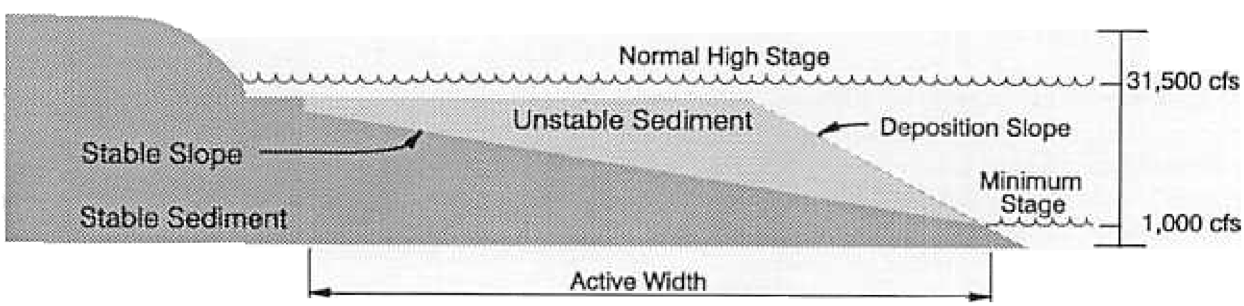


Figure III-20.—Conceptual cross section of a sandbar affected by fluctuating flows. Daily fluctuations create an unstable zone within the sandbar. The minimum stage determines the boundary between the stable and unstable zones.

The number of sandbars used as campsites increased between the inventories of 1973 and 1983 in both narrow and wide reaches as a result of the 1983 flood (Kearsley and Warren, 1993). The floods and prolonged high releases of 1984-86, followed by fluctuating releases in 1985-86, caused net erosion of many campsites. The 1991 inventory indicated that erosion has reduced the number of campsites to slightly more than the 1973 count in wide reaches and less than the 1973 count in narrow reaches (see figure III-21). Vegetative overgrowth further reduced the number of campsites in all reaches.

Other Factors. Sandbars also are eroded by natural forces not influenced by dam operations, such as wind, waves, rainfall, flash floods, and debris flows. Sandbars that are not inundated by dam releases are susceptible to erosion by wind and the effects of camping use.

Recreation causes sandbar erosion, but this erosion is primarily limited to camping beaches.

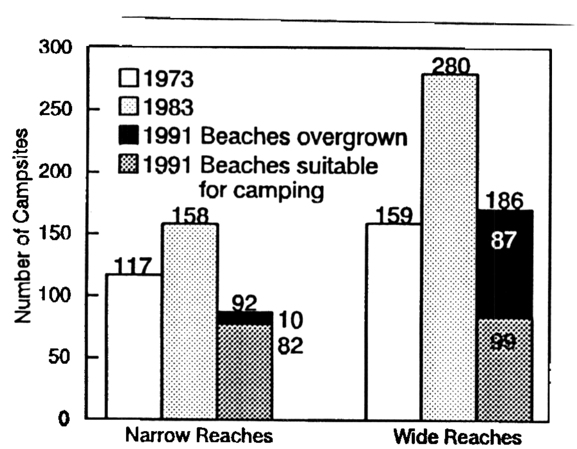


Figure III-21.—Comparison of sandbars used as campsites based on inventories conducted in 1973, 1983, and 1991. The number of campsites increased in both narrow and wide reaches as a result of the 1983 flood. By 1991, erosion reduced the number of campsites to slightly above 1973 levels in wide reaches and below 1973 levels in narrow reaches; vegetative overgrowth further reduced the number of campsites (source: Kearsley and Warren, 1993).

The amount of erosion is thought to be small in comparison with other causes of erosion. Valentine and Dolan (1979) estimated that on a typical camping beach, human foot traffic moves about 4 cubic yards of sand (less than 1 percent) per year into the river. Sand eroded from elevations above maximum flow would be permanently lost; sand eroded from lower elevations could be replaced by subsequent high flows.

High Terraces

High elevation alluvial terraces in wide reaches of Grand Canyon support native vegetation and may contain buried or partly buried archeological remains. The archeological remains are susceptible to exposure and loss by erosion. Most of this discussion of high terraces is based on the work of Hereford et al. (1993).

The high terraces were deposited by large floodflows (100,000 cfs and greater) prior to the dam and commonly have been reworked by wind and runoff from local rainfall. The larger the floodflow, the higher the terrace and the older the deposit (see figure III-22). The highest terraces are more than 1,000 years old, while the lowest terrace is about 30 years old.

Many high terraces are eroded by runoff from local rainfall resulting in networks of deep water-carved gullies (arroyos). Such erosion was extensive during the heavy rainfall of 1978-85, one of the wettest periods on record. This erosion does not occur if runoff filters into the ground before draining to the next lower terrace. However, if runoff drains to the next lower terrace, arroyos will erode to that level, exposing or eroding archeological remains, if present. Arroyo-cutting of even the lowest terraces indirectly causes erosion of higher terraces. In some cases, windblown sand may refill the arroyo.

The oldest and highest terraces eroded prior to the dam and will continue to erode. However, predam annual floodflows maintained the lowest high terrace and prevented some arroyos from cutting all the way to the Colorado River (see figure III-22). The lower peak discharges and

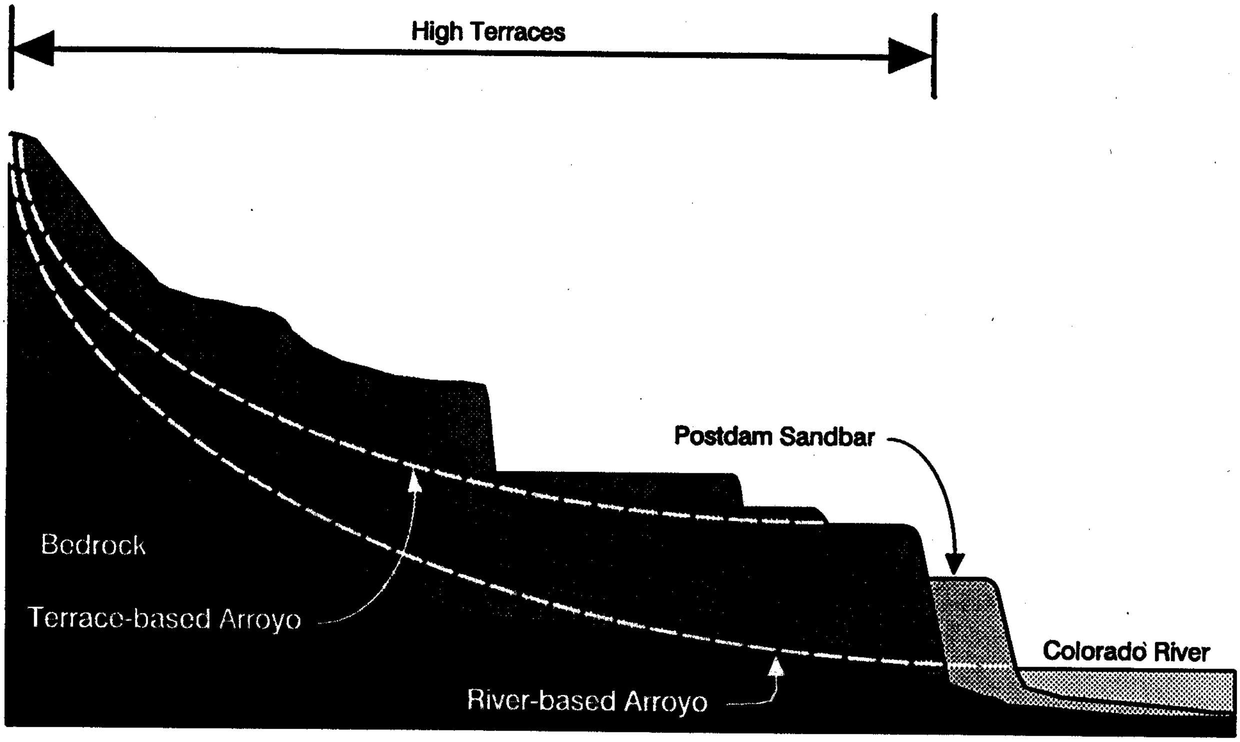


Figure III-22.—Conceptual cross section of arroyos draining high terraces typically found in a wide reach of Grand Canyon. The larger the floodflow, the higher the terrace and the older the deposit. Some arroyos drain to a lower terrace (terrace-based arroyo). Since construction of the dam, some arroyos have cut to the Colorado River (river-based arroyo) (modified from Hereford et al., 1993).

smaller sand concentrations of postdam flows are not sufficient to maintain even the lowest high terrace. Erosion of high terraces will continue through rilling and arroyo-cutting regardless of dam operations, except where site-specific protection may be implemented.

High terraces can be directly eroded by floodflows. Predam floods in some locations caused the river to shift laterally and erode terraces. The 1983 flood caused additional erosion of terraces in some locations, mainly between the dam and RM 36. The frequency of floods greater than 45,000 cfs is used as an indicator of impacts to those terraces.

Debris Fans and Rapids

Formed at the mouths of tributary canyons, debris fans are sloping deposits of poorly sorted sediment ranging in size from clay and silt to large boulders. Deposited by debris flows (see section on riverbed sand), debris fans are important geomorphic features in Grand Canyon; without them, there would be few rapids or sandbars (Webb et al., 1988).

Where debris fans extend into the Colorado River, they obstruct the channel, making it narrower and raising the bed elevation; and rapids or riffles are formed (see figure III-17). As the river reworks a debris fan, debris bars—consisting of well-sorted cobbles and boulders mixed with sand—may form downstream (Webb et al., 1989). Some debris bars form secondary rapids.

Webb et al. (1989) state that "large rapids may be the most obvious geomorphic manifestation of sediment transport from small drainages in Grand Canyon National Park." Deep pools that form upstream from rapids provide space for temporary storage of substantial amounts of riverbed material—mostly sand and gravel. As discussed in the section on riverbed sand, debris fans that constrict the river channel also create downstream eddies in which most of the camping beaches used by river runners are deposited.

For a given flow, the constriction width and riverbed elevation at a rapid control the velocity and water surface elevation of the upstream pool, which in turn control the amount of sand and gravel that can be deposited in the pool. Aggraded debris fans will allow the channel to store more sand in the associated pools and eddies.

More than 100 rapids and numerous riffles between Lees Ferry (RM 0) and Bridge Canyon (RM 235) were documented by Stevens (1983). The debris fans that form rapids will continue to be replenished and enlarged by infrequent debris flows, but Glen Canyon Dam has greatly reduced the magnitude and frequency of floodflows and, thereby, the capability of the river to move boulders from the rapids. In fact, many debris fans are accumulating sediment finer than boulders (Melis and Webb, 1993).

Formation of new rapids and steepening of existing ones will continue. Debris flows created rapids at RM 127.6 in 1989 and at RM 62.5 in 1990, and recent debris flows steepened 24-Mile, Specter, and Bedrock Rapids (Webb, in press).

In the absence of floods, there will be a continuing buildup of boulders and smaller particles on many rapids (Graf, 1980; Melis and Webb, 1993). The channel will become more constricted, resulting in steeper rapids. Such rapids could become more dangerous to navigate. Constriction ratios and elevation drops at rapids can be used as measures of long-term hydraulic effects of changes in debris fans that intersect the river. The constriction ratio described by Kieffer (1985, 1987, 1990) is the ratio of channel width at the narrow part of the rapid to the channel width of the pool upstream. Many rapids have a constriction ratio of 0.5, which may be an indicator of equilibrium (Kieffer, 1985, 1987, 1990).

As future debris flows deposit new material in a rapid, riverflows within the operational range of Glen Canyon Dam Powerplant will remove some of the new material. However, floods of 100,000 to 200,000 cfs or more probably would be necessary to remove the largest boulders from some debris fans, to increase the constriction ratio, and to decrease the elevation drop (Kieffer, 1985). For example, the 1966 debris flow on Bright Angel Creek (Cooley et al., 1977) deposited material in Bright Angel Rapid (RM 87.9) that could not be reworked completely by riverflows in the range of powerplant releases. The 1983-86 floods and sustained high releases returned this rapid to its pre-1966 condition but could not do the same at Crystal Rapid.

In 1966, a debris flow in Crystal Creek (RM 98.1) changed this previously minor rapid to one of the largest in the canyon. The debris fan temporarily dammed the river completely, and the channel that subsequently was cut through the debris fan was constricted to 25 percent of the upstream width. The 1983 flood release of nearly 100,000 cfs increased the constriction ratio to about 40 percent (Kieffer, 1985). Thus, Crystal Rapid will remain a formidable obstacle for river runners in the fore-seeable future. It serves as an example of what may happen at other rapids when they aggrade with new debris flows in the absence of large floods in the Colorado River. For purposes of this EIS, relative capacity to move boulders from debris fans will be used as an indicator of impacts.

Lake Deltas

The ultimate destiny of all reservoirs is to be filled with sediment. The coarser particles (mostly sand) carried into the reservoirs by tributaries are deposited as deltas in the tributary arms. Most of the finer particles (silt and clay) are carried far into the reservoir, where they settle out as lakebed deposits. Deltas fill the upstream parts of the tributary arms first, building toward the submerged mainstem channel and eventually the dam. Some sediment deposited in upstream parts of deltas may be transported downstream by floodflow when the reservoir is low.

The characteristics of a delta depend on such variables as quantity and size of inflowing sediment, reservoir operations, and hydraulics in the tributary arms. Other factors include erosion and vegetative growth along the margins of the tributary arms and turbulence and density currents in the reservoir. The longitudinal profile of a delta depends primarily on lake levels (determined by hydrology and reservoir operations) and the slope of the channel through the delta (Strand and Pemberton, 1982).

Lake Powell Deltas

Large deltas have formed in the major tributary arms of Lake Powell—Colorado, Dirty Devil, Escalante, and San Juan Rivers and Navajo Canyon (figure III-23). The upper surfaces of the deltas are important substrate for vegetation and riparian habitat and can affect recreational navigation and reservoir water quality. The shape and location of the deltas are affected mainly by the changing water surface elevation of Lake Powell. Sand and larger-size sediments generally settle in the upstream shallow parts of the tributary arms, forming deltas, while most silt and clay deposit in deeper areas downstream.

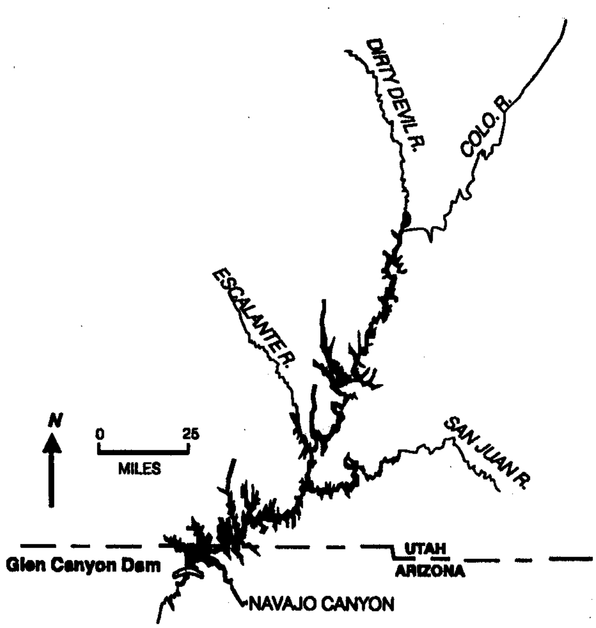


Figure III-23.—Lake Powell and major tributaries.

Lake Powell is located in the Colorado Plateau province, an area characterized by broad, cliff-edged mesas separated by narrow, steep-walled canyons. The lake occupies a long, narrow canyon of the Colorado River and the many slender arms of the tributaries. When Lake Powell is full (at elevation 3700 feet above sea level), the reservoir extends 186 miles up the Colorado River and 75 miles up the San Juan River, creating 1,960 miles of winding canyon shoreline. In 1986, Lake Powell had a total storage capacity of 26.2 maf and a surface area of 161,000 acres (Ferrari, 1988).

Longitudinal profiles of the original river bottom and the 1986 average bottom of the Colorado River are shown in figure III-24 and for the other major deltas in appendix D. Plots of delta profiles in reservoirs commonly exhibit a definite break at the delta crest. For purposes of this EIS, changes in elevation of the major delta crests will be used as indicators of impacts of the alternatives on Lake Powell deltas. Delta crest elevations and other characteristics of the major deltas, last measured in 1986 (Ferrari, 1988), are listed in table III-8.

The length of a delta exposed above the water surface can change dramatically with changes in lake elevation. For example, when Lake Powell elevation decreased 10 feet (from 3700 to 3690 feet), the length of the San Juan delta exposed above the water surface increased by more than 7 miles.

Each year from 1980 through 1987, Lake Powell filled or nearly filled (above elevation 3682 feet) but fluctuated 25 feet or more during the course of the year. During this period, sediments were deposited in the lake at relatively high elevations. Since 1987, the level of Lake Powell has receded, vast areas of the deltas have been exposed, and vegetation has become established. Vegetation tends to stabilize deltas by reducing the velocity of tributary floodflows which, in turn, causes more silt and clay deposition than would occur during normal flows.

In 1991, the San Juan River changed course through its Lake Powell delta. The river now has a waterfall (15- to 18-foot fall) near Piute Farms

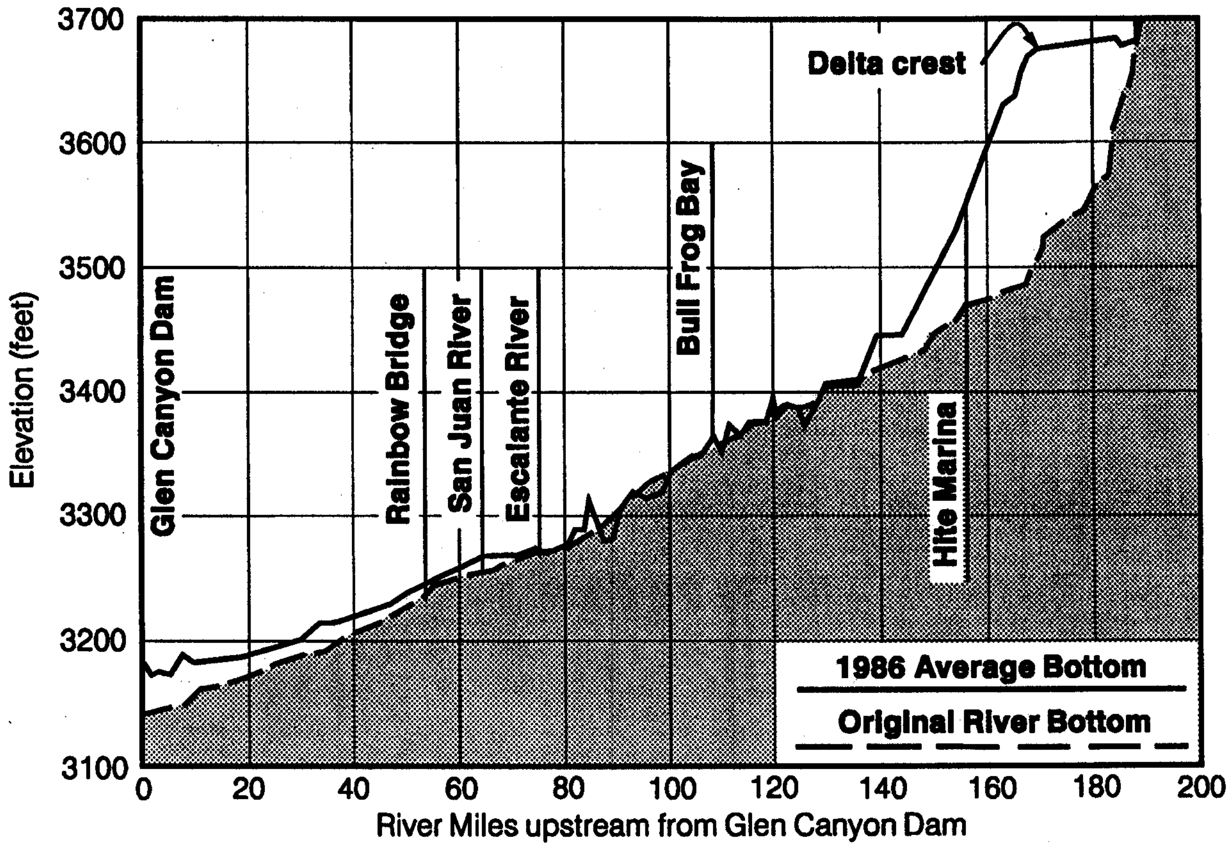


Figure III-24.—Profile of Colorado River bed in 1958-59 and 1986 (source: Ferrari, 1988).

Wash (approximately 53 miles upstream from the mouth of the San Juan River). The rock outcropping that creates this waterfall effectively prevents erosion of the delta upstream, even though the reservoir elevation has receded.

Table III-8.—Major Lake Powell sediment deltas

Tributary arm of Lake Powell	Delta crest elevation (feet)	Length upstream from delta crest (miles)	Maximum delta depth (feet)
Colorado	3670	19	170
Dirty Devil	3685	11	95
Escalante	3685	4	50
San Juan	3690	20	80
Navajo Canyon	3690	3.2	50

Estimates of the time required for complete reservoir sedimentation are best expressed in hundreds of years. The 1986 survey results indicated that about 868,000 acre-feet of sediment had been deposited below elevation 3700 feet since dam closure in March 1963. This total sediment volume represents a 3.2-percent decrease in total storage capacity in 23 years. At that rate, the estimated time to completely fill the reservoir with sediment would be more than 700 years; however, sediment would reach the level of the penstocks at the dam in about 300 to 500 years.

Of the 868,000 acre-feet of sediment in Lake Powell, 54 percent was estimated to be in the Colorado River arm, 32 percent in the San Juan River arm, and 14 percent in the remaining tributary arms. Rising water in Lake Powell has caused some slumping of formerly stable cliffs and slopes. The total volume of slumped material is difficult to measure, but it is estimated to be small compared to the volume of sediment carried by the major tributaries.

The chemical quality of sediments deposited in Lake Powell would be an important consideration in the design of a sand augmentation program. See the discussion of water quality in the preceding WATER section.

Lake Mead Delta

All sediment transported into Lake Mead by the Colorado River and tributaries is trapped in submerged canyons and valleys as deltas and lakebed deposits. The magnitude and pattern of dam releases and tributary floodflows may affect the rate of aggradation and the configuration of the deltas. If changes are large enough, marsh and riparian habitat and navigation may be affected (see VEGETATION and RECREATION in this chapter).

The coarsest sediment (mainly sand) begins to drop out of suspension at the point where the Colorado River intersects Lake Mead. The location along the river where this occurs depends on the level of the lake, which is controlled primarily by releases from Glen Canyon Dam and Hoover Dam. The maximum recorded lake level, about 1220 feet above sea level, corresponds approximately to the elevation of the riverbed downstream from RM 235 (Bridge Canyon) in Lower Granite Gorge. River mile 236 is the approximate upper end of the Colorado River delta, which presently extends past Pierce basin to about RM 290. River and lake currents carry large volumes of fine sediment far into Lake Mead. Lakebed deposits extend all the way to Hoover Dam at RM 355 (figure III-25).

Downstream from RM 236, riverflow and sediment deposition and erosion are affected by the level of Lake Mead. Ranges in stage for daily and annual flow fluctuations are substantially less than those upstream. All former rapids have been submerged. Recirculation zones that create and maintain sandbars and return-current channels upstream generally are absent in this reach at flows within powerplant capacity. The backwater effect of the lake causes river velocities to decrease, and more of the finer-size sediment settles out. Channel margin deposits have larger percentages of silt and clay than upstream sandbars. Sediment deposited when the lake level is

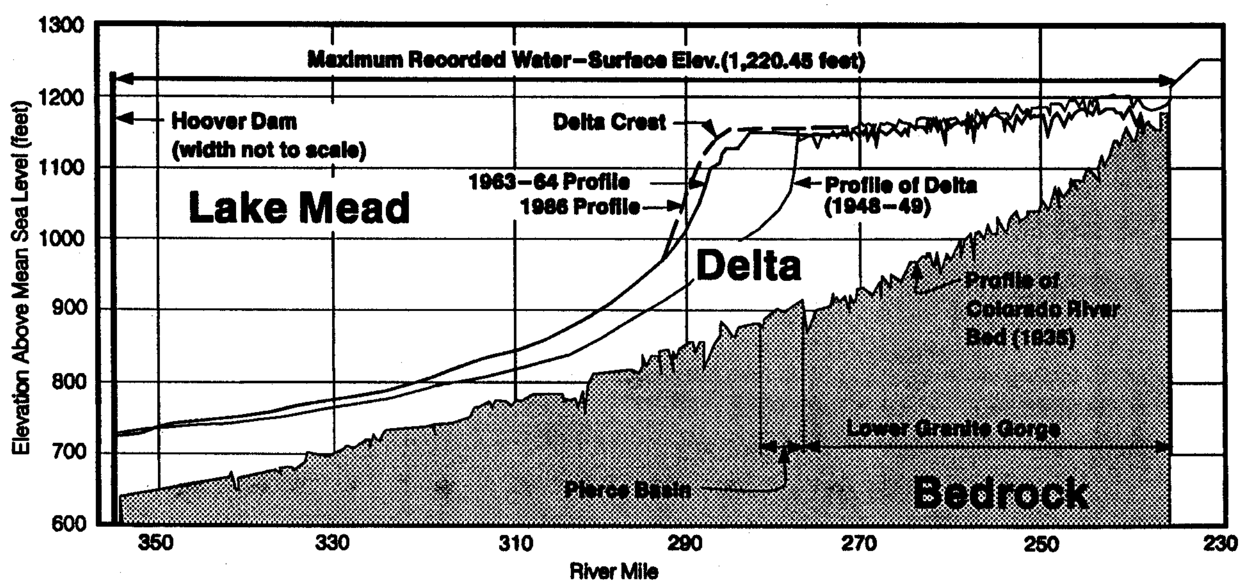


Figure III-25.—Profile of Colorado River bed and sediment deposits in Lake Mead. Vertical scale is exaggerated (modified from Lara and Sanders, 1970).

relatively high is exposed to erosion during subsequent periods when the lake level is lower. Exposed deposits tend to have steep faces (many nearly vertical), which are more susceptible to erosion; bank caving is common. Without replenishing flood releases, predam flood deposits of sand and finer sediment above high lake level are subject to long-term erosion by wind and local runoff.

The shape of the Colorado River delta profile is affected mainly by lake level. The delta surface in Lower Granite Gorge and upper Lake Mead is relatively flat and is mostly sand. The delta face dips steeply, constantly building towards Hoover Dam as new sediment arrives. The elevation of the delta crest where the slope changes from relatively flat to relatively steep (see figure III-25) can be used as an indicator of changes in the delta. According to a 1948-49 survey of the delta deposits (Smith et al., 1960), the delta crest was at RM 278; by 1963-64 (Lara and Sanders, 1970), it had progressed to RM 286. In 1963-64, the maximum thickness (depth) of the delta was about 250 feet. The lakebed deposits consisted of 12 percent sand, 28 percent silt, and 60 percent clay (Lara and Sanders, 1970). The delta contains a much higher percentage of sand.

Lara and Sanders (1970) estimated that the closure of Glen Canyon Dam extended the life of Lake Mead to about 500 years. Average accumulation of sediment in Lake Mead was estimated by Smith et al. (1960) to be about 100,000 acre-feet per year during the first 14 years after closure of Hoover Dam in 1936. Lara and Sanders (1970) estimated about 91,000 acre-feet per year during the first 30 years, for a total accumulation of about 2.72 maf. Since construction of the dam, the rate of accumulation has declined substantially.

FISH

The present Colorado River aquatic ecosystem downstream of Glen Canyon Dam differs from the "natural" system that predated human influence. The natural ecosystem contained communities of native species that evolved in a heavily sedimented river subject to extreme seasonal variability in flow and temperature. This ecosystem was characterized by relatively low productivity and species diversity. Eight native fish species were known to have inhabited Glen and Grand Canyons.

Human influence began when warmwater non-native fish species were introduced, possibly as early as the late 1800's (Carothers and Brown, 1991). These species would have affected the abundance of native fish through competition and predation. However, due to the very limited data collected prior to construction of Glen Canyon Dam, the predam distribution and relative abundance of native and late non-native fish is largely unknown and subject to much speculation. Limited sampling in Glen Canyon by Woodbury et al. (1959) and McDonald and Dotson (1960) resulted in only two fish species reported from the Colorado River mainstem: channel catfish, a non-native (about 90 percent), and flannelmouth sucker, a native (about 10 percent). Tributaries had a more diverse fish assemblage, including 20 species: 14 non-native, 6 native. Flannelmouth sucker and speckled dace, both native species, dominated.

Construction of the dam permanently altered the Colorado River downstream, creating a relatively clear river with near constant year-round cold temperatures and daily fluctuating, but seasonally modulated, flows. The result has been a more productive aquatic ecosystem with a higher species diversity than existed before the dam. The dam shifted the basis for river productivity from material of terrestrial origin to predominantly algal production.

This river ecosystem is a mixture of native and non-native plant and animal communities. It is characterized by a food base (the *Cladophora*-diatom-*Gammarus* food chain) and by introduced coldwater fish (predominantly rainbow trout) that were only present in cold tributaries before the dam. These dam-induced river conditions are most evident in the upstream reaches of the mainstem closest to the dam. With distance downstream, the river tends to become more turbid and slightly warmer, productivity decreases, coldwater fish decline in abundance, and warmwater fish increase in abundance.

Water temperatures throughout the mainstem (with possible minor exceptions at warm springs) limit the possibility of successful reproduction by warmwater fish, including the five native fish still present in this portion of the Colorado River system. Of these five species, two are relatively common, one is a candidate for Federal listing under the Endangered Species Act, and two are protected under the Endangered Species Act. Decline of the native fish in Glen and Grand Canyons is attributed to hostile postdam river conditions and the presence of non-native competitors and predators. Tributaries to the Colorado River in Grand Canyon are used by native fish species for spawning and rearing of young.

Because this EIS deals with water release patterns and to some extent water quality, aquatic biological resources would be directly affected by decisions based on EIS findings. Relatively subtle changes can have direct and indirect effects on native fish, coolwater and warmwater non-native fish, and trout below Glen Canyon Dam.

The ability of fish populations to persist and thrive depends on how well their life requirements are met for each life stage. Life stages include newly spawned eggs, embryos, fry and larval stages, juvenile, and adult—including the ability of adults to successfully reproduce. Important life requirement factors include:

- Presence of physical characteristics (habitat) that allow for fish to reproduce and survive (recruit)
- Presence of a food supply adequate for fish growth
- Ability to avoid or minimize competition and predation that otherwise could limit or threaten a fish population

The size and health of fish populations of Glen and Grand Canyons are a result of how well the life requirements of each life stage are met.

Aquatic Food Base

The physical characteristics of water in Glen and Grand Canyons have changed considerably since closure of Glen Canyon Dam because of the effects of Lake Powell and reservoir water releases (see discussion of water quality under WATER). Previously, the aquatic food base was based on coarse organic material carried into the river from the drainage basin. Today, that coarse material is trapped in Lake Powell, and the benthic algae in the river has become an important part of the aquatic food base. Productivity of the aquatic food base downstream of the dam is now determined by how and when water is released and by what that water carries in it combined with the organic material contributed by tributaries.

Releasing water from deep below the surface of Lake Powell reduces the variation in temperature, water clarity, total dissolved solids, and nutrients that were typical of the Colorado River prior to dam construction (Maddux et al., 1987). Nutrient concentrations and proportions in the river through Glen and Grand Canyons are determined largely by the reservoir depth from which water is released. Therefore, the productivity of the Glen Canyon tailwater is dependent on Lake Powell as a nutrient source and a sediment trap.

In general, Lake Powell traps important nutrients like phosphorus and nitrogen as it traps incoming suspended sediments. But phosphorus and nitrogen flowing in from the huge drainage basin of the Colorado River above Lake Powell are two of the keys to biological productivity of the reservoir and the river below it (Maddux et al., 1988). Organisms that inhabit Lake Powell also consume a portion of incoming available phosphorus. Some phosphorus—either dissolved or as part of the minute planktonic plants and animals of Lake Powell—is released into the river below the dam. The concentration and proportion of this important nutrient in relationship to other nutrients is influenced by the depth from which water is released (Angradi et al., 1992). It has been suggested by several authors that phosphorus is potentially the limiting plant nutrient in the system (Maddux et al., 1988; Angradi et al., 1992).

Cladophora and Associated Diatoms

Cladophora, along with the organisms that live on it, forms the basis of a highly productive food chain below Glen Canyon Dam. Discharges from the dam are clear, so light penetrates deeper into the water and permits the filamentous green alga *Cladophora glomerata* (Angradi et al., 1992; Pinney, 1991) to capitalize on the available nutrients released through the dam. *Cladophora* and diatoms that live on it form the habitat for an important community of aquatic invertebrates dominated by the shrimp-like amphipod *Gammarus lacustris* and by chironomid and other fly larvae.

The importance of *Cladophora* is increased by the diatoms that encrust it. These diatoms carry the important nutritional material that benefits invertebrates like *Gammarus*, which selectively consume some diatoms without consuming the *Cladophora* (Pinney, 1991). Fish like rainbow trout and humpback chub consume *Cladophora* and benefit directly or indirectly from the energy-rich diatoms that live on it.

Among other variables, the distribution of *Cladophora* depends on light penetration, exposure to air, and available substrates (exposed rock such as cliff faces and large cobbles where *Cladophora* can attach itself) (Pinney, 1991). The general trend in the distribution of *Cladophora* suggests that the upper reaches of the river are very productive, while production declines downstream (Usher et al., 1988; Blinn et al., 1992; Angradi et al., 1992; Yard et al., 1993). This may be explained by a combination of factors:

- Increased turbidity below the Paria and Little Colorado Rivers and resulting changes in light penetration
- Declining available phosphorus as waters pass downstream
- Canyon width

Usher et al. (1987) suggested that seasonal growth of *Cladophora* might be regulated by light or nutrient levels in waters of relatively constant temperature. Blinn et al. (1992) showed that wide canyon reaches produced higher standing crops than narrow reaches, and Yard et al. (1993) showed that wider reaches had generally greater light penetration, at least partially explaining that phenomenon. Yard et al. (1993) also indicated that suspended sediment plays a significant role in limiting light penetration and supported Pinney's (1991) speculation that seasonal changes in light intensity and fluctuating flow levels are the most regulating factors for *Cladophora*.

At flows of 5,000 cfs or less, enough light penetrates to the bottom of the river channel to allow *Cladophora* to photosynthesize along the length of Grand Canyon (Yard et al., 1993). As river stage increases, the depths where *Cladophora* can thrive may decrease. Yard et al. (1993) also showed that at higher flows (15,000 cfs), light would not penetrate to the channel bottom, potentially shading out algal growth along a portion of the channel bottom in reaches below about RM 150. Tributaries contribute turbid inflows, which also affect the zone where *Cladophora* can live. As a result, this zone is measurably narrower in the mainstem below the confluence of the LCR than it is above the confluence with the Paria River.

The prolific growth of *Cladophora* has established the upper portion of the river as an important production area that feeds immediate downstream reaches with particulate organic matter in the form of *Cladophora* and aquatic invertebrates in the current as drift (Maddux et al., 1988; Angradi et al., 1992). In studies conducted at Lees Ferry, increasing flows significantly increased the standing crop and biomass of invertebrates but not algae in the drift (Leibfried and Blinn, 1987).

Compared among fluctuating flow months and steady flow months with lower discharges, drift densities of *Cladophora* were highest during June 1985, when high steady flows of about 35,000 cfs were released from Glen Canyon Dam (Leibfried and Blinn, 1987). These data contrast with those of Blinn et al. (1992), who found that periods of steady flows resulted in significantly less drift of *Cladophora* and associated invertebrates than periods of fluctuating flows during interim operations.

Cladophora is the dominant alga in the reach below the dam (Blinn et al., 1992). Algal production is maintained because of the clear, cold releases from the dam. Downstream, a blue-green alga (*Oscillatoria* sp.) becomes codominant in the middle canyon and dominant in the lower canyon (figure III-26), likely because of its tolerance of exposure and lower light levels (Blinn et al. 1992). Inundation with cold, nutrient-carrying water permits abundant growth of *Cladophora*, while exposure can cause mortality (Angradi and Kubly, 1993). For example, Pinney (1991) recorded highest biomass of *Cladophora* from areas beneath the fluctuation zone and less biomass from areas exposed by large daily fluctuations. Usher and Blinn (1990) reported that exposure of more than 12 hours can cause decreases in *Cladophora* biomass from drying (summer), freezing (winter), or ultraviolet light damage. Angradi found that even 6 to 8 hours of exposure caused significant decreases in *Cladophora* biomass (Angradi and Kubly, 1993; Arizona Game and Fish Department, 1993).

Once affected, *Cladophora* is not very resilient. Pinney (1991) suggested recovery times of 2 weeks to 1 month under steady flow conditions. Other researchers have suggested that "disturbances severe enough to destroy the periphyton (*Cladophora*) will have protracted (several months to greater than 1 year) ecosystem level effects under fluctuating flows" (Angradi et al., 1992;

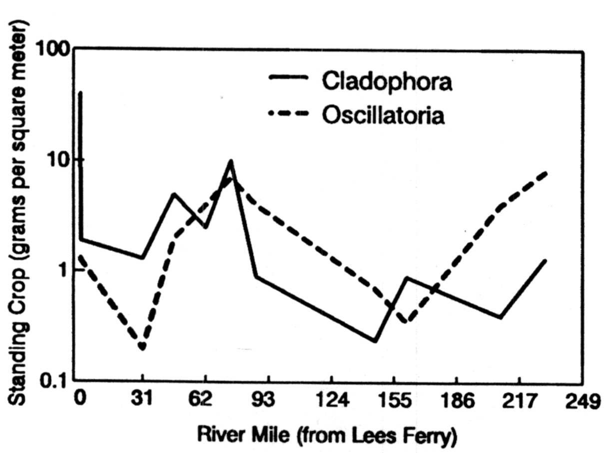


Figure III-26.—Cladophora declines with distance from the dam and Oscillatoria becomes codominant (source: Blinn et al., 1992).

Angradi and Kubly, 1993). Angradi and Kubly (1993) reported that gross primary productivity of permanently inundated *Cladophora* was 10 times that of the surviving algae in the zone subject to daily fluctuation.

In summary, *Cladophora* depends on and is susceptible to influences of dam operations. The cold, clear water released from the dam promotes its establishment, but fluctuating river stages result in stranding of some *Cladophora* for varying periods. The GCES (Leibfried and Blinn, 1987; Usher et al., 1988; Blinn et al., 1992; Angradi et al., 1992; Angradi and Kubly, 1993) showed that *Cladophora* isolated out of the water for more than 12 hours (and perhaps as little as 6 hours) would dry out and die. Much of the drift that feeds fish and other aquatic organisms is *Cladophora*—either dead from drying or scoured loose by water flow—and invertebrates forced to move to avoid drying. That drift also settles to the bottom in eddies and backwater areas where it is fed on by organisms and recycled through the food chain.

Other Aquatic Food Sources

The drift also contains zooplankton that originate from Lake Powell (Haury, 1988) and consequently may reflect the level at which water is withdrawn from the reservoir. Years in which the reservoir is quite low may see shifts in the composition and density of these plankton as waters are withdrawn from layers closer to the surface. These microscopic animals are important food sources for fish and other aquatic organisms. They typically are important to recently hatched larval or juvenile fish (trout, flannelmouth sucker, and bluehead sucker) (Haury, 1988; Maddux et al., 1987; Arizona Game and Fish Department, 1994).

Larger aquatic invertebrate organisms (macroinvertebrates) are extremely important members of the aquatic community (and aquatic food base) of the Colorado River and may even bridge the gap into the terrestrial community. *Gammarus lacustris* has become an important member of the macroinvertebrate community. *Gammarus* was first introduced into Bright Angel Creek during the 1930's by the NPS and began colonizing the river shortly thereafter (Carothers and Minckley, 1981). *Gammarus* and a species of snail (*Physa* sp.) were also introduced to the river below Glen Canyon Dam by the Arizona Game and Fish Department (AGFD) during 1967-68 as a food source for the developing trout fishery (Arizona Game and Fish Department, 1968). Other important species probably already resided in the Colorado River, including aquatic worms (*oligochaetes*), chironomid midges, and buffalo gnats (Carothers and Minckley, 1981).

Researchers have found that wide canyon reaches (Blinn et al., 1992), eddies, and backwater areas are very important to the production of aquatic invertebrates (Carothers and Minckley, 1981). These areas of slower current tend to accumulate organic material from the drift (detritus) that forms the basis for their food source. In addition to habitat, the constant cold water temperature influences the diversity and density of these invertebrates.

Aquatic invertebrate drift appears to be controlled by discharge from Glen Canyon Dam. Valdez et al. (1992) observed little drift of invertebrates during steady flows under interim operations. Significantly lower drift density for macroinvertebrates was found in samples collected around the LCR during interim operations than before (Valdez et al., 1992). At Lees Ferry, Blinn et al. (1992) found significantly greater drift densities for macroinvertebrates during fluctuating flows than during steady flows.

In total, the aquatic food base of the Colorado River below Glen Canyon Dam is a community of algae and invertebrate animals that forms the powerhouse for the aquatic ecosystem and, in some cases, an energy transfer route between the aquatic and terrestrial ecosystems. Solar energy, captured by *Cladophora* and the diatoms that encrust it, is transmitted through the food chain to many invertebrate and vertebrate species. The amount of energy that can be captured and made available to the food chain appears to be determined by the area of cobble bars inundated on a reliable basis (Blinn et al., 1992). Reliable minimum stage (the river stage that can be relied upon over extended periods of time) and reliable wetted perimeter together become an important index of algal biomass and reflect the strength of the aquatic food base.

Algal colonization experiments by Angradi (Angradi et al., 1992) illustrated the concept of reliable minimum flow by anchoring sandstone tiles in the river to measure the accumulation of growing *Cladophora* at different river stages. Figure III-27 shows the accumulation of algae at different river stage levels (-10.5-mile bar above Lees Ferry) during the spring of 1991. The figure illustrates the ability of the aquatic food base to develop in response to minimum flow. Even tiles that were dewatered only 20 to 30 percent of the time showed less accumulation of attached algae than tiles that were always inundated.

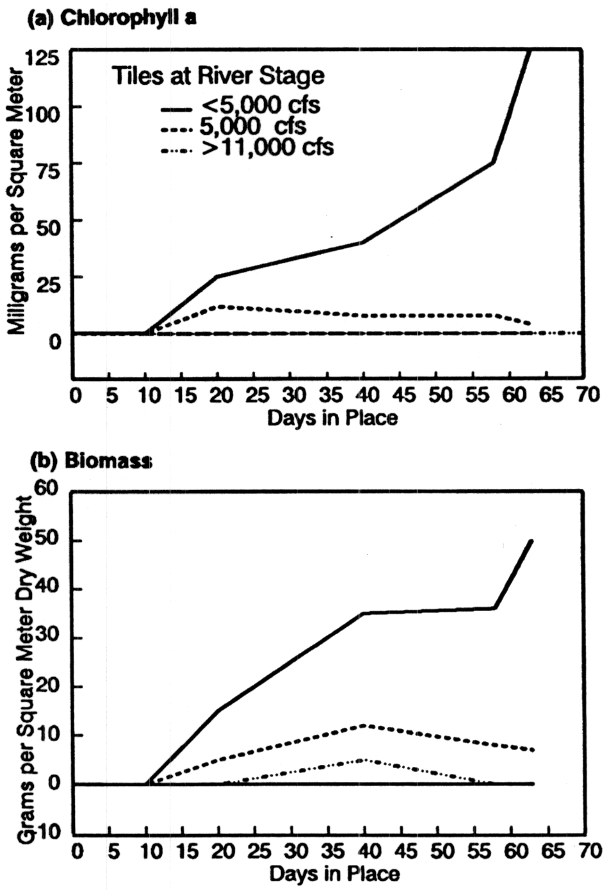


Figure III-27.—Accumulation of Cladophora measured as (a) Chlorophyll a, and (b) in biomass. Tiles placed below 5,000 cfs were always inundated (modified from Angradi et al., 1992).

Because of its sensitivity to flow, reliable minimum stage and reliable wetted perimeter in the Glen Canyon are used as indicators of effects to the aquatic food base.

Native Fish

The native fish of the Colorado River system make up one of the most unusual assemblages of fish specially adapted to their environment found anywhere in the world. These warmwater fish have adapted to the challenge of living in a highly variable environment subject to seasonal extremes of flow and water temperature, short-term flow changes from local storm events, and highly turbid conditions. Recent history has introduced new challenges by modifying the fish's evolutionary environment. Construction of major dams has modified flow extremes, cleared and cooled the waters, converted rivers to lakes, and cut off natural movement corridors. In addition to these physical modifications, fish not native to the Colorado River drainage have been introduced and compete with and/or prey upon the natives.

The cold, clear, fluctuating dam releases have caused declines in the number of kinds of warmwater fish, both native and non-native, that reside in Glen and Grand Canyons (Minckley, 1991).

Of the eight species of native fish, three have been extirpated from Glen and Grand Canyons, two are listed as endangered and one as a candidate species under the Endangered Species Act, and the remaining two species are relatively common (see table III-9). The Colorado squawfish, the roundtail chub, and the bonytail chub are considered extirpated from Grand Canyon, and the razorback sucker is very rare. The population of humpback chub in Grand Canyon is the largest of five remaining populations and the only population of the species in the Lower Colorado River Basin.

Endangered Species

Humpback Chub (Federally Endangered). The Grand Canyon population of the humpback chub is found in Marble and Grand Canyons, including several tributaries to the mainstem river. Mainstem studies have found the humpback chub more abundant in the reaches immediately upstream and downstream of the LCR (Kaeding and Zimmerman, 1983; Maddux et al.,1987; Valdez, Masslich, and Leibfried, 1992). The possibility exists that humpback chub found in the Middle Granite Gorge and lower Grand Canyon may represent a separate population. The genetic

Table III-9.—Native fish of Glen and Grand Canyons

Species	Status	Occurrence
Humpback chub	Federal endangered State endangered	One population in the Lower Colorado River in Grand Canyon
Razorback sucker	Federal endangered State endangered	Rare in Grand Canyon
Colorado squawfish	Federal endangered State endangered	Extirpated from Grand Canyon
Bonytail chub	Federal endangered State endangered	Extirpated from Grand Canyon
Roundtail chub	Being considered for listing	Extirpated from Grand Canyon
Flannelmouth sucker	Being considered for listing	Still common in Glen and Grand Canyons
Bluehead sucker	No special status	Still common in Grand Canyon
Speckled dace	No special status	Widely distributed in Arizona; common in Grand Canyon

identity of the humpback chub throughout the Grand Canyon is being investigated in a basinwide study of the genus *Gila* (U.S. Fish and Wildlife Service, 1991a).

The humpback chub evolved under seasonally variable environment with seasonally changing temperatures, large annual spring-summer floods, and short-term rainfall flood events. Since the closure of Glen Canyon Dam, the species has experienced daily stage fluctuations in a consistently cold environment.

Habitats of adult and juvenile humpback chub in the Colorado River mainstem have not been satisfactorily determined, and response of adult humpback chub to daily fluctuations is the subject of an ongoing radio tracking research study in the Grand Canyon (Valdez, Masslich, and Leibfried, 1992). Preliminary information from that study and from studies conducted in the upper Colorado River (Valdez and Nilson, 1982; Kaeding et al., 1990) found humpback chub have an affinity for specific locations and use habitats such as eddies, return-current channels, and runs. In Grand Canyon, 48 humpback chub moved an average of 0.8 mile over a period of 5 to 149 days (Valdez, Masslich, and Leibfried, 1992).

Daily habitat use and movement of adult humpback chub are influenced by time of day, riverflow and fluctuations, and turbidity. Movements of humpback chub in response to changes in flow may be due to increased availability of food or to changes in the above habitats (Valdez, Masslich, and Leibfried, 1992). In February, adults were found to form aggregations in eddies and deep pools, while in March through May they moved toward the mouth of the LCR, apparently to stage for spawning (Valdez and Hugentobler, 1993). Valdez and Hugentobler (1993) hypothesized that these movements were triggered by daylight length. The lower 9 miles of the LCR are important habitat for the humpback chub (Kaeding and Zimmerman, 1983).

Razorback Sucker (Federally Endangered). The razorback sucker is rare in the Grand Canyon reach of the Colorado River, with only a few captured during recent surveys (1984-90). It is uncertain whether they reproduce in the area. While the historical status of the species is unknown, the canyons may have been refuges from high water temperatures or droughts that occasionally plagued the basin (Minckley, 1991). Historic habitat for the species may have included large backwaters and oxbows of the Colorado River and its large tributaries. While successful natural reproduction and recruitment in riverine habitats has not been documented recently, the species does reproduce and recruit in ponds and other similar habitats where there are no fish predators (Minckley et al., 1991).

Razorback suckers, like other "big river" endangered fish, are long-lived. Ages of individuals from Lake Mohave (downstream from Lake Mead), determined from polished and sectioned ear bones, range from 24 to 44 years (McCarthy and Minckley, 1987). Many of these fish would have hatched at or prior to reservoir impoundment.

Adult razorback suckers are found in the Colorado River above Lake Powell and in the lower San Juan River. Recent collections of razorback suckers from the western portion of Lake Mead (Sjoberg, written communication, 1990) have renewed investigations and interest in increasing this limited population in Lake Mead. An enhanced Lake Mead population would have access to over 250 miles of habitat in Grand and Marble Canyons.

Flannelmouth Sucker (Federal Candidate). The flannelmouth sucker is now listed as a category 2 species under the Endangered Species Act. The species is found in the Paria and Little Colorado Rivers; Shinumo, Bright Angel, Kanab, and Havasu Creeks; as well as in various locations in the mainstem (Arizona Game and Fish Department, 1993). During GCES Phase I, most juvenile and larval flannelmouth suckers were collected in the lower reaches of the river, while larger adults were found in the upper reaches—including the reach above Lees Ferry (Maddux et al., 1987). Recent collections in the Paria River have found flannelmouth suckers in reproductive condition, but survival of young-of-year life stages has not been documented (Gorman et al., 1993; S.J. Weiss, 1993). Larval through adult-size flannelmouth suckers are found in the LCR (Arizona Game and Fish Department, 1993).

Other Native Fish

Other native fish of the Colorado River through Glen and Grand Canyons include the speckled dace and bluehead sucker. Bluehead sucker and speckled dace are most common in the lower reaches of the river (Maddux et al., 1988) and use tributaries extensively (Maddux et al., 1988; Allen, 1993; Gorman et al., 1993; Otis, 1993; Mattes, 1993). Native fish depend on the diversity of habitats available in the river system. Backwaters, eddies, tributaries, and the mouths of tributaries appear to be essential to their life cycles, particularly reproduction and recruitment.

Water temperature is an overriding constraint for native fish in the Colorado River mainstem (figure III-28). Minckley (1991) indicated that "water temperature too low for reproduction or larval development clearly results in loss of populations and is the culprit excluding natives from Marble/Grand Canyons." In discussing the larger causes of collapse of native fish populations throughout the basin, he indicates that "introduction and enhancement of non-native fishes as a result of river alterations forced the native species to extinction." At the same time, the "cold water of today is as large a deterrent for non-native warmwater species as for natives" (Minckley, 1991). Because the temperature of dam releases is not altered by any of the alternatives, other factors become important, including 1) access to tributaries for reproduction and 2) availability of warmer, low velocity environments in the main channel for rearing of young fish flushed from the tributaries.

General information on the biology and habitat requirements for the humpback chub, razorback sucker, and other native fish of the Grand Canyon can be found in the individual species accounts by Minckley (1991); the *Humpback Chub Recovery Plan* (U.S. Fish and Wildlife Service, 1990b); a compendium of existing information on the four "big river" endangered fish (Miller and Hubert, 1990); and the chapter on management of the razorback sucker by Minckley et al. (1991). This last reference also includes information on native and endangered fish in the Western United States.

Mainstem Reproduction

Water temperatures in the river are too low to allow development of eggs spawned there, which

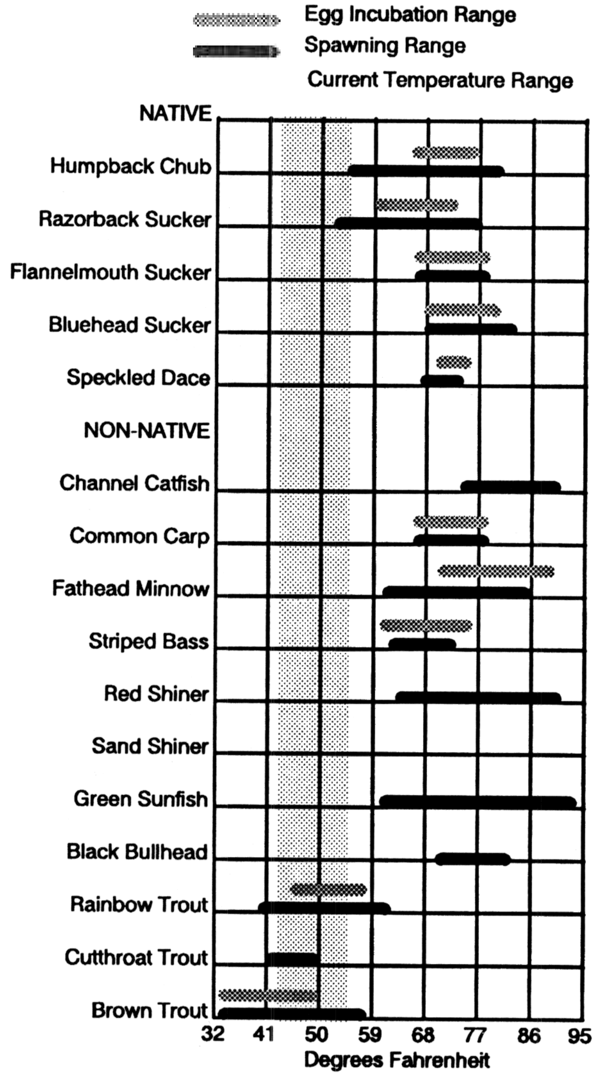


Figure III-28.—Spawning and egg incubation temperatures for native and non-native fish. Shaded area denotes current temperature range.

directly limits successful reproduction to tributaries (Hamman, 1982; Marsh, 1985; Valdez, 1991; and Maddux et al., 1987). Under extended drought conditions when the elevation of Lake Powell is very low (approximately 5 percent of the time), the released water may be slightly warmer than under normal conditions. Therefore, access to tributaries and tributary mouths for spawning is of primary importance to these species. Major tributaries (primarily the Paria and Little Colorado Rivers and Kanab Creek, but also Shinumo, Bright Angel, Diamond, Havasu, and Spencer Creeks) appear to contribute to native fish productivity.

Besides water temperature, other environmental conditions important to spawning and egg development include streamflow and habitat (Valdez, Masslich, and Leibfried, 1992); however, quantities or measures of these conditions have not been verified.

Tributary Reproduction

Low flows of 1,000 cfs (Labor Day until Easter) or 3,000 cfs (Easter until Labor Day) may limit access to tributaries (except perhaps the LCR), especially at night, when adult spawners likely would be moving. Indirectly, this fluctuation pattern may further limit reproduction of native fish. Evaluation of aerial videography indicates that flows above 5,000 cfs are clearly sufficient to allow access to major tributaries for spawning (with the exception of Havasu Creek, which is inaccessible under all normal operational flows due to the presence of a prominent physical barrier) (Arizona Game and Fish Department, written communication, 1993). Other detailed accessibility surveys have not been performed on any major tributary. Reliable minimum flow is used as the indicator for accessibility to tributaries for reproduction.

The cold water released from the dam limits egg and larvae survival of most native fish in the mainstem, and successful reproduction and development of early life stages of humpback chub in the Grand Canyon is known only in the LCR. Under interim operations, there has been some evidence of limited chub reproduction in the mainstem in the vicinity of RM 30 in association with warm springs (Valdez and Ryel, in preparation; Arizona Game and Fish Department, 1994).

Eggs and larval fish can be flushed into the mainstem by periodic floodflows in the tributaries. Angradi et al. (1992) reported measurable drift of native fish eggs and larvae from the LCR near its mouth. Temperature shock to these flushed eggs and larval fish may be lethal (Hamman, 1982; Marsh, 1985; Maddux et al., 1987; Hendrickson, 1993; Lupher and Clarkson, 1993). Research with larval humpback chub demonstrated that coma or reduced activity was induced by cold shock (from 68 °F to 50 °F), with potentially severe implications for survival (Lupher and Clarkson, 1993). It was further demonstrated that growth of larval and juvenile chub was markedly reduced at 50 °F and 58 °F. Thus, there is some dependence on tributaries to accommodate the earliest life stages of native fish, and mainstem rearing habitats would be limited to relatively warm refuge areas (backwaters).

Very young native fish are found in specialized mainstem habitats, suggesting that refuge areas play a role in recruitment of native fish. Humpback chub hatched in the LCR in the spring grow to sufficient size to be able to withstand the cold temperatures of the mainstem by October (Maddux et al., 1987). This life stage and 1-year-old humpback chubs have been found in the mainstem in backwater eddies, connected backwaters, and nearshore channel margins (Angradi et al., 1992; Valdez, Masslich, and Leibfried, 1992). Backwaters, eddies, and nearshore areas are the habitats used by early life stages of humpback chub in the Upper Colorado River Basin (Holden and Stalnaker, 1975; Tyus et al., 1982). The AGFD (Maddux et al., 1987; Angradi et al., 1992) found similar habitats important to early life stages of native fish, particularly backwaters connected to the mainstem during June through September. Compared to mainstem eddy habitats, backwaters offer higher zooplankton and benthic invertebrate densities (Kubley, 1990; Arizona Game and Fish Department, 1994), lower current velocities, and refuge from predatory fish. Other mainstem nearshore habitats, adjacent to riffles and runs with cobble and gravel substrates, are very productive. Data reported by Leibfried and Blinn

(1987) show a fivefold increase over backwaters in invertebrate density in these habitats.

Mainstem Recruitment and Growth

Return-current channel backwaters (slackwater areas partially isolated from the main channel) and shallow nearshore areas along the main channel are important refuges for young native fish exiting tributaries and serve as nursery areas in the mainstem. Native fish require these shallow, productive, warm refuges during their first year of life. Maddux et al. (1987) found that young-of-year humpback chub, flannelmouth suckers, bluehead suckers, and speckled dace used backwaters extensively. They found these areas to be very important on a seasonal basis, when the sun can warm the backwater above ambient river temperature.

Angradi et al. (1992) illustrated the morphology of return-current channel backwaters (see figure III-17), emphasizing that during lower, steadier flow, return-current channel backwaters showed potential for warming. Maddux et al. (1987) found that in summer months during periods of steady flow, some backwaters reached nearly 77 °F, while main channel waters remained near 50 °F. Arizona Game and Fish Department (1993) reported similar summertime warming trends. They also suggested that rather shallow, return-current channel backwaters would cool to near ambient river temperature at night even if the backwater remained relatively stable. The combination of increased temperature and concentration of organic material makes return-current channel backwaters relatively productive zones capable of providing forage for young native fish during summer months.

Return-current channel backwater areas are most abundant at lower flows. Pucherelli (written communication, 1987) found that the number and area of backwaters between RM 52 and RM 72 increased as flow decreased. As river stage increases, return-current channel backwaters become eddies. Recent examination of aerial videotape suggests similar trends, with a nearly threefold increase in the numbers of backwaters as flows decline from 15,000 cfs to 5,000 cfs (J. Weiss, 1993; McGuinn-Robbins, 1994). Return-current channel backwater habitats are functionally eddies at flows above 10,000 cfs.

Return-current channel backwaters have a tendency to fill with sediment through time. Excavation of return-current channel backwaters takes place in eddies during periods of high flow (Pucherelli, written communication, 1987). The exact flow magnitude necessary to maintain or restore filled backwaters is not known. Comparisons of backwater counts at near 5,000-cfs flows made during postflooding events in 1985 with backwater counts made during 5,000-cfs releases in 1991 showed nearly an 80-percent decline in the number of backwaters over the 6-year period (J. Weiss, 1993). This decline is attributed to backwaters filling with sediment and vegetative growth. Natural flooding events triggered by winter flooding in the LCR in 1993 resulted in creation or restoration of some backwater habitats (McGuinn-Robbins, 1994).

Daily fluctuations destabilize backwaters (Valdez, 1991; Angradi et al., 1992) by alternately draining and refilling them with cold mainstem water. Juvenile native fish forced into the mainstem may suffer direct mortality from several causes: temperature shock; reduced growth resulting from high energy expenditures associated with high velocity, cold waters; and exposure to non-native predators (Arizona Game and Fish Department, 1993; 1994).

Food resources for adult native fish in Grand Canyon are generally not considered limiting. Adult humpback chub feed mostly on aquatic invertebrates, particularly immature chironomids, simuliids, and *Gammarus* (Kaeding and Zimmerman, 1983; Valdez and Hugentobler, 1993). The algae *Cladophora* is frequently found in humpback chub stomachs and may serve as a source of diatoms or other food items (Kaeding and Zimmerman, 1983; Kubly, 1990). The adult native suckers are adapted to somewhat different foraging strategies: flannelmouth feeding on small insects and benthic animals, bluehead scraping bottom substrates, and razorbacks sieving plankton or detritus (Maddux et al., 1987; Minckley, 1991).

Food resources for early life stages of native fish are of more concern. Studies by the Arizona Game and Fish Department (1993) in the LCR suggest a dependence on macroinvertebrates in drift. Foraging by these larval fish (humpback chub, flannelmouth sucker, bluehead sucker, and speckled dace) in the LCR appeared to be selective for aquatic insects.

The indicator for mainstem recruitment and growth of young native fish is a combination of minimum reliable stage during the summer rearing period (principally July through September) and daily range of fluctuation. High daily minimum flows (above 10,000 cfs) reduce the numbers of return-current backwater habitats, and daily fluctuations in river stage have the potential to destabilize backwaters by alternately flooding and drying them. Adult native fish are more tolerant of low temperature and variable flow than are larvae and juveniles. Nonetheless, temperature, availability of food items, and energy expenditures can constrain growth. Because the number of eggs produced by a female depends on the size and condition of an individual, reduced growth can influence the reproductive potential of an individual fish and the population as a whole. The indicator for growth among the adult native fish is the aquatic food base.

Non-Native Warmwater and Coolwater Fish

While coldwater trout species make up the majority of non-native fish in the Colorado River through Glen and Grand Canyons, other species have been introduced through the years (see table III-10). Anecdotal evidence suggests that channel catfish and carp have been present in the Colorado River system since the late 1800's (Carothers and Brown, 1991). Predam data are sparse and come only from Glen Canyon (Woodbury et al., 1959; McDonald and Dotson, 1960); however, they suggest that warmwater non-natives dominated natives by the late 1950's. Channel catfish represented 90 percent of fish captures reported from Glen Canyon by Woodbury et al. (1959).

Mainstem Reproduction

Near the time of Glen Canyon Dam closure in 1963, warmwater non-native fish found near the damsite included not only channel catfish and common carp, but common fathead minnow, green sunfish, killifish, largemouth bass, mosquito fish, and red shiner (Stone, 1965).

During the 4 years immediately following dam closure, relative abundance of native fish increased over non-natives downstream in the Glen and Marble Canyon reaches. However, mainstem stocking of rainbow trout at Lees Ferry had begun during this period. By 1968, non-native fish were again more abundant than natives in these upper reaches, although species composition had shifted from warmwater non-natives to coldwater non-natives (figure III-29). It is important to note that during this early postdam period, water temperature still varied seasonally from 45 °F to 70 °F (Stone, 1964; 1965; 1966; Stone and Queenan, 1967; and Stone and Rathbun, 1968).

In the mid-1970's, a warmwater non-native species, common carp, was still abundant in the upper reaches and dominated the lower reaches. In 1978 and 1979, carp accounted for over 68 percent

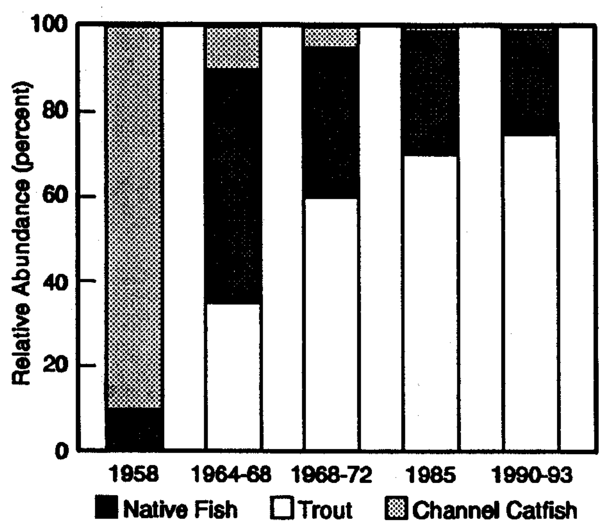


Figure III-29.—Composition of native and non-native fish in the upper reach of the Colorado River mainstem (source: Leibfried and Zimmerman, 1994).

Table III-10.—Introduced fish present in the Colorado River through Glen and Grand Canyons

Species	Temperature preference	Occurrence
Rainbow trout	Cold	Abundant–upper; common–middle
Brown trout	Cold	Common in Upper Gorge
Brook trout	Cold	Rare
Cutthroat trout	Cold	Rare
Channel catfish	Warm	Common–lower (Present Lakes Powell and Mead)
Carp		WarmCommon–middle and lower
Fathead minnow	Warm	Common–lower
Striped bass	Cool	Seasonal–lower (Common–Lakes Powell and Mead)
Red shiner	Warm	Absent (Present Lake Mead)
Green sunfish	Warm	Rare–lower (Present–Lakes Powell and Mead)
Largemouth bass	Warm	Rare–lower (Present–Lakes Powell and Mead)
Smallmouth bass	Cool	Absent (Present Lake Powell)
Walleye	Cool	Rare (Present Lake Powell)
Plains killifish	Warm	Rare–lower
Black bullhead	Warm	Rare

of all fish collected in the mainstem between Lees Ferry and Separation Canyon (RM 239.5) (Carothers and Minckley, 1981). By the mid-1980's, however, a coldwater non-native—rainbow trout—dominated the fishery, accounting for some 66 percent of all fish caught by electrofishing in the mainstem from Lees Ferry to Diamond Creek (RM 225) (Maddux et al., 1987). Carp abundance approached that of rainbow trout only in the lowest reach, below RM 166.5.

The Glen and Grand Canyon fishery has been, and continues to be, influenced by the presence of two large reservoirs: Lake Powell upstream and Lake Mead downstream. Both reservoirs serve as sources of incursions into Glen and Grand Canyons by non-native fish. Currently, Lake Powell is managed as a warm/coolwater fishery featuring largemouth bass, smallmouth bass, bluegill, walleye, crappie, channel catfish, and striped bass. Lake Mead is managed as a warm/coolwater fishery featuring largemouth bass, bluegill, channel catfish, and striped bass. The primary forage for these multilayered sportfish communities is the threadfin shad.

Cold water releases from Glen Canyon Dam limit successful non-native fish reproduction and survival of young in the mainstem just as they do native fish.

Tributary Reproduction

Spawning and rearing habitat for warmwater non-natives is limited in the main channel due to perennially cold releases. Minimum reliable discharge is used as the indicator of tributary accessibility for reproduction.

Mainstem Recruitment and Growth

Growth of warmwater non-natives is limited by temperature, as is growth of native fish. The aquatic food base is used as the indicator for growth potential of non-native warmwater and coolwater fish.

Interactions Between Native and Non-Native Fish

The presence of warmwater, coolwater, and coldwater species is an issue of considerable importance. Competition from and predation by non-native fish has been cited along with habitat modification as causes of the decline of native fish in the Colorado River system (Holden and Stalnaker, 1975; U.S. Fish and Wildlife Service, 1990b; Minckley, 1991). The cold waters released from Glen Canyon Dam not only put some of the warmwater native fish at risk by limiting natural reproduction but also may benefit them by limiting the numbers and activities of non-native predators and competitors.

Striped Bass and Other Predators

One way that non-native fish directly influence native fish is through predation upon one or more of their life stages. Because of its position in the large lakes above and below Glen and Grand Canyons and its reputation as a voracious predator, the striped bass could become an important influence on native fish populations. Generally, striped bass are found in the lower reaches of Grand Canyon below Lava Falls, but in recent years isolated individuals have been captured near the mouth of the LCR.

Striped bass in the Southwest are far from their native range on the Atlantic coast, where they typically reside at sea but ascend rivers along the coastal plain to spawn. After spawning, they exit the riverine spawning areas (Crance, 1984), but some individuals stay in cool tailwater areas (Coutant, 1985). Striped bass appear to display this ascent and retreat spawning behavior in the Southwest, and recent research by Valdez and Hugentobler (1993) has recorded a definite seasonality in their collections of striped bass in Grand Canyon (April through July). Primary concerns of this research include whether operational changes would encourage greater movement of striped bass upstream into Grand Canyon, whether bass might become resident in the river, and whether they might feed on native fish. Predation by striped bass has been an issue of some concern. The level of that concern has been tempered somewhat by recent findings. Of 21 striped bass stomachs examined, only one contained a fish (rainbow trout) (Valdez and Hugentobler, 1993).

The striped bass is not the only predator of native fish. Other non-native warmwater fish are already established in the river. Perhaps prime among those established is the channel catfish. The channel catfish is an omnivore by nature and can compete with as well as prey upon native fish. Channel catfish are established in and around the LCR and are potential predators of native fish, including the endangered humpback chub. Their numbers appear to increase with distance from the dam, reaching peak abundance below Lava Falls at the western end of Grand Canyon (Haden, 1991). Examinations of channel catfish and striped bass stomachs reported by Valdez and Hugentobler (1993) revealed fish remains, but no humpback chub were identified. Several native suckers were found in the stomachs of channel catfish near the LCR. Largemouth bass and green sunfish, currently restricted to the lower river reaches, also are potential predators of native fish. Recent work in Grand Canyon (Valdez and Hugentobler, 1993) documented little predation on native fish by these species. They have been implicated as significant predators elsewhere in the basin.

Trout, among the most numerous fish in Glen and Grand Canyons, also have the potential to act as predators of native fish. Brown trout, usually concentrated between Clear and Bright Angel Creeks (Valdez, 1991), typically feed on fish (piscivorous) at larger sizes. Rainbow trout, though generally not considered piscivores, also have been implicated as possible predators on young native fish and fish eggs (Maddux et al., 1987; Haden, 1991; Angradi et al., 1992; Valdez, 1991). Rainbow trout stomachs examined by Maddux et al. (1988) and BIO/WEST, Inc. (Valdez and Hugentobler, 1993) did not contain any evidence of predation on native fish. Following exceptional production of humpback chub in the spring of 1993, an examination of rainbow trout stomachs collected near the LCR's confluence with the mainstem found very small but identifiable bones of humpback chub, suggesting some predation (Paul Marsh, written communication).

Brown trout, more piscivorous than rainbow trout, have been implicated as an important predator upon humpback chub (Valdez and Hugentobler, 1993). The only documented predation on humpback chubs during 1991 and 1992 in the mainstem was by brown trout (Valdez and Hugentobler, 1993). Thirteen percent (3 fish) of the 23 brown trout collected near the mouth of the Little Colorado River contained identifiable chub remains. Coldwater fish species such as brown trout, cutthroat trout, and brook trout usually prey on other fish, and the recovery plan for the humpback chub recommends against stocking predatory or competitive non-native fish into waters occupied by threatened and endangered species.

Other coolwater fish also could be introduced accidentally from Lake Powell. The walleye and smallmouth bass (both piscivores), currently expanding their distribution in Lake Powell, could reside in reaches in Glen and Grand Canyons. One walleye has recently been collected in Grand Canyon (Valdez and Hugentobler, 1993).

Establishment and Expansion of Other Competitors

While predation has a very direct effect on the abundance of native fish, competition has an indirect—but no less important—effect on their abundance and well-being. Fish life requirements include both the physical characteristics of where they live and reproduce, as well as the food resources they depend on for energy and growth. When access to food resources and shelter is limited through competition, the abundance of the disadvantaged competitor is often reduced. While competition is difficult to document, its results usually are striking. Native fish living in altered habitats and/or competing with non-native fish for limited resources most often have been restricted, or even excluded, in their native range.

Potential competitors with native fish include carp, fathead minnow, killifish, rainbow trout, and red shiner and may include some of the omnivorous species that also prey on native fish. These competitors may share rearing habitats in backwater areas and eddies, on which native fish appear to be dependent.

Native fish species dominate over non-native species in tributaries. Of nine tributaries sampled by Angradi et al. (1992) in Marble and Grand Canyons, seven were found to be dominated by native species, and only two were found to be dominated by non-native species (the coldwater rainbow trout).

Trout populations use some of the same tributaries for spawning as native fish. It was suggested by Maddux et al. (1987) that trout and native fish use tributaries in different seasons, and thus partition the habitat seasonally. Native fish rely on the tributaries during spring months for spawning and during summer months for rearing, while trout rely on tributaries during winter months for spawning and spring months for rearing. Carothers and Minckley (1981) characterized the overlapping use of tributaries by native fish and trout as an example of competition.

In the mainstem, cold water releases from the dam—and possibly daily fluctuations and flood events—have considerably reduced the numbers of individuals and kinds of non-native species that are currently resident (Minckley, 1991). Main channel habitat conditions for all warmwater non-natives are marginal. Channel catfish, carp, and fathead minnow persist and probably rely upon tributary spawning (and backwater spawning in the case of fathead minnow) to maintain their populations.

Trout

The issues defined for detailed analysis under this topic include trout spawning and recruitment and trout food resources. Trout fishing, another important issue, is discussed under RECREATION later in this chapter.

As early as the turn of the century, fish not native to the Colorado River were introduced for sport or food. For the most part, these were warmwater fish from the Eastern United States, but they also included coldwater fish and European transplants (carp, brown trout) considered at the time to be valuable introductions for sport fishing (U.S. Fish and Wildlife Service, 1980b; Arizona Game and Fish Department, 1990b). Plans for the construction of Glen Canyon Dam and the anticipated transition of the Colorado River through Glen and Grand Canyons to a regulated cold stream provided the opportunity to develop a multifaceted reservoir fishery above the dam and a trout fishery below the dam.

Trout, which can be found throughout the Glen and Grand Canyon reaches, are represented by a number of species. Not native to this stretch of the river, trout originally were introduced for sport purposes by NPS, AGFD, and the U.S. Forest Service in the 1920's. NPS discontinued stocking in Grand Canyon National Park in 1964; and the AGFD began stocking rainbow trout at Lees Ferry in 1964 (Reger et al., 1989), a practice that continues today. Rainbow trout make up the major part of the sport fishery in the 15-mile reach below Glen Canyon Dam and the trout fishery in Grand Canyon. Brook trout, brown trout, and cutthroat trout also have been stocked in the Glen and Grand Canyon reaches of the river. Brown trout, never stocked in the Lees Ferry area, increase in abundance below Clear Creek. Brook trout and cutthroat trout have nearly disappeared from the system.

Stocking practices have changed through time, shifting from stocking catchable-sized trout (1964-76) to stocking "fingerling" fish (1976-91). The shift from stocking catchable trout was prompted by the establishment of a reliable food source for trout, *Gammarus lacustris* (Reger et al., 1989). Following 1977, the reputation and importance of the trout fishery at Lees Ferry grew appreciably and established it as a premier fishery. Current practices call for stocking approximately 80,000 Bel-Aire strain rainbow trout annually between Glen Canyon Dam and Lees Ferry. Davis (1991) evaluated strains of rainbow trout that could be used for stocking at Lees Ferry, but no changes in strain have been proposed by the AGFD.

Since the early 1980's, the size of fish harvested from the sport fishery has consistently declined. In 1990 and 1991, the condition (relative plumpness) of rainbow trout showed a marked decline (Arizona Game and Fish Department, 1993), and a large number of trout apparently died. The abrupt decline was attributed to several factors:

- Extended low flow periods (5,000 cfs) during GCES research releases that may have restricted food resources
- Regulation changes that increased the number of individuals maintained in the population
- Eruption of a parasitic infestation in the trout

A combination of these factors likely resulted in the population decline. It has been suggested that the eruption of the parasitic infestation may have resulted from crowded conditions and limited forage (Arizona Game and Fish Department, 1993). The condition of individual trout recovered somewhat during 1992 (Arizona Game and Fish Department, 1993), likely as a result of recovery of the aquatic food base under interim operations implemented in August 1991.

Adult Stranding Mortality

Daily fluctuations have resulted in the stranding of adult rainbow trout, primarily during spawning. Spawning trout display a strong fidelity to a spawning site and may not abandon it even as the water recedes around them (Angradi et al., 1992), thus making them particularly susceptible to stranding.

The causes of death for stranded adults include dewatering, high water temperature, high pH and low dissolved oxygen in stranding pools, and exposure to predation by birds and land animals. All of the evaluated potential stranding pools are isolated at minimum flows of 1,000 cfs or 3,000 cfs.

Stranding is less common in river reaches below the confluence with the Paria River, where trout spawning is tributary-oriented. As with native fish, trout reproduction and recruitment below the confluence with the Paria relies on accessibility to tributaries (Angradi et al., 1992).

Investigation of 11 major stranding pools from February 1990 through March 1991 (Angradi et al., 1992) located 1,924 adult trout stranded by fluctuations. Fifty-one percent of those were dead or dying when investigators arrived at the stranding pools. This incomplete sample of stranded fish—based on up to four visits per month per stranding pool—is equal to about 4 percent of the trout harvested in 1988 at Lees Ferry and nearly 20 percent of the trout harvested in 1991 (under very restrictive regulations). Because these typically are spawning fish, the effects are twofold:

- Relatively large individuals, the result of several years accumulated growth and of value to sport fishermen, are removed from the population.
- Potential reproductive contribution to the population is lost.

The presence of major stranding pools depends on river stage. As stage increases, the number of pools capable of stranding adults decreases. The number of stranding pools (expressed as a percentage of the 11 pools studied) at the reliable minimum flow is used as an index of stranding mortality for evaluation of the alternatives.

Glen Canyon Reproduction and Recruitment

The contribution of naturally reproduced trout to the Glen Canyon reach was estimated at approximately 27 percent during steady, high flow conditions by Maddux et al. (1988). Evidence suggests that interim operations have increased naturally reproduced trout in the Lees Ferry population. Arizona Game and Fish Department (1993) estimated that 78 percent of juvenile trout (smaller than about 8 inches) sampled in August 1992 were naturally reproduced.

The act of spawning is only one variable in determining how many naturally spawned fish are in the population. Attempts to reproduce are not limited by daily fluctuations, as evidenced by the stranding of adult spawning fish. Angradi et al. (1992) illustrated that redd sites were selected based on location of acceptable spawning gravels, regardless of whether they would be exposed by receding river stage. Direct mortality of eggs (Maddux et al., 1988), fry, and young trout (Persons et al., 1985) caused by redd exposure, stranding of young fish, or forcing young fish into unacceptable rearing habitats can prevent successfully spawned young from surviving to a size large enough to cope with changing flow conditions. Maddux et al. (1988) showed that exposure of spawning redds for more than 10 hours resulted in near total mortality of eggs.

Maddux et al. (1988) reported that spawning conditions in the Glen Canyon reach varied from year to year. They suggested that available habitat for spawning (gravels) may be changing in quality as well as quantity. They speculated that, since the high flows of 1983-84, erosion of gravel bars may be decreasing the quality and quantity of available spawning habitat. Angradi et al. (1992) found that the density of redds on gravel bars was related to the size distribution of gravels. They also speculated that loss of finer gravels may be resulting in reduced area available for suitable spawning sites in the uppermost reaches of Glen Canyon, particularly since there are no sources to replenish those gravels.

Angradi et al. (1992) mapped redd sites on four spawning bars in the Glen Canyon reach. Their data suggest that at least 90 percent of the utilized spawning habitat was within the zone of potential daily fluctuation (minimum flows as low as 3,000 cfs) and, if used by trout, the spawn would likely fail. Actual minimums during peak trout spawning seasons could be as low as 1,000 cfs.

These redd sites mapped by Angradi et al. (1992) are used as the indicators of effects on natural reproduction and recruitment in the reach between Glen Canyon Dam and the Paria River (the Lees Ferry fishery). The proportion of redds that would not be exposed (expressed as a percentage) is used as the indicator. Ultimately, this proportion may determine whether the fishery must be maintained by stocking or could become self-sustaining (a condition desired by the angling public).

Downstream Reproduction and Recruitment

While the trout in Glen Canyon spawn in the main channel, it is assumed that downstream populations in Grand Canyon are largely maintained by tributary spawning. It is unknown whether main channel spawning significantly contributes to the population.

Tributary populations may have persisted for many years with limited use of the main channel. NPS and the U.S. Forest Service began stocking tributaries in the 1920's (Carothers and Minckley, 1981), and trout use of the mainstem was likely limited in summer months when water temperatures were unsuitable. Tributary populations have persisted without augmentation since stocking ended in 1964. Accessibility to tributaries is the prime issue for maintaining these populations. It is assumed that trout access has been sufficient under pre-1989 operational criteria, since trout dominate in these upper river reaches. Only extremely low flow in the mainstem, especially when coupled with low discharge from the tributary, would preclude its use.

Growth and Condition

Trout tend to be opportunistic feeders and often consume foods based on their size. In Glen and Grand Canyons, trout fry appear to be rather dependent on zooplankton in the mainstem (Haury, 1988; Maddux et al., 1988). Adults, on the other hand, feed on chironomid midge larvae, *Cladophora*, *Gammarus*, and decaying organic material. Fish material appeared in less than 1 percent of stomach samples (Maddux et al., 1988).

Rainbow trout usually are not considered herbivores, but some researchers have indicated that the occurrence of *Cladophora* in their stomachs is no accident, or at least that they have benefited considerably from consuming it. It can be argued that *Cladophora* is consumed coincidentally when trout forage for bottom dwelling invertebrates like *Gammarus*. It also has been argued that trout benefit directly from feeding on *Cladophora* as well as indirectly by consuming the invertebrates that depend upon it (Pinney, 1991). Montgomery et al. (1986) and Leibfried (1988) proposed that the high fat content of the diatoms encrusting *Cladophora* provide a ready energy source and may be partially responsible for the enhanced growth of trout in the tailwater area. The amount of *Cladophora* in the diet of adult rainbow trout generally declines from upstream populations at Lees Ferry to downstream populations in the lower Grand Canyon, which probably reflects availability (Maddux et al., 1988). The aquatic food base is used as the indicator for growth and condition of trout.

VEGETATION

Plant communities found in northcentral Arizona reflect the influences of climate, topography, soil, and elevations that characterize the area. For example, the uplands surrounding Grand Canyon support a unique blend of plants influenced by three adjacent deserts: the Mohave to the west, the Sonoran to the south, and the Great Basin to the east and north (Carothers and Brown, 1991). However, the Colorado River and operation of Glen Canyon Dam have little effect on the majority of plant life surrounding Grand Canyon. The river, as influenced by dam operations, affects a narrow band of vegetation along the river corridor known as the riparian zone. The riparian zone will be the focus of this discussion and chapter IV analyses.

Riparian Vegetation

Plant communities affected by releases from Glen Canyon Dam exist in a restricted zone at the juncture between the river's aquatic communities and upland plants adapted to desert conditions. Riparian zones are supported by inflowing water—either perennial, intermittent, or ephemeral—and occur in a continuous area inhabited by aquatic through semiaquatic, riparian, semiriparian, to upland vegetation (Johnson and Lowe, 1985). There is a dynamic interaction between water and plants in the riparian zone: the availability of water supports plants that could not otherwise survive in a desert climate, and the type of vegetation that survives reflects the water regime that supports it.

Thick growth and the variety of plant species present in the riparian zone provide a structural diversity that makes these areas some of the most important wildlife habitat in the region. Riparian vegetation supplies food and cover for abundant insects emerging from the river, as well as its own resident invertebrate populations. These resources, in turn, support numerous mammals, birds, reptiles and amphibians, and other invertebrates (Carothers and Brown, 1991). Vegetation may trap sediment during high flows, and nutrients within the sediment become available for plant growth. Various plants in the riparian zone and many of the animals supported by it are important to Native Americans.

Because of the dynamic interaction between riparian vegetation and water availability, changes in dam operations that change specific water release patterns would be expected to affect the abundance and distribution of plants. These linkages—and anticipated changes—form the basis of analyses in the remainder of this document. However, because of the variety of plants growing in the riparian zone and their differing water requirements, a comprehensive evaluation of the effects of all alternatives on all plants is beyond the scope of the report. Therefore, two plant groups were selected to serve as indicators of riparian vegetation for detailed evaluation: woody plants (trees and shrubs) and emergent marsh plants (cattails and others). The following discussion explores existing conditions and how they reflect the predam environment and current dam operations.

Woody Plants

Plants in this group occur throughout the riparian zone from the dam to Separation Canyon (although data are available only to Diamond Creek). However, predam flows and postdam discharges have created conditions that define two subzones of vegetation: the OHWZ and the NHWZ (figure III-30). Each zone has its own water-dependent characteristics. Woody riparian plants also are associated with Lakes Powell and Mead and, because dam operations can affect this vegetation, are discussed below.

Old High Water Zone. Vegetation found within the OHWZ reflects historic and current regional climates and the influences of the high water stage of unregulated flows. Before Glen Canyon Dam, floodflows regularly scoured most vegetation from the river's banks up to an elevation about equivalent to the 100,000-cfs stage (Brian, 1987). The OHWZ developed above the scour zone from a stage equivalent to about 123,000 cfs and in some places extended up the bank to about 300,000 cfs (Stevens and Ayers, 1993). Thus, plants that can withstand conditions created by periodic flooding characterize the OHWZ. Dominant plants include netleaf hackberry in the upper reaches of Marble Canyon and other sites and honey mesquite and catclaw acacia in the lower reaches of the river.

There are an estimated 1,870 acres of vegetation in the OHWZ (Stevens, written communication, 1992). The exact relationships between the postdam river and the OHWZ are not clear. Some believe that without periodic inundation, plant germination in the OHWZ is limited, and growth of established plants is affected (Anderson and Ruffner, 1987). However, mesquite and acacia (including young plants) can be found growing at sites well-removed from the influences of river flooding. Age of plants may also play a role; plants in the OHWZ are long-lived, with some trees aged at several hundred years old (Hereford, verbal communication, 1992).

The OHWZ may be declining in some areas. Dying trees are evident along some river reaches. Mesquite appears to be less drought resistant than acacia, and the latter may become the dominant tree in the OHWZ (Anderson and Ruffner, 1987). Reduced flood frequency (a change in water regime) has permitted upland plants to move into some OHWZ areas. Common upland plants

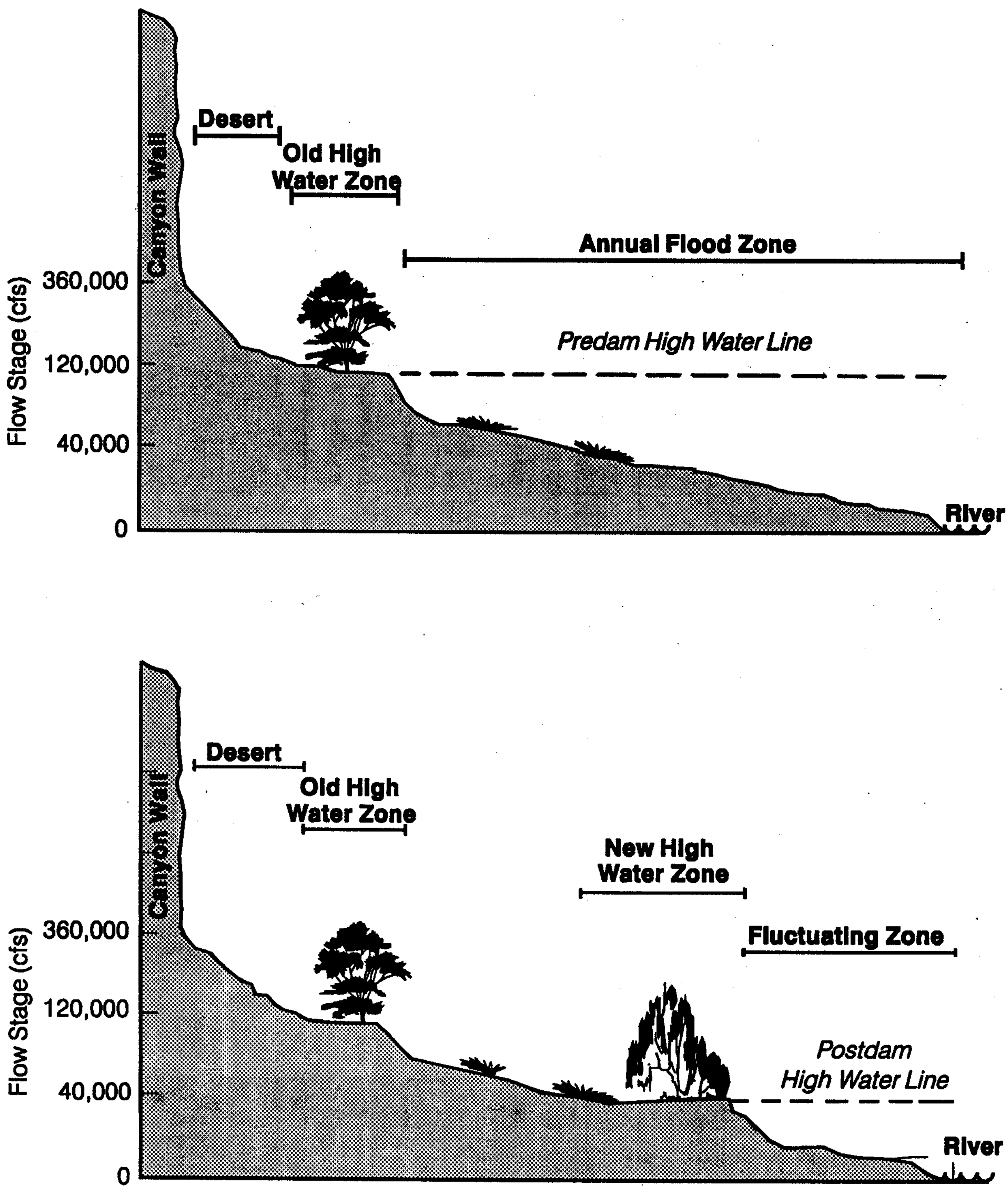


Figure III-30.—Grand Canyon riparian zone, predam (before 1963) and postdam (after 1963).

adjacent to or moving into the OHWZ include barrel cactus below RM 26, brittle bush below Marble Canyon, creosote bush and ocotillo below Havasu Creek, and cholla cactus below Lava Falls (Carothers and Brown, 1991).

New High Water Zone. Before construction and operation of Glen Canyon Dam, little vegetation grew in the scour zone below the OHWZ. After the dam controlled annual spring flooding, additional vegetation began to develop near the river below the OHWZ. From 1963 to 1980, as the dam filled, a zone of vegetation developed that was characterized by high densities near the high water stage of the dam-regulated river (Carothers et al., 1979). This vegetation developed rapidly and has become known as the new high water zone. Between 1965 and 1973, vegetation at selected sites increased at a rate of one-half acre per river mile per year (Pucherelli, 1986). Between 1973 and 1980, the rate of increase slowed to one-fourth acre per mile per year.

The NHWZ exists in the predam scour zone (figure III-30), between the discharge stages of about 22,000 to 40,500 cfs (Stevens and Waring, 1986). Common woody plants in this zone include both native and non-native species: seep-willow, arrowweed, desert broom, coyote willow, and tamarisk. Tamarisk, a non-native tree common throughout the Southwest, is the dominant woody plant in the NHWZ. Mesquite and other plants have moved into the NHWZ from the OHWZ.

Vegetation occupies approximately 1,320 acres in the NHWZ (Stevens, written communication, 1992). Woody riparian vegetation is not continuous along the river's banks throughout the canyon. Rather, stands of dense vegetation are found on sediment deposits associated with debris flows from tributaries or on lateral margin deposits between rapids. Between sediment deposits, scattered plants grow between rocks and boulders. In many locations, vertical rock walls confine the river and support no vegetation. Between Lees Ferry and Diamond Creek, less than half the riverbank miles support dense riparian vegetation.

Floodflows.–Riparian systems change as the water conditions that bound them change. The development of riparian vegetation in the NHWZ that began with the construction of Glen Canyon Dam was interrupted by high floodflows in 1983-86. In 1983, flows in excess of 90,000 cfs removed more than 50 percent of the plants at sample sites below the 60,000-cfs stage by either scouring, drowning, or burial beneath newly deposited sediments (Stevens and Waring, 1986).

Different plants are affected differently by high discharges. Species with deep taproots, such as acacia, mesquite, and tamarisk, are resistant to scouring, and losses ranged from 0 to 20 percent (Stevens and Waring, 1986). In contrast, high scouring losses (68 to 100 percent) were experienced by shallow-rooted clonal species such as coyote willow, arrowweed, giant reed, cattail, and bulrush. Willow, acacia, tamarisk, and arrowweed were resistant to drowning, while mesquite (50-percent loss), *Brickellia* spp. (62-percent loss), *Baccharis* spp. (64- to 79-percent loss), *Aplopappus* spp. (83-percent loss), and desert-adapted species drowned from inundation. Species tolerant of burial included tamarisk and clonal forms such as horsetail, giant reed, willows, camelthorn, aster, and arrowweed. Burial-intolerant species included mesquite, acacia, *Baccharis* spp., *Brickellia* spp., or desert plants. The riparian zone is a dynamic system, and Stevens and Ayers (1991) estimate that levels of riparian vegetation before interim flows were at 75 percent of 1982 levels.

Daily Flows.–While major flood events cause a temporary rearrangement of plant communities, daily release patterns dictate stability of sediment deposits and ultimately the area that will be occupied by riparian vegetation. Thus, daily fluctuating releases from Glen Canyon Dam influence expansion of vegetation from the NHWZ to sites at lower elevations. Fluctuating releases wet a large area that encourages seed germination, but recurring changes in river stage uproot seedlings before they can become established in sandy substrates. Tamarisk has been successful in expanding into some cobble bars disturbed by the flood releases of 1983-86 (Stevens and Waring, 1986).

Daily fluctuations not only affect area coverage of vegetation but also species composition to some degree. At many sites, tamarisk marks the 30,000-cfs stage—unable to expand to higher elevations without the disturbances of higher flows and unable to expand to lower elevations because of daily fluctuations. Sediment deposited by the high flows of 1983 is no longer wetted and is being colonized by coyote willow and arrowweed via rhizomes or underground running shoots from adjacent stands.

Plant species composition also depends on location in Grand Canyon. River elevation decreases almost 2,000 feet from Lees Ferry to Lake Mead, and the accompanying climatic changes affect plant community composition. For example, coyote willow is more common in the upper canyon, while arrowweed and horsetail are more common in the lower canyon. While various herbaceous plants form a ground cover near the high water stage below woody plants in the upper canyon, bermuda grass becomes the dominant ground cover at many sites below Havasu Creek.

Lakes Powell and Mead. Woody riparian vegetation also is associated with Lakes Powell and Mead. Lake levels have declined since the high floodflows of 1983-86 because of a regional drought. Riparian vegetation has increased on sediment exposed by declining water levels, and woody vegetation has become abundant below Separation Canyon into Lake Mead.

Emergent Marsh Plants

Common emergent marsh plants found in the study area include cattails, bulrushes, and giant reed. Another plant—horsetail—is not generally considered emergent marsh vegetation but is included in this discussion because it develops and grows under conditions similar to the other species listed. These conditions include a reliable water source and sediment properties found only at certain sites.

Deposits containing clay/silt sediments are necessary for development of emergent marsh vegetation (Stevens and Ayers, 1993). Low water velocity sites, such as eddies and return-current channels along the river (see figure III-16) and the deltas of Lakes Powell and Mead, permit clay/silt particles to settle from suspension. These deposits provide a higher quality substrate for seed germination and seedling establishment than underlying sand because of their greater nutrient levels and moisture-holding capacity. With an appropriate water regime, these are the sites that support emergent marsh vegetation.

Marsh plants were selected as one of the indicators of riparian vegetation because their requirements place them between the aquatic and terrestrial systems at the aquatic end of the riparian zone. Together with woody plants (which require drier conditions), these indicators are assumed to represent the range of riparian system responses to dam operations.

Marsh Plants Along the Colorado River. Patches of marsh vegetation can be found in backwaters, channel margins, seeps and the mouths of tributary streams, and in other isolated sites within the fluctuating zone located between the NHWZ and the minimum discharge stage. Prior to closure of Glen Canyon Dam, annual floodflows prevented the establishment of marsh plants along the Colorado River in Grand Canyon (Stevens and Ayers, 1993). By 1976, 65 distinct sites supported about 12 acres of marsh vegetation. Further expansion occurred until 1983-86, when floodflows eliminated cattails and bulrushes from all but 17 sites.

Stevens and Ayers (1991) identify two types of marsh plant associations. Wet marsh plants include cattails, bulrushes, and some less common emergent plants. These associations develop on sediment deposits containing about half clay/silt and half sand, at sites between 10,000- and 20,000-cfs stages that are inundated once every 1.1 to 2.5 days (figure III-31). Patches of dry marsh plants (horsetail, giant reed) occur between discharge stages of about 20,000 to over 31,500 cfs that are inundated once every 3 days.

Emergent marsh plants commonly occur in small patches along the river between the dam and Lees Ferry (Stevens and Ayers, 1991). The average size ranges from 0.05 (dry) to 0.1 (wet) acre, with the largest (Cardenas Marsh), just over 1 acre in size.

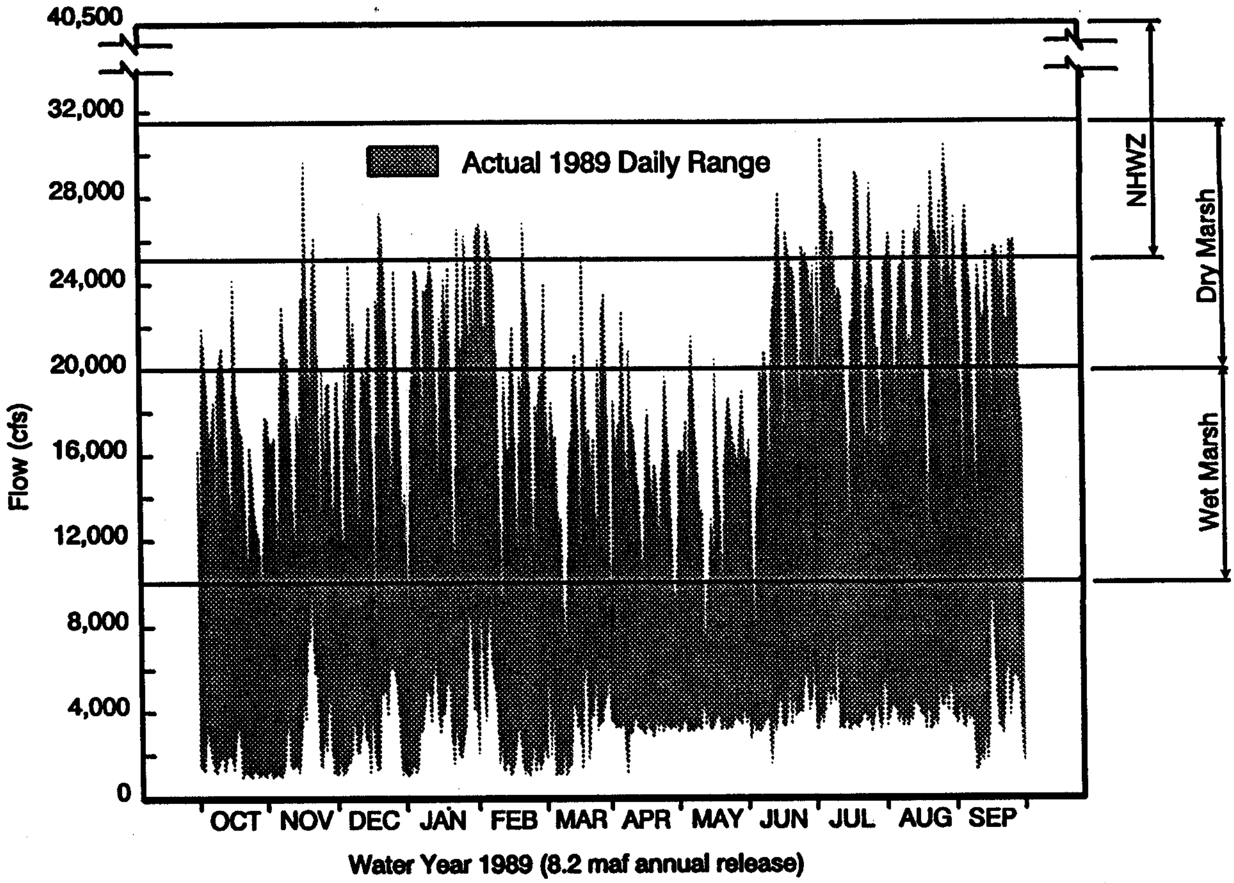


Figure III-31.—Wet marsh, dry marsh, and new high water zone plants occupy flow-stage bands defined by frequency and duration of inundation.

The aggregate acreage of emergent marsh plants along the Colorado River between the dam and Diamond Creek is 62 acres (19 acres of wet and 43 acres of dry marsh plants).

Marsh Plants Associated With Lake Mead. As with woody plants, emergent marsh vegetation is associated with Lake Mead and has increased in coverage since the high flows of 1983-86. Lake Mead's delta supports hundreds of acres of cattails and bulrushes. Although no data are available, it is assumed that these stands of vegetation have the size, continuity, productivity, and other properties necessary to function as true marshes.

WILDLIFE AND HABITAT

Wildlife is both diverse and abundant along the river corridor through Glen and Grand Canyon. Riparian vegetation, which developed along the river after construction of Glen Canyon Dam, plays an important role as habitat to support this diversity and abundance. No detailed survey data prior to dam construction are available, but it is assumed that wildlife inhabiting the river corridor were species characteristic of the adjacent upland desert, tributaries, and OHWZ communities. The densities of some species in the riparian zone today are among the highest recorded anywhere.

It is reasonable to assume that, as riparian vegetation increased, wildlife also increased to the levels observed today.

Riparian vegetation, and particularly that in the NHWZ, is among the most important wildlife habitat in the region. The structural diversity of the plant species and thick growth found in the riparian zone provides many habitat resources in a relatively small area. Riparian plants provide food and cover for insects emerging from the river, as well as providing habitat for its own resident invertebrate populations. The plants, insects, and other resources found in the riparian zone, in turn, support numerous mammals, birds, reptiles and amphibians, and other invertebrates.

Wintering waterfowl found along the river corridor cannot be directly linked to riparian vegetation, but they are attracted to and use the clear open water of the Colorado River within Glen and Grand Canyons. Although no predam survey data are available, the turbid river water was probably not very attractive to waterfowl. Dam construction resulted in clear, cold water that now supports an abundant green alga, *Cladophora glomerata*, and the aquatic food chain associated with it. Increased waterfowl numbers are probably a response to this increased aquatic productivity (Stevens and Kline, written communication, 1991).

The variety of animals present in the river corridor, their habitats, and how they use their habitats result in a complex system that would be difficult to evaluate in detail. However, like other resources in the study area, this system is linked to the river and ultimately to Glen Canyon Dam operations. These linkages and anticipated changes form the basis for analyses in the remainder of this document. Two resources were selected for detailed evaluation to serve as indicators of wildlife: riparian habitat (woody and emergent marsh plants), to represent terrestrial wildlife, and the aquatic food base, to represent wintering waterfowl requirements. The following discussion explores existing wildlife and habitat and how they reflect predam conditions and dam operations.

Riparian Habitat (Woody and Emergent Marsh Plants)

Mammals

Some 26 species of mammals are considered uncommon to abundant along the Colorado River corridor in Grand Canyon (Carothers and Brown, 1991). Of these species, only the deer mouse depends directly on the riparian zone for its existence. Deer mice were not found along the river prior to construction of Glen Canyon Dam. Riparian vegetation may have provided a competitive edge for deer mice over cactus mice along the river's banks. Both the brush mouse and pinyon mouse have increased in numbers since closure of the dam and subsequent development of the NHWZ. Small mammals use all types of vegetation, from dense patches of marsh plants to scattered desert shrubs.

The beaver is a large aquatic rodent that lives in dens in stable deposits above the fluctuating zone and feeds on riparian vegetation. Although the river corridor through Grand Canyon may not appear to be beaver habitat, Stevens (written communication, 1992) developed a conservative 1991 estimate of 200 beavers between Lees Ferry and Diamond Creek (225 miles). Beavers can affect plant species composition and coverage by their feeding activities. Cuttings and drag marks from these animals are common on beaches supporting stands of coyote willow.

Six bat species are uncommon to abundant along the river corridor (Carothers and Brown, 1991). While these species also inhabit desert habitats, they may be attracted to the river corridor by the insects associated with the river and riparian vegetation. Bats are important prey for peregrine falcons (B.T. Brown, 1991b).

There is one record of the spotted bat in the river corridor. This species is mentioned here because it is a candidate species under the Endangered Species Act. Very little is known about the spotted bat or its habitat requirements. The single record indicates that it is rare, and this species will not be treated in detail in this document.

Ringtail and the western spotted skunk are among the most common small mammals in the study area. These species may have become more abundant since construction of the dam. Whether riparian vegetation has contributed to this increase or human use at beach campsites has increased their food supply is unknown (Carothers and Brown, 1991).

Desert bighorn sheep and mule deer are the largest mammals that use sections of the river corridor. Bighorn sheep come to the river to drink and feed during the heat of summer (Carothers and Brown, 1991). Although rapidly increasing discharges may occasionally strand individual animals, the size, strength, and mobility of these two species make it unlikely that river discharge causes direct effects.

Birds

The importance of riparian vegetation as wildlife habitat, specifically in the NHWZ, is exemplified by bird use. Some 303 species of birds have been recorded in the Grand Canyon region, with 250 (83 percent) of these in the river corridor (Johnson, 1991). Most birds use the corridor as a travel lane through the desert and are not affected by dam operations. However, birds that nest in the riparian zone along the river corridor are directly and indirectly affected by flows.

Some 48 species of birds nest along the river (modified from Carothers and Brown, 1991). Fifteen species nest in both the OHWZ and NHWZ, with an additional 14 species nesting exclusively in the NHWZ (figure III-32). One species nests primarily in the OHWZ. The number of nests at some sample sites in the riparian zone exceeded densities comparable to 800 pairs per 100 acres, among the highest ever recorded in North America (Brown and Johnson, 1988). Bell's vireo, summer tanager, hooded oriole, and great-tailed grackle have expanded their nesting ranges into Grand Canyon in response to riparian vegetation development (Carothers and Brown, 1991).

Riparian vegetation supplies both cover and food to birds and to a principal prey: insects. Of the 30 bird species that nest exclusively in the OHWZ, NHWZ, or both, 13 are insectivors; and at least 10 more bird species feed insects to their young. Other species that may not nest in riparian vegetation—such as phoebes, swifts, and swallows—feed on the insects associated with this zone.

Little direct effect has been recorded on birds nesting along the river corridor under historic dam operations. Bird populations were studied during the flood years of the 1980's when segments of riparian vegetation were inundated for long periods. Brown and Johnson (1988) recorded only one nest lost at flows up to 31,000 cfs. At higher discharges, bird nests located near water or on the ground risk inundation. Discharges of 40,000 cfs inundated 90 percent of common yellowthroat nests. Above 40,000 cfs, nests of Bell's vireo, yellow-breasted chat, black and Say's phoebe, and violet-green swallow were affected.

Mallards nest in dense vegetation—such as patches of emergent marsh plants—above the high water stage. Dense vegetation provides cover and abundant insects for foraging young. Mallard pairs were observed in almost every large eddy in Marble Canyon and upper Grand Canyon reaches in the summer of 1991 (Stevens, written communication, 1992).

Vegetation within the riparian zone is not continuous but rather occurs in disconnected blocks or patches. Factors that affect the patch sizes of vegetation—such as disease, fire, beach erosion, or colonization of barren sites—can indirectly affect habitat use by breeding birds. For example, patches of vegetation in the NHWZ must be at least 1.2 acres in size before black-chinned hummingbirds will use them for nesting (B.T. Brown, 1991c). Habitat patch size also is important to other species. Factors that decrease patch size would limit subsequent habitat use, while factors that permit increases in area would promote increased use by some nesting birds.

Amphibians and Reptiles

Some 27 species of amphibians and reptiles (herpetofauna) inhabit the river corridor

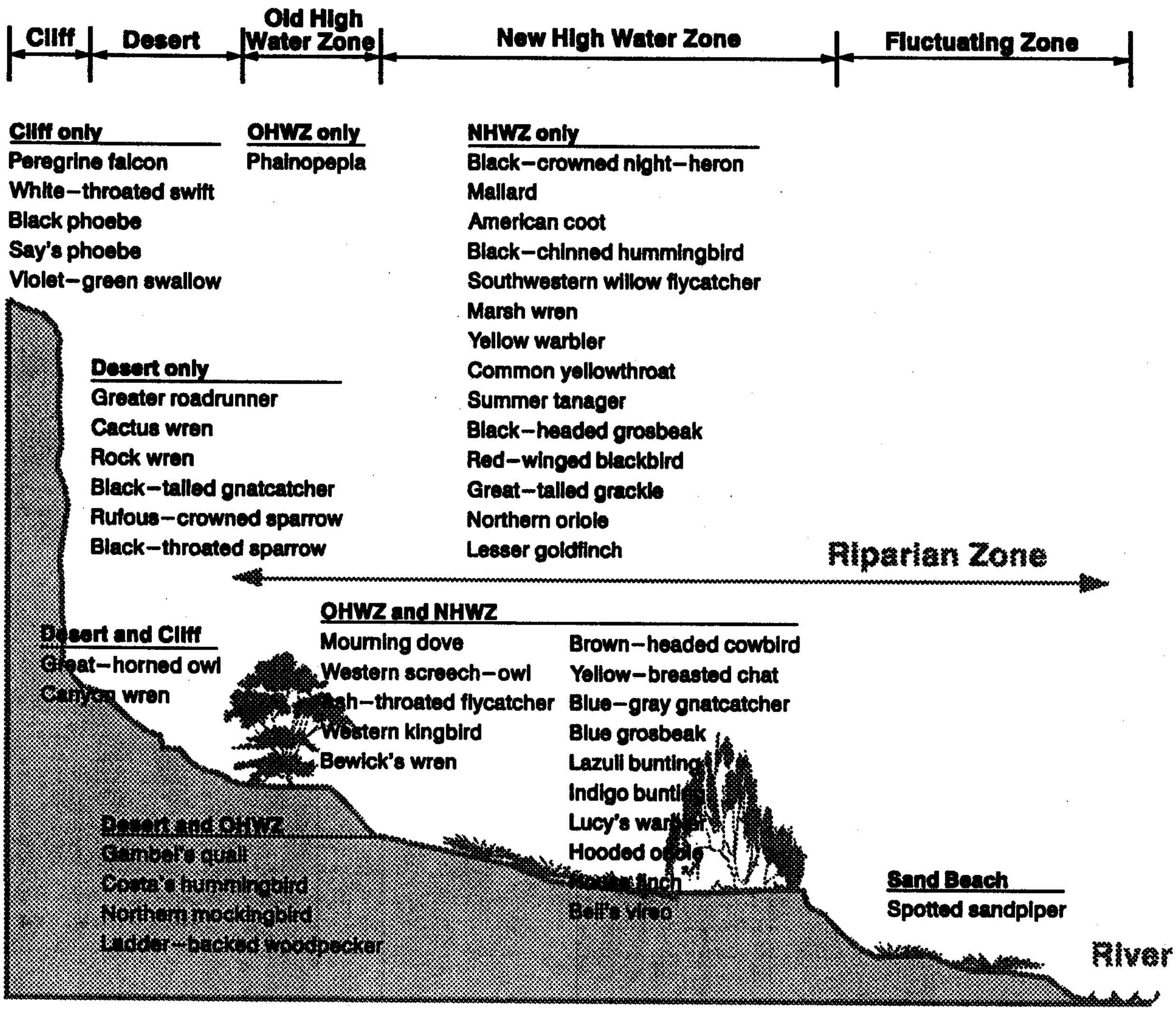


Figure III-32.—The importance of riparian vegetation as wildlife habitat is exemplified by nesting birds. The majority of birds nesting along the river corridor (30 to 48 species) nest in riparian vegetation.

(Carothers and Brown, 1991). In contrast to birds, only three species—Woodhouse's toad, leopard frog, and the desert banded gecko—are restricted to riparian vegetation. Although survey data are limited, the leopard frog is considered very rare in Grand Canyon. Recent sightings are limited to Cardenas Marsh (Miller et al., 1982) and Glen Canyon above Lees Ferry (Pinnock, verbal communication, 1993). Woodhouse's and red-spotted toads are common campsite visitors. The desert banded gecko is also considered rare (Carothers and Brown, 1991), but little is known about this nocturnal lizard in Grand Canyon (Miller et al., 1982). Most of the remaining species use both upland desert and riparian sites, and 10 of these species are considered common to abundant (Carothers and Brown, 1991). The densities of some species indicate the importance of the riparian zone to this group of wildlife.

Specific sites within the NHWZ, including the interface between the water and exposed sediment and open tamarisk sites, support lizard densities equal to or higher than any other sites reported in the Southwest (Warren and Schwalbe, 1988). The river is the source of abundant invertebrate food, while riparian vegetation—together with various other substrates including cliff faces—provides structural diversity. Together, these features create habitat conditions for some species of herpetofauna that may be unique in southwestern riparian zones.

While mammals and birds use riparian vegetation primarily for cover and secondarily for insect food, amphibians and reptiles focus their feeding activities on the many insects associated with riparian vegetation (Carothers and Brown, 1991). The importance of insects to herpetofauna is illustrated by the distribution of four common species: the side-blotched, the western whiptail, the desert spiny, and the tree lizard. Individuals of these species are most abundant within 16 feet of the water's edge, moderately abundant in the NHWZ and OHWZ, and least abundant at upland sites adjacent to the riparian zone (Warren and Schwalbe, 1988).

The NHWZ fluctuating zone is a particularly important source of food. The western whiptail commonly feeds in the fluctuating zone on harvester ants, stranded *Gammarus*, and black flies (Carothers and Brown, 1991). Warren and Schwalbe (1988) observed eight western whiptails and five desert spiny lizards feeding along a section of shoreline at Cardenas Marsh. Some species select specific substrate within the riparian zone. For example, side-blotched lizards are most commonly observed in open areas with rocks or bare soil, western whiptails on bare soil or litter, desert spiny lizards on large boulders or large tree trunks, and tree lizards on vertical cliff faces along eddies and quiet shorelines just above the splash zone (Warren and Schwalbe, 1988).

Numbers of lizards observed in the NHWZ were lowest in dense tamarisk sites (Warren and Schwalbe, 1988). Along the Gila River—a similar desert habitat with dense tamarisk—only desert spiny and tree lizards were captured in dense tamarisk (Jakle and Gatz, 1985). Jakle and Gatz speculated that dense stands of tamarisk do not provide suitable habitat for lizards.

Terrestrial Invertebrates

Invertebrates play a major role in both aquatic and terrestrial food chains in Grand Canyon. Some insects hatching and emerging from the river may swarm into the NHWZ and land on riparian vegetation, rocks, and other substrates, supplying abundant food for various forms of mammals, birds, and herpetofauna. Vegetation within the riparian zone also supports resident insect populations that are independent of the river. To date, several thousand species of insects, representing 260 families, have been identified along the river corridor (Stevens and Waring, 1986). Spiders, scorpions, and other invertebrates also are present in the varied substrates of the riparian zone.

Aquatic/Aerial Forms. The Colorado River mainstem supports a relatively low diversity of invertebrates, but these few species have high populations and produce a high biomass (see discussion of macroinvertebrates under FISH in this chapter). In contrast, the tributaries support high species diversity, with each tributary and spring supporting a different assemblage of species. Chironomid midges, simuliid black flies, and amphipod crustaceans dominate the aquatic food chain in the river (Carothers and Brown, 1991).

Species that develop in the clear, cold river water and then emerge to live in the air above are often important in terrestrial food chains. For example, black flies develop as larvae attached to underwater rocks. Instead of emerging directly from the water as adults like chironomid midges, black flies must first reach land and dry their wings (Carothers and Brown, 1991). These vulnerable emerging flies are an important source of food for numerous species that forage in the zone of fluctuating discharge.

Adult chironomid midges are a significant food resource available to predacious insects, amphibians, reptiles, and birds in this system (Stevens and Waring, 1986). Following emergence, chironomids prefer to alight on willows rather than on tamarisk. Adult chironomid populations were lowest during years of high flood discharges and large fluctuations.

Leibfried and Blinn (1987) noted a lack of invertebrates at sample sites exposed to fluctuating flows. More recently, Blinn et al. (1992) found a total of only 33 invertebrates in 900 samples from 10 sites in the fluctuating zone between Lees Ferry and Diamond Creek.

Ground-Dwelling Forms. Another group of insects important in terrestrial food chains are species that live just below or on the ground. One of these species best known to campers is the harvester ant. Before Glen Canyon Dam, annual flooding removed colonizing harvester ants from the scour zone. Populations rose to 2.4 nests per 100 square yards after closure of Glen Canyon Dam but were reduced to predam levels by the 1983-86 floods (Carothers and Brown, 1991). Current population levels have stabilized at about 0.35 nest per 100 square yards. Harvester ants feed on vegetation or other insects, human food debris, and black flies. They are in turn fed upon by predacious insects, herpetofauna, birds, and mammals.

Vegetation-Using Forms. Although most terrestrial insects use plants to some extent, several forms exhibit important relationships with riparian vegetation. While tamarisk is the most abundant woody plant along the Colorado River in Grand Canyon, it supports only four or five species of insects. Among these are leafhoppers and armored scales restricted to tamarisk, a lady bug that preys on the armored scales, and Apache cicadas (Carothers and Brown, 1991). In contrast, coyote willow—second only to tamarisk in abundance—supports many different species of insects. Tamarisk produces a much greater amount of insect biomass primarily due to large outbreaks of leafhoppers (Carothers and Brown, 1991). Leafhopper outbreaks provide food that may be used by native predacious insects, amphibians and reptiles, birds, and mammals.

The insect community continues to develop as riparian vegetation becomes established. Tributaries support different insect species than the river corridor and may serve as population reservoirs for mainstem colonization.

Wintering Waterfowl (Aquatic Food Base)

The numbers of waterfowl using Grand Canyon increase in late November, peak in late December and early January, and then decrease in February, March, and April (Stevens and Kline, written communication, 1991). During peak winter concentrations in 1990-91, some 19 different species of waterfowl used the river between Lees Ferry and Soap Creek at a density of 136 ducks per mile. An average density of 18 ducks per mile occurred over the entire upper Grand Canyon (RM 0-77). It is assumed that the birds are attracted to and use the river because of the open water and abundant food resources available.

No specific information on feeding is available for wintering waterfowl in Grand Canyon. However, the diets of individual species are well known from other studies and indicate that foods taken from the river would range from plants through invertebrates to small fish. The variety and abundance of waterfowl using the river during winter indicate that a productive aquatic system exists below the dam. As described in the section on aquatic resources under FISH in this chapter, this system is supported by clear, cold releases from the dam and is based on the linkages between *Cladophora*, diatoms, *Gammarus*, and larval insects.

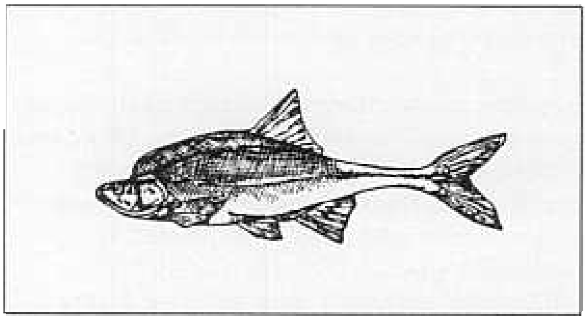
ENDANGERED AND OTHER SPECIAL STATUS SPECIES

The Federal endangered species considered in this report include the humpback chub, razorback sucker, bald eagle, peregrine falcon, and Kanab ambersnail. The southwestern willow flycatcher has been proposed for listing as endangered, and the flannelmouth sucker is a candidate species being considered for listing. Other Arizona species of concern in Grand Canyon are the southwestern river otter, osprey, and belted kingfisher.

An "endangered species" is defined as a species in danger of extinction throughout all or a significant portion of its range. Candidate species include category 1—a species for which there is substantial information to support listing as threatened or endangered—and category 2—a species for which some information indicates that listing is possibly appropriate, but biological data on vulnerability and threat are not currently available.

Endangered Species

Humpback Chub



The humpback chub evolved in the Colorado River system 3 to 5 million years ago but was not described as a species until 1946 (Miller, 1946). It was on the original 1967 Federal list of endangered species and remains endangered today. The Grand Canyon population of humpback chub is considered especially important to the recovery of the species (U.S. Fish and Wildlife Service, 1990b).

In 1978, a FWS biological opinion found that Glen Canyon Dam operations had an adverse affect on essential humpback chub habitat and were jeopardizing the continued existence of this species by limiting its distribution and population size. The opinion also stated that dam operations were modifying major portions of humpback chub and Colorado squawfish habitat and were limiting recovery of both species. A jeopardy biological opinion was not included for the Colorado squawfish since it was considered extirpated from Grand Canyon in 1978 and remains in that status today. The opinion suggested Reclamation fund long-term studies on:

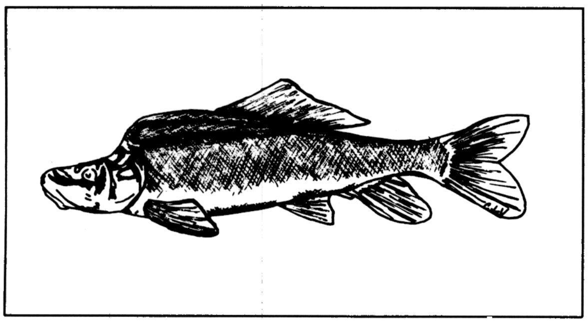
- Impacts of warming the release water
- Ecological needs of endangered species below Glen Canyon Dam
- Reducing known factors constraining humpback chub populations
- The relationship between mainstem and tributary habitats

Following GCES Phase I, Reclamation in 1987 requested formal consultation on the existing operation of Glen Canyon Dam. A draft biological opinion was prepared but not made final. Discussions between FWS and Reclamation resulted in an agreement for Reclamation to fund seven conservation measures that would identify actions to assist in removing jeopardy for the humpback chub. AGFD, FWS, Hualapai Tribe, NPS, Navajo Nation, and Reclamation have been working cooperatively to implement the conservation recommendations.

With the announcement of the preparation of this EIS, FWS recommended that a biological opinion, including the seven conservation measures, be prepared for the preferred alternative. The draft biological opinion was submitted to Reclamation in October 1993. The preferred alternative was revised to be consistent with the reasonable and prudent alternative contained in the draft biological opinion. Comments on the draft EIS and the draft biological opinion led to further refinements of both documents. FWS issued a final biological opinion with a jeopardy finding for humpback chub and razorback sucker (see chapters IV and V). The final reasonable and prudent alternative can be found in attachment 4.

Information on designation of critical habitat for the humpback chub is included in the next section on the razorback sucker. Humpback chub habitat requirements and general biology are described in the FISH section of this chapter.

Razorback Sucker



The razorback sucker was listed as an endangered species throughout its range on October 23, 1991 (U.S. Fish and Wildlife Service, 1991b). Specific habitat requirements for the species are not well known and are the subject of several research programs. However, two major causes for its decline throughout its range were cited in the listing rule:

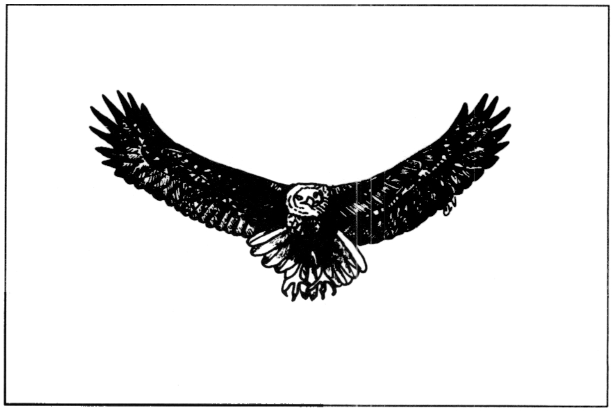
1. Modification of the natural riverine habitats (including impoundment of rivers), modification of historic hydrologic patterns, and cold water from bottom release dams

2. Predation by and competition with non-native fish introduced into the razorback's native range

FWS has completed the process of determining critical habitat for all of the "big river" endangered fish species. Critical habitat is defined by the Endangered Species Act as habitat containing the physical and biological features essential to the conservation of a listed species and may include occupied or unoccupied habitat. A proposed rule was published in January 1993 and the final rule in March 1994. Critical habitat for the humpback chub includes the lower 8 miles of the LCR and Colorado River from RM 34 to RM 208. For the razorback sucker, critical habitat includes the Colorado River from the confluence with the Paria River (RM 0) to and including Lake Mead.

The limited information on razorback sucker habitat requirements is presented in the FISH section of this chapter.

Bald Eagle



The bald eagle was listed as endangered in 1978 and retains that status in 42 states. On July 12, 1994, FWS proposed to reclassify the bald eagle as threatened.

The Colorado River corridor through Grand Canyon is used by migrating bald eagles in the winter. While eagles are capable of taking fish from a river system with characteristics identical to the Colorado River before Glen Canyon Dam, they were not often observed in Grand Canyon until after the rainbow trout fishery was established. Eagles were first recorded in the winter of 1985-86 (4 birds) and have increased to a high of 26 birds counted in a single day at Nankoweap Creek in the winter of 1989-90. Some 70 to 100 bald eagles moved through the area in February and March of 1990 (National Park Service, 1992). Bald eagle use of the river corridor is opportunistic and currently concentrated around Nankoweap Creek, where the birds exploit an abundant food source in the form of winter-spawning trout.

Use of the river by eagles may increase and eventually expand to other locations. For example, bald eagles are regularly located along the river corridor above the LCR and occur around Lake Powell (National Park Service, 1992).

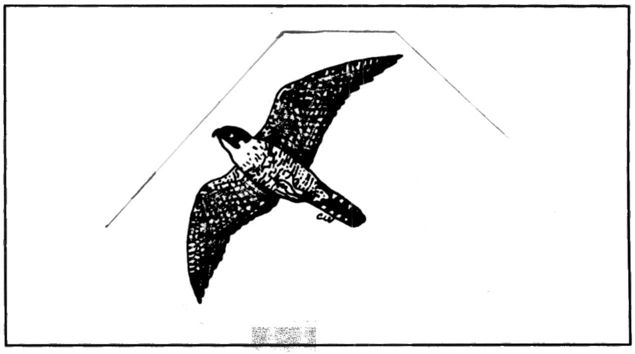
Bald eagles have been recorded wintering on Lake Powell in numbers ranging from 30 to 50 individuals since the early 1980's (Stevens, written communication, 1993). They are present from November through March, apparently using the recreation area both as a migration route and as a winter stopover.

Eagles eat trout stranded in isolated pools along the river near the creek mouth, but the main feeding activity is in Nankoweap Creek itself (National Park Service, 1992). Eagles appear to shift foraging strategies in response to food availability. At low riverflows, foraging is concentrated at the creek mouth and the lower 150 feet of stream. Bald eagle foraging locations appeared to be flow dependent. Increasing riverflows are directly related to an increase in bald eagle foraging attempts more than 150 feet above the creek mouth. However, the success rate for prey capture is the same at the creek mouth or 150 feet above it.

It appears that the number of eagles at Nankoweap Creek is related to the number of spawning trout. More than 500 trout have been recorded at Nankoweap Creek during recent years, with the spawning run peaking at 1,500 fish in 1990 (National Park Service, 1992). The number of trout attempting to ascend and spawn depends on the number of spawning trout in the river and conditions in Nankoweap Creek.

Eagle numbers at Nankoweap Creek were down in 1990-91, as were the numbers of spawning trout. Low discharges in Nankoweap Creek, low water temperature, and ice may have limited the number of trout attempting to ascend and spawn in the creek.

Peregrine Falcon



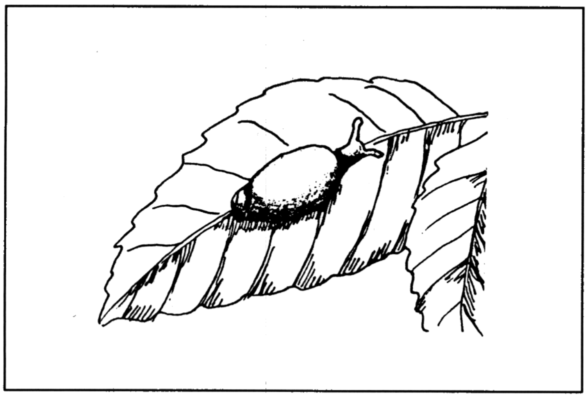
Peregrine falcons were listed as endangered in 1970 but have generally increased nationwide since the prohibition on use of certain pesticides.

Grand Canyon and surrounding areas support the largest known breeding population of peregrine falcons in the contiguous United States (Carothers and Brown, 1991). Between 1988 and 1990, 71 different breeding areas were identified in Grand Canyon National Park. Extrapolation estimates indicate that 96 pairs of peregrine falcon may exist in the study area (B.T. Brown, 1991b). The birds using Grand Canyon appear to be part of an increasing Colorado Plateau peregrine falcon population. For example, more than 60 territories around Lake Powell have been geographically defined and confirmed to be occupied, within which about 50 peregrine breeding areas have been specifically located (Stevens, written communication, 1993).

Although relationships are still under investigation, it is assumed that the peregrine falcon's success in the area is at least partially due to the abundant prey: violet-green swallows, white-throated swifts, several species of bats, ducks, and other prey. Prey species are plentiful because of large insect populations produced in the clear river water.

The relationships between aquatic productivity, insects, prey species, and peregrine falcons are largely speculative. No specific data are available that could be used to refute or confirm the above relationships, and no data are available on peregrine falcons in Grand Canyon before Glen Canyon Dam. Swifts and swallows make up a significant part of the diets of peregrine falcons elsewhere in the Southwest where falcon densities are identical to those in Grand Canyon (Hays and Tibbitts, 1989; Tibbitts and Ward, 1990; Berner and Mannan, 1992). At those sites, surface water is often unregulated, limited (small perennial streams), or virtually absent (ephemeral streams).

Kanab Ambersnail



The Kanab ambersnail was designated an endangered species in 1992. Only three known populations exist—two near Kanab, Utah, and one in Grand Canyon on land around a perennial stream that plunges from the canyon wall to the Colorado River (Spamer and Bogan, 1993). Since the listing of this species in 1992, one of the Utah populations is believed extirpated.

The Kanab ambersnail is a terrestrial snail in the family Succineidae. It has a mottled grayish to yellowish-amber shell and lives in marshes and seeps located at bases of sandstone cliffs. Vegetative cover is necessary for this mollusk. Individuals in Grand Canyon are associated with cardinal monkey flower and water cress. The assumed habitat is a densely vegetated, wetted area of about 340 square yards. The availability of cardinal monkey flower or other vegetation and the presence of rock ledges influence the distribution of this species towards the river. Since implementation of interim flows in 1991, Kanab ambersnail habitat has increased down to an elevation equivalent to the 20,000-cfs river stage.

Other Special Status Species

Flannelmouth Sucker

The flannelmouth sucker is listed as a category 2 species under the Endangered Species Act. The species is found in the Paria and Little Colorado Rivers; Shinumo, Kanab, and Havasu Creeks; as well as various locations in the mainstem, especially western Grand Canyon (Arizona Game and Fish Department, 1993). Habitat requirements and general biology of the flannelmouth sucker are discussed in this chapter under FISH.

Southwestern Willow Flycatcher

Nesting pairs of the southwestern willow flycatcher in Grand Canyon increased following closure of Glen Canyon Dam. In the 1980's, the population along the Colorado River in Grand Canyon was believed to be no more than a few dozen pair but represented the largest population of willow flycatchers in Arizona (Unitt, 1987). Carothers and Brown (1991) attribute this response to increases in riparian vegetation following reduced high flood discharges.

In a 1991 survey conducted in Glen Canyon and the upper portion of Grand Canyon to Cardenas Creek, only two pair of nesting birds were detected. It has been speculated that changes in the numbers of nesting pairs may be related to brown-headed cowbird parasitism and habitat fragmentation (B.T. Brown, 1991a). On July 23, 1993, this bird species was proposed to be listed as endangered (see discussion under "Consultation" in chapter V).

Arizona Species of Concern

The State of Arizona lists three species of concern that may use the river corridor and tributaries in Grand Canyon: the southwestern river otter, belted kingfisher, and osprey.

The southwestern river otter is considered an endangered species by the State of Arizona. River otters have always been considered rare in Grand Canyon, with the last sighting reported in 1983 (Bravo, verbal communication, 1991). The southwestern river otter is listed as a category 2 species under the Endangered Species Act but generally is believed to be extinct.

The osprey is a rare fall, spring, or accidental transient in the canyon listed by the State as a "State threatened" species (Arizona Game and Fish Department, 1988). The belted kingfisher is a "State candidate" species found in low numbers year round in the canyon and its tributaries. Both birds are rare or uncommon in Grand Canyon.

CULTURAL RESOURCES

Cultural resources include prehistoric and historic archeological sites, traditional cultural properties, sacred sites, collection areas, and other resources that are important to Native Americans in maintaining their cultural heritage, lifeways, and practices. Both archeological sites and Native American traditional cultural properties exist in the corridor of the Colorado River between Glen Canyon Dam and Separation Canyon, a 255-mile section of the Colorado River within Grand Canyon and Glen Canyon. The affected area also includes lands adjacent to the Navajo Nation, the Havasupai and Hualapai Reservations, and Lake Mead National Recreation Area.

Both historic and prehistoric resources relate to cultural traditions beginning with the Archaic peoples (*ca.* 2500 B.C.), continuing through the Puebloan and Cohonina peoples (*ca.* A.D. 500–1200), the Cerbat tradition (*ca.* A.D. 1300–1700), and Paiute groups (possibly Archaic through historic times). Apachean occupation of the Grand Canyon region is documented by the late 17th century, and use by numerous groups continues to the present. Historic Angle-American use of the area began in 1869 with the first attempt to explore the Colorado River and subsequent exploration and economic exploitation of the area.

The following Native American groups have ancestral claims to the canyon and continue to use the area today:

- Havasupai
- Hopi
- Hualapai
- Navajo
- Southern Paiute
- Zuni

Archeological Sites

Archeological research in Grand Canyon began in 1869 with the first report of "Moqui" ruins by John Wesley Powell, the first Anglo-American to travel the length of the Colorado River (Powell, 1875). Professional archeological work was begun in the Lees Ferry area by Julian Steward in the early 1930's (Steward, 1941) and by Walter Taylor along the Colorado River in Grand Canyon in 1953 (Taylor, 1958). Site reporting over the years and limited surveys of the rims and the inner canyon have recorded over 2,600 sites in Grand Canyon and 2,300 sites in Glen Canyon. A complete archeological inventory of the river corridor, encompassing all traversible terrain from the river up to and including predam river terraces, was completed for this EIS.

A total of 475 prehistoric and historic sites were located within the affected environment, many representing use by Puebloan people including the Hopi and Zuni, Pai and Paiute, and the Navajo and Anglo-Americans. A total of 323 sites have been determined eligible for inclusion on the *National Register of Historic Places* (National Register) as contributing elements to the Grand Canyon River Corridor Historic District. One site has been recommended for archeological testing before the determination of eligibility is made. The remaining sites either were ineligible or were not evaluated because they are outside the zone of potential impact.

Anglo-American historic resources within the affected area total 71 sites or components and represent use of the area between 1869 and 1940. One historic resource located in the Colorado River, the Charles H. Spencer Steamboat, was listed on the National Register in 1974 as part of the Lees Ferry Historic District. A separate nomination was prepared for the steamboat, and it was listed as an individual property in 1989. All other historic properties within the area are considered eligible for inclusion in the National Register.

Native American Traditional Cultural Properties and Resources

Six Native American tribes have ancestral and modern day ties to Grand Canyon and the Colorado River. While archeological data can provide some information concerning traditional uses of the area, each tribe has its own account of its history and relationships with other tribes. The Colorado River, the larger landscape in which it occurs, and the resources it supports are all considered sacred by Native Americans. Within this larger landscape are sites, locations, and natural resources that are of traditional significance to all tribes or to individual tribes. These Native American traditional cultural properties are tangible historic properties eligible for the National Register (Section 101(d)(6)(A) of the National Historic Preservation Act, as amended) because of their association with cultural practices and beliefs rooted in history and their importance in maintaining the cultural identity of ongoing Native American communities. Many Native Americans believe that humans cannot own the land and its resources; rather, humans belong to the land. The following discussions summarize the importance of Grand Canyon and the Colorado River for all of the affected Native Americans of the region.

Havasupai Tribe

The Havasupai Tribe is one of two tribes still living within a segment of Grand Canyon. Their home within Cataract (Havasu) Canyon encompasses part of their 185,000-acre reservation, which includes land on the rims both east and west of Havasu Canyon proper. Traditionally, the Havasupai farmed the canyon areas during the summer months, moving to the plateaus during the winter to hunt and gather from the plentiful resources available. Their ancestral lands covered an area from the Colorado River on the north to the Bill Williams Mountains and the San Francisco Peaks on the south, and from the Aubrey Cliffs on the west to the LCR gorge on the east. Archeological evidence of their ancestral uses of the area dates to as early as A.D. 700, although the majority of remains found within Grand Canyon date to after A.D. 1100 (Dobyns and Euler, 1958; Euler, 1958).

Many of the native flora and fauna found in the canyon are important to the Havasupai, both economically and religiously. Native plants are used for medicinal purposes, as well as for everyday items such as basketry. Animal resources are very important for the basic subsistence of the tribe. Havasupai ancestral lands provided most of the resources needed to live successfully in and around Grand Canyon. The Havasupai were active trading partners with other tribes—most notably the Hopi, Hualapai, Navajo, and Mohave.

The Havasupai people are one of 14 bands of Pai Indians. Other local bands of Pai are known today as Hualapai and Yavapai. All share common ancestry and similar language, with Havasupai and Hualapai having nearly identical dialects. Formal divisions among the bands did not occur until white settlers moved into their homelands. While most bands were subdued and forcibly moved off their traditional lands, the Havasupai remained isolated in their canyon home. This isolation kept them from many of the direct military conflicts encountered by other neighboring tribes. They were, however, confined to a 500-acre reservation in 1882. Their reservation was expanded to its present site in 1975.

The Colorado River plays an important role in defining the Havasupai as a people. Many religious stories of origin exist for the bands of the Pai, with water a key element in most. One tells of the creation of the people from reeds cut down along the river. The Havasupai consider the Colorado River the spine of their lifeline and, as such, sacred in itself.

Hopi Tribe

Grand Canyon is significant in defining the cultural and religious life of the Hopi people. Archeological sites, religious shrines, springs, locations of medicinal herbs, and other sacred places in Grand Canyon are important because of their role in perpetuating Hopi life and culture. These places provide a vital spiritual and physical link between the past, the present, and the future.

Hopi culture begins with the emergence of the people into this present world from the *Sipapu*, a travertine cone in Grand Canyon. After their emergence, Hopi people migrated around the Southwest until all clans came back together at the center of their universe: the Hopi Mesas. For many clans, these migrations included residence in Grand Canyon. This is well documented in the archeological record (Fairley et al., 1994). Of the 475 cultural resource sites identified by the NPS during its survey of the canyon bottom, at least 180 consisted of the remains left by a prehistoric Puebloan people. Conventional archeological theory, as well as Hopi oral history, holds that these sites were produced by the ancestors (*Hisatsinom* in the Hopi language) of the present day Hopi people.

Evidence shows that use of Grand Canyon by the Hisatsinom began around A.D. 700–800. These people increased in number and began to use all portions of the northern and eastern canyon bottom, as well as both the north and south rims. By the 10th century, small pueblos dotted much of the arable land in the canyon bottom. Associated with some of these pueblos were *kivas*, ceremonial structures found in every modern Hopi village and centers of religious life. By A.D. 1200, the Hisatsinom had largely moved from Grand Canyon, migrating to areas nearer to the present day Hopi Mesas. Ties to the Grand Canyon region were not severed, however, as evidenced by Hopi ceramics dating to post-A.D. 1300 found throughout the canyon. Similarly, ritual pilgrimages to Grand Canyon for salt, minerals, and other resources—as well as to visit shrines—have continued into the 20th century.

Just as modern Hopi villages have shrines associated with them, so do their prehistoric counterparts. Any pueblo that contains a *kiva* can be assumed to have shrines. While people may no longer regularly deposit offerings at these shrines, they are still sacred areas.

Hopi people have a number of concerns about their ancestral homesites being damaged by erosion. The Hopis value these sites as markers on the landscape that serve to physically document their cultural claim to the land. Many of these sites contain the remains of Hopi ancestors. Proper respect for and treatment of the dead are extremely important values in Hopi culture. Hopi people feel that human graves should not be excavated solely to satisfy scientific curiosity. When graves are disturbed by erosion, however, most Hopis believe these graves should be reburied away from danger, not taken out of the canyon. Nondestructive study of human remains during the process of relocating graves is acceptable to most Hopi people.

Like ruins, rock art ties modern Hopi people to land inhabited by their ancestors. The Hopis have a rich interpretive scheme for assigning meaning to rock art. Their oral history records a number of clans residing in Grand Canyon. Hopi elders have observed the symbols of the Fire, Strap, Spider, Kachina, Lizard, Turkey, Bow, Water, Bear, Greasewood, and Badger Clans immortalized in petroglyphs in the canyon. The many handprints at rock art sites are interpreted as the markings left by clan leaders during Hopi migrations.

All of the springs in Grand Canyon have spiritual importance to the Hopi people. One of these springs, Vasey's Paradise, was specified by Spanish priests as the location from which the Hopi people were to collect holy water and drinking water for the Catholic missions. It is important to the Hopi that these springs are not damaged in any way by the Glen Canyon Dam operations.

Hopi people continue to use Grand Canyon for important ceremonial and ritual purposes. The Hopi Salt Mines on the Colorado River are the focus of an arduous pilgrimage associated with initiation rites of Hopis. The Twin War Gods established the steep trail down the walls of Grand Canyon for this salt pilgrimage and identified many shrines where offerings and rituals are conducted along the way. Hopis continue to use these places for prayer and make offerings at them during winter ceremonies conducted on the Hopi Mesas. Circumstances relating to trail access and theft of ritual items have precluded the initiation rites which would allow Hopis to take part in the pilgrimages. Without initiation, Hopi visits to the mines are considered too dangerous. All of the Hopi ancestors have returned to Grand Canyon and now spiritually occupy it. The presence of their ancestors makes Grand Canyon an especially holy and spiritually dangerous place, and all use thus requires proper spiritual preparation and a respectful attitude.

The Hopis believe that humans are stewards of the earth and should nurture all living things. All living things play an important role in creation and therefore have a right to exist. The Hopi people think the loss of any fish, animal, or plant would impoverish the world and thus have a negative impact on Hopi life.

Given the sanctity of Grand Canyon, the Hopis are concerned about the attitudes of people who use the canyon for recreation or scientific research. With the proper attitude, use of the canyon for these purposes can be both enjoyable and educational. Using the canyon with a disrespectful attitude can cause serious spiritual problems.

While the Hopis no longer live in Grand Canyon, their concern for its physical and spiritual well-being is not diminished. In fact, their concern for the area is increased, because the Hopis are not there to take care of the sites. The Hopis feel that Glen Canyon Dam should be operated to limit sediment loss and minimize impacts to areas most important to the Hopi way of life.

Hualapai Tribe

The Hualapai Tribe has a long history in Grand Canyon. Their reservation borders 108 miles of the river corridor, although their ancestral interests are much broader. Natural features served as boundaries for their ancestral territory: the Colorado River on the north and west, the San Francisco Peaks on the east, the Bill Williams and Santa Maria Rivers on the south. Within the region, the Hualapai lived in groups composed of 14 bands. Each band consisted of nuclear and extended families who used this vast range for their livelihood. No single band owned the territory. The people lived in harmony as a group and also lived in harmony with nature.

The various bands descended from one people, a group known archeologically as the Cerbat. Culturally, both the Hualapai and Havasupai—along with the Yavapai—are referred to as *Pai* (meaning "the people") and consider themselves as "one ethnic group, the only true human beings on earth." Physical remains of their presence in Grand Canyon date at least to A.D. 1300. Evidence of earlier use of the region has been documented near Hoover Dam at Willow Beach, where dates may extend back as far as A.D. 600 (Schroeder, 1961), and sites with associated ceramics date from A.D. 700-1890 (Dobyns and Euler, 1958).

The Colorado River is a significant landmark for the Hualapai both spiritually and physically. The Hualapai believe that the river is the backbone or spine known as *"Ha'yitad."* Historically, all of the Yuman language family tribes were located on or near the river. There is a common bonding creation account which took place at "Spirit Mountain," or *"Wikahme,"* along the Colorado River near Bullhead City, Arizona (Watahomigie et al., 1983).

Grand Canyon and surrounding plateaus offered the Hualapai the necessary resources to live successfully in the region. Wild game was the prime source for survival, most notably, the desert bighorn sheep. Other game animals including deer, elk, and antelope also provided shelter, clothing, tools, weapons, and ceremonial objects (Watahomigie et al., 1986). Plants were important, both for food and for medicinal purposes. The major wild foods were derived from cactus fruit and from seeds of grasses and plants native to the area (Watahomigie et al., 1982).

Hualapai historical accounts are recounted through oral traditions. The names of the landsites of sacred canyons are derived from important area events. Trails and trade routes within Grand Canyon allowed the Hualapai to exist successfully within the region, not only with bands of the Pai but also with neighboring tribes such as the Hopi, Paiutes, Mohaves, and Navajos.

The Hualapai Indians have occupied and used the lands and waters lying within their ancestral territory, as well as within the present reservation, for more than 1,000 years—long before the records and history of white society in the area. Evidence of their occupancy, use, and ownership of the territory is contained in their family and tribal records, traditions, and legends—unwritten, but faithfully transmitted from parent and leader to offspring and follower, from a people that lived in the distant past to the present.

Navajo Nation

The Navajo Reservation borders part of the affected environment, from Glen Canyon Dam to the confluence of the LCR—a distance of 76.5 miles. Throughout the Colorado River corridor are places of historical, cultural, and religious importance to Navajo people.

Archeological and linguistic evidence suggests that the Apacheans (Athabaskan-speaking ancestors of the modern Navajos and Apaches) entered the North American Southwest sometime between A.D. 1000 and the 1400's (Brugge, 1983; G.M. Brown, 1991). During this time, the Apacheans traded and intermarried with neighboring Puebloan and other groups. Traditional Navajo culture of today is the result of these interactions (Brugge, 1983; Kelley et al., 1991).

Historical accounts refer to ancestral Navajo interactions with Havasupais in the Grand Canyon region by the 1600's (Navajo Nation, 1962). Evidence clearly establishes Navajo settlement on the plateaus surrounding Grand Canyon by the 1700's (Navajo Nation, no date). By at least the mid-1800's, Navajos were fully using resources in and around Grand Canyon for farming, livestock grazing, plant gathering, hunting, and religious purposes, as well as seeking refuge from Mexican slave raiders and non-Navajo Indian Tribes. During the 1860's, when Navajos were conquered by the U.S. Army and incarcerated at Fort Sumner, New Mexico, many Navajo families escaped into the canyon and lived there for several years. The canyon continued to provide protection to Navajos and their herds of sheep, goats, and horses during the federally imposed livestock reduction program of the 1930's and 1940's.

The boundary of the traditional Navajo homeland is symbolized by the four sacred mountains (although the aboriginal use area extends beyond these mountains): *Sis Naajinii* on the east (Blanca Peak near Alamosa, Colorado), *Tsoo Dzil* on the south (Mount Taylor near Grants, New Mexico), *Dook'o'oosliid* on the west (San Francisco Peaks near Flagstaff, Arizona), and *Dibe Ntsaa* on the north (La Plata Mountains near Durango, Colorado).

Navajos believe they originated from three underworlds and emerged through a series of events into this, the fourth world. These worlds were given to the Navajo people by the Holy People. Water is the basis for the origins of many Navajo clans and is important in oral tradition and many ceremonies.

The Colorado River is a sacred female being to the Navajo's, forming a protective boundary on the western border of Navajo land. It is inseparable from the larger sacred landscape of which it is an integral part. Oral traditions and physical places connect Grand Canyon to its tributaries and the landforms that surround it. Prayers are offered to all these places. The LCR is considered a sacred male being. These rivers provide protection to the Navajo people, not only in the water that is ceremonially used, but in the refuge the canyons have provided to Navajos throughout history. These are among the many sacred and secular resources these canyons, collectively called Grand Canyon, provide to the Navajo people.

In addition to ceremonial uses of water, the Colorado River and its tributaries have provided water for both people and livestock for many generations. The beaches provided arable land for corn fields, and the river terraces provided habitat for the deer, bighorn sheep, and other game that Navajos hunted. The beaches and terraces also support the vegetation that continues to be used for medicinal, ceremonial, and daily domestic purposes. The salt mines also provide salt that is still used ceremonially and was historically used for seasoning food. The many trails used to access the canyons also serve both sacred and secular purposes.

Any effects on Grand Canyon and its resources from the operation of Glen Canyon Dam ultimately affect the stories that are told about them. These stories are the most irreplaceable of Navajo cultural resources.

Southern Paiute Tribe

The traditional lands of the Southern Paiute people are bounded by more than 600 miles of Colorado River from Kaiparowits Plateau in the north to Blythe, California, in the south. According to traditional beliefs, Southern Paiute people were created in this traditional land. Through this creation, the Creator gave Paiute people a special supernatural responsibility to protect and manage this land, including its water and natural resources. *Puaxant Tuvip* (sacred land) is the term that refers to traditional ethnic territory.

Southern Paiute people express a preservation philosophy regarding *Puaxant Tuvip* and the water, minerals, animals, plants, artifacts, and burials existing there. Natural resources are perceived as having their own human-like life force. The Colorado River is one of the most powerful of all natural resources within traditional lands. Elders tell children about its power and the gifts it provides when talked to and treated with great respect. Traditionally, Southern Paiutes lived, farmed, collected plants, and hunted along the Colorado River where it passed through their land. For this reason, the riverbanks are full of culturally meaningful human artifacts and natural elements.

Historically, most Southern Paiute people died when Europeans encroached upon *Puaxant Tuvip,* bringing domestic animals and diseases. Paiute people soon lost control over most of the tributaries of the Colorado River, including the Santa Clara River, the Virgin River, and Kanab Creek. As Paiute people were forced out of these riverine oases, they retreated to Grand Canyon to live in refuge. Thus, Grand Canyon became the final refuge for traditional Southern Paiute life and, as such, assumed additional cultural significance.

Modern Southern Paiute people continue to use Grand Canyon and the Colorado River in traditional ways because they believe the Creator requires them to do so. If a land and its resources are not used in an appropriate manner, the Creator becomes disappointed or angry and withholds food, health, and power from humans. For this reason, Paiute people continue to visit the canyon and river to harvest plants and fish and to conduct ceremonies—even though access to these areas is now limited.

Zuni Tribe

The traditional territory of the Zuni Tribe is bounded by the San Francisco Peaks on the northwest corner and by portions of the LCR and the Pueblo Colorado Wash on the far northern boundary. Although they do not reside in the directly affected environment, Zunis have close ties to the Colorado River and Grand Canyon. The area of Zuni traditional use extends considerably beyond their traditional territorial boundaries and includes Grand Canyon.

Archeological sites, traditional cultural properties, and other sacred locations along the Colorado River corridor and the LCR are important to Zuni traditional and cultural values, providing important spiritual linkages to the place of emergence for the Zuni Tribe. Areas where soil, water, plants, and rocks are collected for ceremonies, as well as a portion of the Zuni Grand Canyon Trail, are located within the affected environment of the Colorado River.

From the moment that the Zunis arrived on the surface of the earth, Grand Canyon and the Colorado River have been sacred. Creation narratives describe the emergence of the Zuni people from Earth Mother's fourth womb, coming out into the sunlight at the bottom of Grand Canyon. The narratives also describe the Zunis' subsequent search for the center of the world, the Middle Place. The people moved up the Colorado River and then up the LCR, periodically stopping and settling in locations along the rivers. At the junction of the LCR and the Zuni River, many *Kokko*—or supernatural beings—came into being. After a long search, the Zunis located the Middle Place and settled there in the village of Zuni.

Trails used by the Zunis for religious purposes have special significance and are cared for by means of particular blessings and prayers. Once a trail is blessed, it remains blessed permanently. The Zuni people thus have important concerns about the ancient Zuni trail from their village to the bottom of Grand Canyon.

Zunis pray not only for their own lands but for all people and all lands. To successfully carry out the prayers, offerings, and ceremonies necessary to ensure rainfall for crops and a balanced universe, Zunis must collect samples of water, plants, soil, rocks, and other materials from various locations. While collecting these materials, Zunis also pray and leave offerings at the locations within the project area. Samples of water from the bottom of Grand Canyon carried in sacred gourds have special significance to Zuni ceremonies and very special meaning to the Zuni people.

The Zuni Tribe is in the process of identifying cultural resources of importance to the tribe within the EIS study area. When these studies are completed, the Zuni Tribe will be able to more fully assess impacts to the resources, as well as traditional and cultural values.

AIR QUALITY

Air quality was identified as an issue for this EIS during public scoping. The area of potential impacts includes not only the immediate Grand Canyon vicinity, but also the regional area served by Western's Salt Lake City Area Integrated Projects.

Grand Canyon Air Quality

Grand Canyon enjoys some of the cleanest air in the lower 48 States, resulting in a visual range that sometimes exceeds 240 miles (Bowman, 1991). Under the provisions of the Clean Air Act, Grand Canyon National Park falls under the designation of a class I area. Class I areas have special significance for their natural, cultural, recreational, or wilderness characteristics. The Clean Air Act includes standards or increments for maximum allowable increases in ambient pollutant concentrations over baseline conditions. The increments for sulfur dioxide (SO_2), nitrogen dioxide, and total suspended particulates are more stringent in class I areas than in other areas and are highly protective of class I area air quality.

Influences on the air quality of the Grand Canyon region include fog, rain, winter storms, and air pollution. During most of the year, a white veil of haze hangs in the canyon—air pollution carried by the wind. Navajo Generating Station near Page, Arizona, has been identified as a major source of canyon air pollution. A survey of park visitors (Bell et al., 1985) concluded that visitors are very aware of the haze and feel that it detracts from their visit.

Regional haze generally is at its worst during summer months. Average visibility is only 100 miles, and it drops below 68 miles 10 percent of the time (Bowman, 1991). Air is carried into the Grand Canyon area from the south and west, where it picks up heavy loads of pollutants from urban and industrial areas. By the time the air masses reach the canyon, they are well mixed, and the haze spreads evenly throughout the lower atmosphere. As a result, haze is more apparent when viewing distant landmarks than when viewing the canyon.

During the winter, strong cold fronts bring in clean air from sparsely populated areas. Average visibility is 158 miles, but it reaches more than 211 miles 10 percent of the time (Bowman, 1991). Between the passages of cold fronts, however, the air stagnates. Under these conditions, pollution from local sources sinks into the canyon, where it can be trapped by strong inversions until a front again brings in clean air.

Haze appears when light passes through tiny particles in the air and is scattered in many different directions (Malm, 1983). More particles mean more scatter. The observer sees this scattered light as a white haze. Some of the particles that scatter light are natural; the sky is blue because some gases in the atmosphere scatter blue light. Other natural particles also scatter or absorb light. Dust raised by the wind, smoke and soot from forest fires, and volcanic ash and gases scatter light and produce haze. Usually these particles are rather large (more than 2.5 microns in diameter). The large size means two things:

- They settle out of the air faster.
- They are only about one-tenth as efficient at scattering light as small particles.

Figure III-33 shows the relative proportions of various fine particles measured in Grand Canyon air in 1982-83.

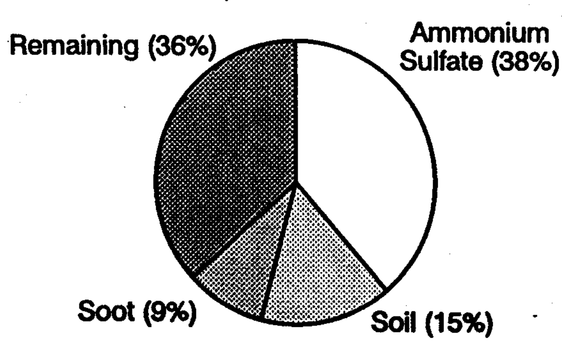


Figure III-33.—Various types of fine particles measured at Grand Canyon, 1982-83. (Percentages were rounded to the nearest whole number.)

Anthropogenic (human-created) haze is usually different, resulting from fine particles such as soot from fires and diesel engines, dust from farming and dirt roads, and other sources. However, not all particles can be easily categorized as natural or human created. For example, forest fire smoke may be from a natural wildfire or a prescribed fire. Other particles have few natural sources; sulfates almost always are the result of human activities (with the exception of volcanic eruptions).

Sulfates

Sulfates are the major contributors to haze at Grand Canyon and in the rest of the United States (Shaver and Morse, 1988; Malm, 1989). Their role in creating haze is shown in figure III-34 (Malm, 1989). Sulfates are produced from SO_2, a colorless gas released from many sources, especially burning fossil fuels and smelting metals. If SO_2 were to remain a colorless gas, it would not be a visibility problem (although it would continue to contribute to acid deposition). But SO_2 is not inert; it reacts in the air to form sulfate particles. This reaction depends on a number of factors but occurs fastest when the relative humidity is high. The sulfates then bind with water vapor to form tiny particles that very efficiently scatter light.

The major sources of sulfate at Grand Canyon are to the south and west of the park (Malm, 1989). During the summer, wind patterns bring air over distant SO_2 sources such as southern California. While this air travels to Grand Canyon, SO_2 converts to sulfate, thus creating the thick summer haze. During the winter, air from distant areas is clean, but during periods of stagnation, there is time for the SO_2/sulfate conversion to create haze from local SO_2 sources including areas to the north and east. Figure III-35 shows year-round averages for sulfate sources affecting Grand Canyon from 1981 to 1985. The relative importance of a source area may vary throughout the year and even with the passage of a specific air mass. The absolute amount of sulfate varies from

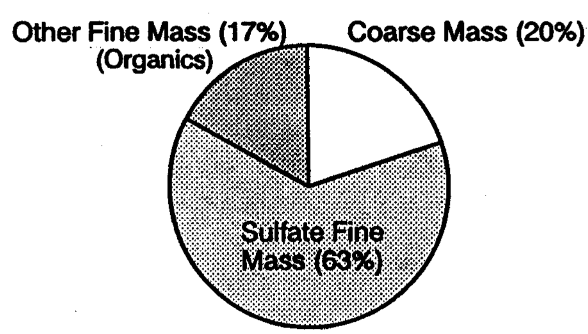


Figure III-34.—The amount of haze caused by various particles in Grand Canyon air.

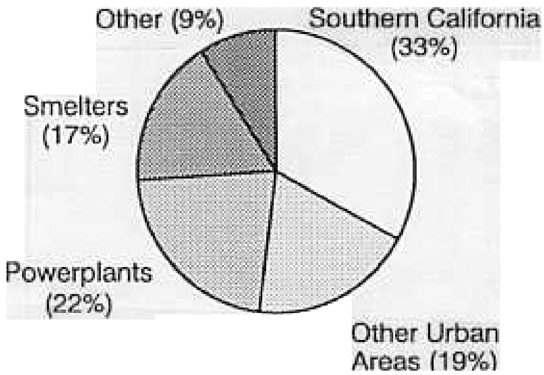


Figure III-35.—Sources of sulfates at Grand Canyon, 1981-85.

year to year as well. For example, during 1980-85, there was a 50-percent increase in summer sulfate levels measured at the canyon (Malm, 1989).

One source of sulfate in Grand Canyon is Navajo Generating Station, identified as a major SO_2 contributor by an NPS study. In response to the study, the Environmental Protection Agency mandated modifications to reduce emissions beginning in 1995. These modifications are scheduled to be in service for all three powerplant units by August 1999.

Regional Air Quality

Changes in dam operations may affect regional air quality. Glen Canyon Powerplant is integrated into a regional power system (chapter III, HYDROPOWER). Although the total annual generation would not vary significantly if power production at Glen Canyon Dam was shifted from daytime to nighttime (or from peak to off-peak months), power for those periods would have to be replaced elsewhere in the system. This replacement power could be generated by new, cleaner-burning powerplants, which would result in less emissions than generation by existing powerplants. This change could be apparent either in the region, or elsewhere in the marketing area served by the Salt Lake City Area Integrated Projects.

SO_2 is now a regulated pollutant associated with adverse health effects. Nitrogen oxide (NO_x) emissions also are produced from burning fossil fuels and react in the atmosphere to form ozone and acid aerosols. Most utilities presently concentrate their efforts on reducing SO_2 and NO_x emissions, so changes in these emissions will be tracked under this analysis.

RECREATION

Dam operations affect the experience of recreationists using the Colorado River in Glen Canyon and Grand Canyon, as well as those using Lake Powell and Lake Mead. The recreationists most affected by different flows are anglers, day rafters, and white-water boaters.

The 15-mile segment of the Colorado River below Glen Canyon Dam, located within the Glen Canyon National Recreation Area, is the last remaining riverine section of the 189-mile river-carved channel that was once Glen Canyon. This segment, the Glen Canyon reach, is used by a variety of recreationists including fishermen, boaters, day rafters, campers, and hikers.

The Colorado River through Marble and Grand Canyons is the longest stretch of river (278 miles long, with over 160 recognized rapids) for recreational use entirely within a national park. The river is surrounded by more than 1 million acres of land with little human development. Some of the world's most challenging and exciting white water occurs here. The river's isolation in the mile-deep gorge of Grand Canyon gives it primitive recreational qualities and enhances off-river hiking, climbing, and sightseeing.

Hoover Dam impounds the water of the Colorado River, forming Lake Mead—the largest reservoir in the Western United States. About 100,000 boaters annually use the stretch of Lake Mead and Grand Canyon from South Cove to Separation Canyon for scenic boating, camping, fishing, water-skiing, and other recreational pursuits.

Fishing

A discussion of trout as a biotic resource can be found under FISH in this chapter.

Fishing in Glen Canyon

The Glen Canyon trout fishery is a byproduct of Glen Canyon Dam. Discharge from the dam is colder, carries less silt, and is more stable on an annual basis than it was in this section of the Colorado River prior to construction of the dam. This altered environment is ideal for trout, allowing AGFD to begin a stocking program in 1964. As many as 100,000 rainbow trout have been stocked in some years; and in more recent years, brook and cutthroat trout have been stocked as well. *Gammarus*, shrimp-like amphipods, were introduced in 1968 to provide a forage base for trout and have flourished, providing ample support for the fishery.

The introduced trout have created an important fishery that is considered by many to be blue ribbon quality. This blue ribbon fishery developed under postdam conditions. Surveys of Arizona anglers conducted by AGFD in 1981 and 1989 found that, collectively, trout were the most desired sport fish in the State (this preference has been recognized since territorial days).

Each year, more than 19,000 anglers fish for trophy-sized rainbow trout in the 15-mile reach below the dam. Of these, about 11,000 anglers fish by boat, while 8,000 wade or fish from the bank in the Lees Ferry area. Angler days decreased from a peak of 52,000 in 1983 to only 15,000 angler days in 1985, but now participation has returned to a level exceeded only by the 1982-84 peaks (Reger et al., 1989).

NPS places higher priority on maintaining native fish species than on maintaining recreational resources. However, NPS recognizes that this stretch of the Colorado River is now a cold water fishery and thus designates trout as a recreational resource.

Fishing Trip Attributes. The fishing day for boat anglers averages about 7 hours, while shore anglers fish for an average of 4-1/2 hours (Reger et al., 1989). Use levels peak in early spring and fall, corresponding to times when air temperatures are less extreme and flows fluctuate least. Catch rates are highest in midsummer and midwinter.

A study by Bishop et al. (1987) revealed that the attributes that contribute most—either positively or negatively—to the Glen Canyon fishing experience are the size and number of fish the respondent expects to catch. The two most important attributes of an excellent or perfect Glen Canyon fishing trip were "catching a trophy fish" and "good weather"; "camping along the river" was the least important attribute. The productivity of the fishery is also a factor in fishing success (see "Trout" in the FISH section of this chapter).

The respondents also were asked to rate the importance of a list of factors that might contribute to a poor fishing trip. The most important flow-related trip attributes to anglers on the Colorado River in Glen Canyon were catching fish, degree of crowding, ability to get upstream, and boat or motor trouble due to low water. Fishing success is believed to be flow-influenced in two ways: rising waters may improve fishing as fish begin to feed on the debris stirred up by the rising water; and flows of 10,000 cfs and less provide gravel and rock bars for fishing and some room for bank fishing between the water's edge and shore vegetation. Low flows influence boaters' ability to get upstream, especially at 3-Mile Bar, and are a potential cause of boat or motor trouble (these topics are covered under "Day Rafting" and will not be treated here). Although not emphasized as an influence on trip attributes, trout stranding may detract from the fishing experience.

Glen Canyon Blue Ribbon Trout Fishery.— The AGFD's management objective for the Colorado River below Glen Canyon Dam is to provide a blue ribbon fishery. To accomplish this, the State of Arizona uses special regulations to improve the natural productivity of the system. Under a blue ribbon fishery designation, the State hopes to provide the opportunity to catch large fish. Blue ribbon fishery management limits the harvest of fish through special regulations that encourage "catch and release" by implementing low daily bag limits, size limits, and gear restrictions.

The fishery in Glen Canyon is one of only two blue ribbon stream fisheries in Arizona, which increases its importance to anglers and AGFD. Blue ribbon fishery waters can be maintained through natural reproduction or by stocking. Under historic dam operations and current fishing regulations, supplemental stocking is necessary in order to maintain catch and harvest rates. Rainbow trout spawning occurs on gravel bars in Glen Canyon, and naturally reproduced fish represent about 28 percent of the average trout harvest (U.S. Department of the Interior, 1988).

Janisch summarized the history of the Glen Canyon fishery in four stages (Bishop et al., 1987).

- Put-and-take era (1964-71)
- Trophy era (1972-78)
- Quality era (1978-84)
- Something less than quality but not put-and-take (1985-present)

From 1964 to 1971, the "put-and-take" era, catchable-sized trout were stocked and most were caught within a few months. The average weight of the rainbow trout taken was less than 0.75 pound during this period, and fishing pressure was relatively light.

Around 1971, *Gammarus* became a major part of the trout's diet, and the trout growth rate apparently increased. This resulted in the "trophy" fishery era from 1972 through 1978. Bag limits of 10 fish weighing a total of 40 pounds were not unusual during this period. In response, the number of angler days rapidly increased. Water temperature and habitat seemed conducive to natural reproduction, so the AGFD fish stocking strategy shifted from introducing catchable-sized trout (as practiced during the put-and-take era) to stocking fingerlings. Research subsequently showed that the fishery heavily depends on stocking and that only limited natural reproduction is taking place (Persons et al., 1985).

In 1978, the bag limit was reduced from 10 to 4 trout in an attempt to protect the resource from ever-increasing fishing pressure. In 1980, a rule was enforced requiring that trout either be released or killed immediately after being caught. This rule was an attempt to discourage people from keeping fish alive for extended periods and then releasing them if a larger fish was taken, a practice resulting in high mortality rates for the released fish. Even though the fishery has declined in productivity since 1978, fishing pressure continued to escalate until 1984. Janisch termed the period 1978-84 the "quality" fishery era. Creel census reports still showed a very respectable average weight of 2.79 pounds for fish caught and kept through this period. However, the days of the trophy fishery were ending, and the average weight of fish taken steadily declined.

Bishop et al. (1987) stated that Janisch characterized the current era (beginning in 1985) as "something less than quality but not put-and-take." Further, catch rates are still relatively high and some large fish are taken, but most fish are small in comparison to the trophy era (Bishop et al., 1987). Management strategy is to reduce fishing pressure and stock trout so the fishery can be restored to the quality, if not trophy, level.

Fish over 20 inches long made up about 25 percent of the harvest in the period 1979-83 and less than 10 percent during 1985-88. In 1984-85, fish less than 15 inches long accounted for about 50 percent of the harvest; this decreased to about 20 percent in 1986. However, the harvest percentage of fish less than 15 inches long has been increasing ever since (Reger et al., 1989).

Angler Safety. This flat water section of river is fished predominantly from boats launched at Lees Ferry. Bank fishing, including fly fishing by wading fishermen, occurs in the area around Lees Ferry. They wade out into the channel to the depth their wading gear permits. The rate of increase in flow directly affects the safety of fishermen, in terms of their ability to move toward shore once they notice changing water levels. Lee and Grover (1992) found that anglers believe high flows (30,000 cfs or more) reduce the potential for safely wading in the river. At least three drownings in the past 12 years possibly are related to river stage or stage change.

Camping and Day Use Sites. Within the Glen Canyon reach are six designated camping areas above the high water zone, generally on terraces. There are up to three campsites per camping area, designated by pit toilets and fire grates. Beaches in this reach are used mainly by anglers and day rafters, with over 50,000 visitors each year. Although the camping surfaces generally are located well above the river, discharge and its influence on sediment deposits and sedimentation processes ultimately will influence the size and distribution of these sites. Other flow-related problems include accessibility to sites and physical space for mooring boats at campsites.

Kearsley and Warren (1993) inventoried sites available in the Glen Canyon reach for camping and day use. Of the potential 18 camping and day-use sites in this reach, only 12 normally are available. The other 6 are low water sites available only when flows are 15,000 cfs or less.

Fishing in Grand Canyon

Fishing in Grand Canyon is largely an activity incidental to white-water boating or backpacking. The exceptions are found mostly in the vicinity of Jackass Canyon and in other side canyons around Marble Canyon.

NPS controls most access to these wild trout fisheries by issuing backcountry and river permits. Commercial river companies are not allowed to offer trips that are primarily for fishing within Grand Canyon; however, fishing is allowed as an incidental activity on river trips. The only restrictions on anglers are localized closures to protect endangered species and a required fishing license from the State of Arizona.

Wild Trout Fishery. The Arizona Coldwater Sportfisheries Plan uses a wildfish concept to "provide anglers the opportunity to catch fish that are naturally reproduced in the wild." The tributary and mainstem fisheries (table III-11) for rainbow and brown trout in Grand Canyon are managed under the wildfish concept.

Table III-11.—Wild trout fishery designations in Grand Canyon (AGFD, 1990)

Bright Angel Creek (12.9 miles)
Clear Creek (4.1 miles)
Colorado River (229.0 miles)
Crystal Creek (5.2 miles)
Deer Creek (0.1 mile)
Havasu Creek (3.5 miles)
Nankoweap Creek (0.1 mile)
Phantom Creek (3.9 miles)
Pipe Creek (0.5 mile)
Royal Arch Creek (0.7 mile)
Shinumo Creek (0.1 mile)
Stone Creek (5.0 miles)
Tapeats Creek (4.5 miles)
Thunder River (0.4 mile)
Vishnu Creek (1.8 mile)

Wild fisheries are sustained entirely by natural reproduction. Since most of the waters within Grand Canyon are accessed by trail or raft, angler density is limited, thus protecting the fishery from overharvest. The daily limit is four fish for the Colorado River from the Marble Canyon Bridge through Grand Canyon to Separation Canyon, including all tributaries. Trout taken from these areas must be either immediately released or killed and retained as part of the bag limit.

Angler Safety. Most Grand Canyon fishing is conducted from either a raft or the riverbank; few anglers wade into the river to fish. As a result, angler safety is not considered a major issue.

Day Rafting

A Glen Canyon raft trip is a leisurely 15-mile, 1-day float trip. In 1991, more than 33,000 visitors took half-day raft tours of the Glen Canyon reach. All Glen Canyon raft trips have professional guides to run the rafts and explain the river attractions. Wilderness River Adventures is the only concessionaire authorized to provide commercial Glen Canyon raft trips. Several tour companies support these trips by busing raft passengers from Grand Canyon south rim and other areas to Glen Canyon.

Trip Attributes

Bishop et al. (1987) found that the only flow-sensitive attribute of a Glen Canyon day-raft trip may be its origin. At low to moderate flow levels (generally less than 29,500 cfs), the 20-person tours depart from a dock near Glen Canyon Dam and float or motor downstream to Lees Ferry. When releases are above 29,500 cfs and outlet works are in use, departure from the base of the dam is unsafe due to the volume and turbulence of the water. In these cases, rafts normally depart from Lees Ferry carrying fewer people (10) and motor part way upstream before floating back downstream. The decreased raft capacity occurs because the pontoons are removed to reduce water resistance while motoring upstream, which reduces stability. Most trips departing from Lees Ferry do not go all the way up the river, and passengers do not get a view of Glen Canyon Dam from the river.

Lee and Grover (1992) found that—at low flows—day rafters were more likely to feel that the water was too low and slow, more likely to wait longer to launch, or more likely to experience minor motor or raft damage. At high flows, rafters were more likely to notice beach erosion at shore stops. Overall trip satisfaction remained high and not significantly different at all flow levels.

Raft trips stop at channel margin sediment deposits for day-use and lunch stops. These sites are beach-like in character and likely to be influenced by discharge from the dam.

Navigability, Access, and Boating Safety

Individuals who boat in the Glen Canyon reach must launch at Lees Ferry and motor upstream. The narrow constrictions and riffles within the reach cause the greatest difficulties during periods of low flow. Certain types of equipment, such as jet boats, can better negotiate the river during periods of low discharge.

During flows of 3,000 cfs and less, few boaters are able to go upriver past 3-Mile Bar (RM -3), a shallow riffle (Welsh, verbal communication, 1991). Damage to boats and motors is more frequent than at higher water levels. In addition, fishing activities at flows less than 3,000 cfs are concentrated within the 3 miles above Lees Ferry, especially on weekends and other high-density days; some boats are stranded upstream of 3-Mile Bar following lowering of flows. If tied too tightly to banks, boats are left "high and dry" above water stage, only to become swamped when discharge increases. During 5,000-cfs flows, about 75 percent of boaters are able to negotiate 3-Mile Bar, while nearly all boaters can do so during 8,000-cfs or greater flows.

Up to 23 rafts are launched daily by the rafting concession. Discharge from the dam becomes an influence on these rafts at constrictions in the channel, causing the most problems during periods of flows less than 5,000 cfs (O'Mary, verbal communication, 1993).

White-Water Boating

The history of running the Colorado River in Grand Canyon can be traced back to 1869, when John Wesley Powell led the first expedition down the Colorado River through Grand Canyon. Commercial river trips began in 1938. Today, white-water boating in Grand Canyon is a major industry, with 17 companies having permits to conduct commercial raft trips in the park. Also, the Hualapai Tribe conducts river trips from Diamond Creek to Lake Mead.

Prior to the early 1960's, there was little concern about resource impacts along the river. Glen Canyon Dam was yet to be completed, and few visitors entered the canyon or ran the river. From 1960 to 1972, the number of boaters annually running the river grew from 205 to 16,432 persons, paralleling a dramatic increase in white-water boating nationwide. In 1972, increasing problems with management of campfires, human waste, and trash along the river; damage to fragile soils and vegetation; unofficial trails; and destruction of prehistoric sites prompted NPS to regulate river use more closely.

Approximately 15,000 to 20,000 commercial and private boaters annually run the river. This range reflects the changing trends in the length of commercial trips—presently, short duration trips. The number of user days is restricted to 115,500 for commercial trips and 54,450 for private parties. Motorized trips are allowed to launch from mid-December through mid-September. Oar-powered craft can be used throughout the year and exclusively during the "oar-only" period from September 15 to December 15. Noncommercial group size averages below the limit of 16, while commercial group size usually is 36 people. The Lower Gorge, beginning at Diamond Creek, is used for the Hualapai Tribe concession as well as by other commercial and private rafters.

The number of visitors on the river is not solely a reflection of increased popularity of white-water sporting nationwide. Before the dam, riverflows were highly variable and ranged from low flows frequently less than 3,000 cfs to peak flows occasionally in excess of 100,000 cfs in spring and early summer. Now, riverflows are within a much narrower range—from 3,000 to 31,500 cfs—and show less seasonal variation, making it possible to raft during all months of the year because of the reduced high and low water risks. However, many people have rafted the river through Grand Canyon (predam) at and below 1,500 cfs. Most commercial and private raft trips take place during May through October.

Commercial trip passengers contract with an outfitter to provide a boat, other rafting equipment, food, and a guide. Commercial trips use both oar- and motor-powered rafts and typically run from 3 to 4 days for a motor trip (only the upper stretch of the river from Lees Ferry to Phantom Ranch) to 20 days for an oar-powered trip (the full 255 river miles through the park). One- to 2-day trips launch from Diamond Creek.

Private parties furnish their own boats, rafting equipment, food, and guides or boat operators. Individuals must apply for private permits, which are awarded in the order that applications are received. Currently, the waiting list for private permits is about 10 to 12 years, although 40 percent of the individuals on the list are able to take trips sooner due to cancellations.

River Trip Attributes

Bishop et al. (1987) asked white-water boaters, including commercial passengers, to report the attributes that contribute most to an excellent Grand Canyon trip. Good weather, good social interaction, good guides, an unrushed pace (time for layovers and stops at attraction sites), and a wilderness experience were the attributes mentioned most often by respondents. Of the attributes listed by at least 15 percent of all respondents, four are potentially affected by discharges:

- Time for layovers and stops at attraction sites
- Good/exciting rapids
- A wilderness experience
- Not feeling crowded

Bishop et al. (1987) asked white-water boaters and commercial white-water guides to provide self reports on the quality of Grand Canyon white-water trips. Both the guides and the passengers reported that the quality of trips was highest during periods of constant flows in the range of 25,000 cfs to 30,000 cfs.

Rapids are important attributes of white-water boating trips (Bishop et al., 1987). Rapids are flow related since a number of small to medium rapids become "washed out" at relatively high flows, while other larger rapids become more exciting to run. Constant daily flows affect trip procedures at major rapids differently for commercial motor, commercial oar, and private trips. Most commercial oar guides stop to scout major rapids no matter what the flow level. In contrast, commercial motor guides are more likely to stop when flows are below 10,000 cfs and above 50,000 cfs. (Releases higher than 31,500 cfs are rare and unscheduled.) Private trip leaders are most likely to scout rapids at moderately high levels of 25,000 to 35,000 cfs. Guides and trip leaders also are more likely to have passengers walk around major rapids at flows above 35,000 cfs. At low flows (5,000 cfs or less), it often becomes necessary to either walk passengers around some rapids or wait for higher water.

Flow levels also can affect trip schedules. Commercial guides are more likely than private trip leaders to attempt to compensate for the speed of the current at high or low constant flows. Nearly all commercial guides will row or motor more at flows of 10,000 cfs or lower, while most will row or motor less at flows higher than 35,000 cfs.

Numerous attractions are found along the tributaries and side canyons of the Colorado River. River trips make planned stops at many of these and schedule short or extended dayhikes. These stops are important attributes of white-water trips. During low flows, both commercial and private trip passengers may have to miss one or more attraction sites because of the additional time needed on the river to maintain a trip schedule.

Finally, white-water boaters may feel more crowded at high flows because the number and size of beaches for camping are significantly reduced. In addition, during daily fluctuations in flows, boaters may congregate above rapids as they wait for the water level to rise. Jalbert (1992) found no relationship between flows and the incidence of on-river contacts between river rafters, probably because other factors—such as launch dates and itineraries—have a greater influence.

Wilderness Values

Studies of wilderness values in Grand Canyon were begun in the early 1970's but postponed due to the controversy over motorized raft use on the Colorado River. An amendment (Public Law 94-31) to the Grand Canyon Enlargement Act of 1975 called for completion of a wilderness study within 2 years. NPS released for public comment a draft environmental impact statement (DES 76-28) and a preliminary wilderness recommendation in 1976. The preliminary recommendation was for designating 82 percent of the park area as wilderness and an additional 10 percent as potential wilderness. Following incorporation of comments, a final EIS was completed in August of 1980 and forwarded to the Department of the Interior. In August 1993, NPS updated this wilderness recommendation, and action by the Congress is pending.

NPS is mandated by the Wilderness Act to protect wilderness values in the park, including those along the river, and to take no action that would potentially compromise future wilderness suitability. Motorized rafts are still in use on the river, and it is anticipated that the Congress, if it enacts a wilderness designation for the park, will stipulate the conditions under which motor use will or will not continue (under the direction of the Secretary of the Interior) on the Colorado River within Grand Canyon.

Wilderness is both a legal and philosophical concept—an area that appears to be influenced primarily by the forces of nature. The presence of Glen Canyon Dam does not preclude wilderness designation for the Colorado River through Grand Canyon, but dam operations can have an influence on the wilderness setting. The feeling of being in a wilderness area can be affected by fluctuations in daily flows since changes in releases from the dam would continually remind boaters of human control over riverflow and thus the recreational environment.

It should be noted that short duration, sometimes high magnitude changes in flow occurred predam—commonly at intervals of a few days or less—due to floods from tributaries and side canyons. Thus, while predam flow did not resemble the daily fluctuations of dam operations, neither was it steady (see WATER in this chapter). However, predam fluctuations did not detract from the wilderness value in that they were "forces of nature" and evidently not "the hand of man."

One of the attributes of an excellent or perfect river trip most often identified by river runners is a wilderness experience. Enjoying a "wilderness experience" is more important to private (noncommercial) rafters and oar trip passengers and least important to motor passengers. Most river runners are aware of wide daily fluctuations, and most feel that the fluctuations make the trip seem less like a natural setting (Bishop et al., 1987)

Safety

Riverflow levels affect accident rates (although the element of risk is a factor that attracts rafters to Grand Canyon); floodflows and low flows are believed to be the most hazardous. Fluctuating flows are not considered a significant factor in river safety. At low flows, major rapids (such as Hance) become difficult to navigate. Depending on the craft being used and the skill of the boatman, it often is necessary to camp above a rapid to wait for the river to rise. As the average daily flow increases, boaters become more tolerant of wider fluctuation ranges (Bishop et al., 1987).

Commercial guides believe that minimum constant flows must be over 8,000 cfs to safely run river trips with passengers. Commercial motor guides prefer flows around 20,000 cfs, while commercial oar guides and private trip leaders prefer higher mean discharges of 25,000 to 26,000 cfs. The preferred mean maximum flow for commercial guides is over 50,000 cfs, while a great number of private trip leaders prefer 40,000 cfs or less (Bishop et al., 1987).

Accident Occurrence. Although the actual boating accident rate is not high, the very nature of the Colorado River in Grand Canyon presents an unusually severe hazard for white-water boaters since rapids are difficult to navigate and people might fall into the water. In addition to the high water velocities and turbulence, the cold water is life threatening.

Flows in the range of 10,000 to 17,000 cfs appear to be the safest (Brown and Hahn, 1987). The chance of hitting rocks generally decreases as flow increases. The chance of going overboard, flipping boats, and sustaining injuries increases with higher flows. Actions taken to avoid rapids—such as walking passengers around a rapid and portaging—increase at extremely high (above 31,000 cfs) and low (below 5,000 cfs) flows. Taking into account a boatman's judgment of risk and the actions taken to avoid accidents, high flows (16,000 to 31,500 cfs) are safest for both private and commercial trips, with medium and low flows presenting increased hazard for both. During flows less than 5,000 cfs, commercial motor trips have the highest rate of all types of accidents, but private oar-powered trips sustain more equipment damage and more frequently have their passengers walk around rapids (Jalbert, 1992). During floodflows, accident risk is much greater for private than for commercial trips.

The risk of accidents varies by the type of boat employed. At extremely low flows (less than 5,000 cfs), motor rigs have the highest incidence of accidents, followed by small (typically private group) rafts (Jalbert, 1992). At flows higher than powerplant capacity, smaller craft—such as small rafts, dories, kayaks, and canoes/inflatables—have more accidents (Brown and Hahn, 1987). It appears the large, oar-powered rafts had the lowest incidence of accidents over the range of flows (Brown and Hahn, 1987; Jalbert, 1992).

Handicapped Accessibility

White-water boating in Grand Canyon—though a rigorous activity—is in demand by many, including handicapped individuals. Federal law ensures that special populations with mobility difficulties can take white-water trips. Since 1991, two such trips annually have been chartered specifically for special populations.

It is likely that many commercial and private rafters could accommodate handicapped individuals for a raft trip down the Colorado River. Potential inconveniences might include steep-pitched beachfaces and poor mooring sites (for example, a highly armored beachface). Where a party might otherwise be required to carry gear around a rapid, it might be necessary to alter an itinerary, set up camp, and wait for more suitable flows.

The greatest risk to disabled populations occurs during flows that have the highest incidence of accidents resulting in persons going overboard. This risk is compounded by the probability that another person will go into the water to help rescue the disabled individual. Dam operations have the greatest influence on handicapped accessibility during low flows, especially those below 5,000 cfs, when passengers (possibly handicapped) need to walk around a potentially unsafe rapid.

Camping Beaches

Sandbars form the camping beaches used by river runners (see SEDIMENT in this chapter). Camping is possible in only a limited number of locations along the river between Glen Canyon Dam and Lake Mead because most of the shoreline is unsuitable. An inventory of these camping beaches in 1975 listed about 333 campsites within the river corridor, but these were unevenly distributed in size and location. These beaches were resurveyed to assess how high flows influence individual beaches (Brian and Thomas, 1984). At least 227 were verified as being inventoried in both surveys. A survey of the Lower Gorge (Ross, written communication, 1992) inventoried 14 camping beaches.

The 1983-84 flood releases caused numerous changes in camping beaches. Of inventoried beaches, 30 percent increased in size, 28 percent decreased in size, and 42 percent remained the same. Beach degradation occurred in narrow, upstream reaches, while aggradation occurred mostly in wide, downstream reaches. The result was 24 beaches removed or nearly eliminated and 50 new campsites deposited. Brian and Thomas (1984) hypothesized that the system was not in equilibrium after the 1983 floods and that the number, size, and distribution of beaches would change depending on the stability of the sediment deposited at the new beaches.

A survey by Kearsley and Warren (1993) revealed that the total number of suitable camping beaches above the new high water zone had declined to 226 sites, a 48-percent decline in the number of sites considered usable. This reduced number of usable camping beaches can be attributed to erosion and vegetation growth. In narrow (critical) reaches of the river, erosion was the primary cause of campsite degradation. Vegetation encroachment accounted for nearly 50 percent of the campsite degradation in wider (noncritical) reaches (figure III-36).

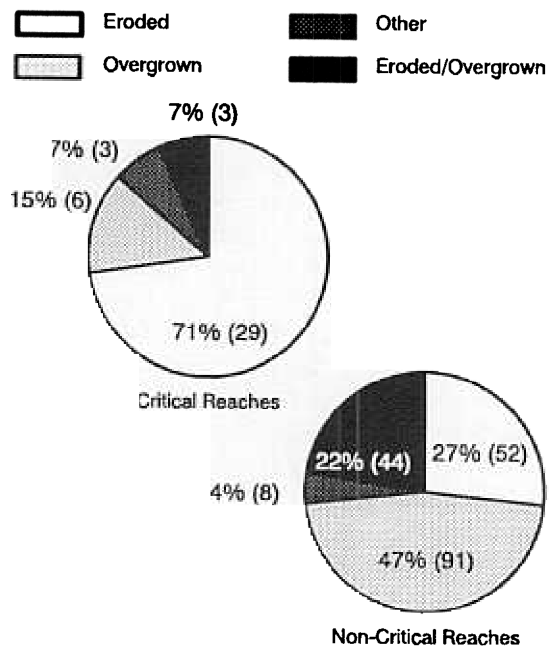


Figure III-36.—Number of camps degraded by reach type and type of degradation.

While flood releases may dramatically impact the size and number of camping beaches, normal dam operations also can affect the long-term characteristics of beaches. Sand storage, erosion, and transport vary with pattern and magnitude of dam releases, as discussed in the SEDIMENT section of this chapter. At a given time, however, campable area depends on the local stage (height) of the river, which is determined by the magnitude of releases and local topography.

Campable Beach Area. Flows affect the usable area of a camping beach. The rise and fall of water levels, as a result of fluctuating discharges, inundates portions of the beaches, strands boats, and influences the wild character of the setting. Daily fluctuations influence campsite selection; many river runners will not choose a campsite that does not offer protection against water level changes (Bishop et al., 1987).

Kearsley and Warren (1993) evaluated the average area for small, medium, and large campsites (based on size of group accommodated) at several discharges. They concluded that campable areas differed significantly under the discharges evaluated. Table III-12 shows the average area of camping beaches by size class and discharge, while figure III-37 shows the percent of beach area change between evaluated discharges. Although large campsites lose more area at higher levels of discharge, this loss is not important in terms of carrying capacity for many camps. The campable area of most large camps far exceeds that needed for the maximum trip size of 36 people. The percent change in area of campsites between discharges for critical reaches was not significantly different than that for noncritical reaches at any discharge level.

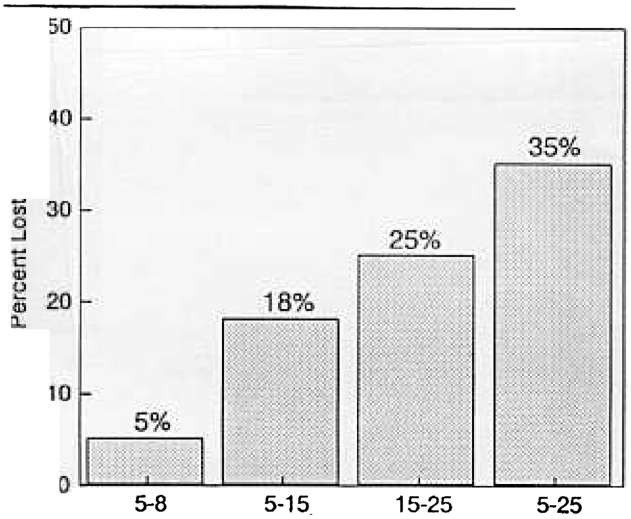


Figure III-37.—Percentage of beach area inundated between discharges.

An average of 35 percent of potential campsite area is inundated when releases increase from 5,000 to 25,000 cfs. About 36 percent of the small and medium sites available at 25,000 cfs become large enough to change size class when dam releases are reduced to 15,000 cfs or less (Kearsley and Warren, 1993).

Beach Availability and Distribution. The location and distribution of beaches, by reach, set the absolute limits on visitor carrying capacity; i.e., the numbers of groups in a critical reach must be equal to or less than the number of campsites available in that reach. The distribution of camping beaches by reach is shown in table III-13.

The number of campsites averages 1.0 per mile, with campsites in critical reaches averaging 0.7 per mile and campsites in noncritical reaches averaging 1.1 per mile (Kearsley and Warren, 1993) (figure III-38). Campsite availability is critically limited in four narrow sections of the river:

- Supai and Redwall Gorge
- Upper Granite Gorge above and below Phantom Ranch (RM 76–117)
- Muav Gorge above and below Havasu (RM 140–165)
- Lower Granite Gorge and Lake Mead (RM 226–270)

Critical reaches have disproportionately fewer large campsites per mile at 0.20 per mile compared to 0.51 large site per mile in noncritical reaches. Deer Creek reach (RM 131-139) has more sites per mile than any other river reach at 2.3 sites per mile. However, because of the popularity of attractions in the area, it is not uncommon for

Table III-12. -Average area in square feet of campsites by size class and discharge for 1991

Size class	25,000 cfs	15,000 cfs	8,000 cfs	5,000 cfs
Small		2,660	3,560	
Medium	4,950	4,940	6,490	7,210
Large	1,720	13,980	17,660	19,340
All	7,720	9,200	11,740	12,910

Note: Low water campsites not included.

Table III-13.—Distribution of camping beaches by reach (Kearsley and Warren, 1992)

Reach	Small (1-12 people)	Medium (13-24 people)	Large (25-36 people)	Total
1	0 (1)	2 (0)	2 (0)	4 (1)
2	4 (4)	3 (1)	3 (0)	9 (5)
3	3 (0)	3 (2)	5 (0)	11 (2)
4	3 (1)	8 (0)	17 (0)	28 (1)
5	1 (1)	7 (0)	11 (0)	19 (1)
6	9 (3)	8 (1)	8 (0)	25 (4)
7	3 (1)	7 (0)	7 (0)	17 (1)
8	1 (1)	13 (0)	7 (0)	21 (1)
9	3 (5)	8 (1)	1 (0)	12 (6)
10	16 (9)	29 (3)	23 (0)	68 (12)
11	2 (1)	6 (2)	4 (0)	12 (3)
12	2 (*)	9 (*)	2 (*)	13 (*)
Totals	47 (27)	102 (10)	90 (0)	239 (37)

Note: Numbers in parentheses indicate additional campsites available at low water (15,000 cfs or less) only.
* Unmeasured.

most of these sites to be occupied during the high use season. As a result of launch limits, usually no more than 60 groups are on the river within Grand Canyon at any one time during the peak season. However, it is not uncommon for all campsites in a critical reach to be in use and for some groups to have to share a camping beach. Lower Granite Gorge to Lake Mead is considered critically limited for camping and affects Hualapai and other commercial and private river recreation by limiting the number of 2-day river trips through the Lower Gorge.

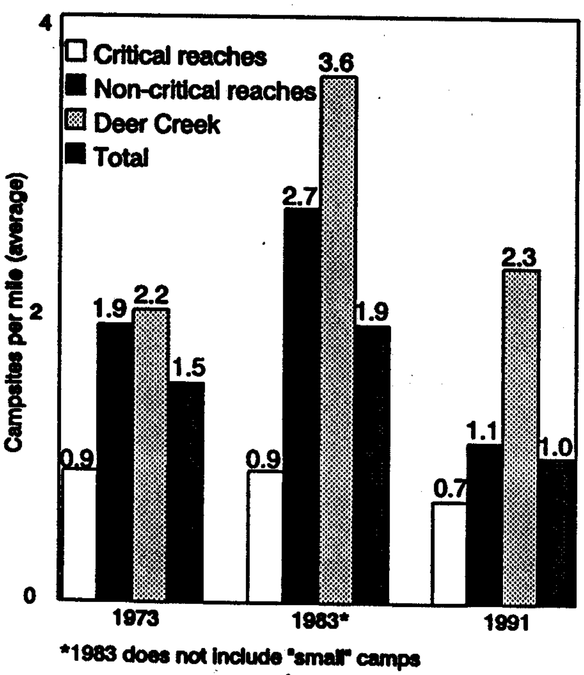


Figure III-38.—Number of campsites per mile by type of reach, 1973, 1983, and 1991 (modified from Kearsley and Warren, 1993).

Thirty-seven favorable sites that become available at discharges of 15,000 cfs or less were identified by Kearsley and Warren (1993). Fifteen (41 percent) of these are in critical reaches of the river, while 22 (59 percent) occur in noncritical reaches. Including these low water sites, the total distribution is 0.85 site per mile in critical reaches and 1.33 sites per mile in noncritical reaches; the low water sites make a more significant contribution to the critical reaches.

Mooring Quality. Kearsley and Warren (1993) analyzed mooring conditions at 129 campsites. Mooring conditions were influenced by large fluctuating flows at all sites. This study indicated that better mooring quality exists under constant flows than under fluctuating flows primarily because overnight boat management problems are eliminated (figure III-39).

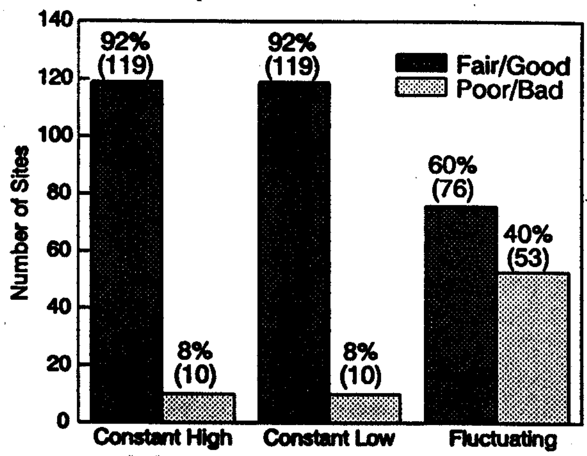


Figure III-39.—Mooring quality on the Colorado River under steady high, steady low, and fluctuating releases.

Fluctuations occurred predam, but they were commonly over a few days or less as a result of tributary or side canyon flooding. Predam fluctuations probably influenced boat mooring—and possibly in ways similar to dam operations—but not with the same frequency and regularity.

Lake Activities and Facilities

Recreation at Lake Powell

Lake Powell is the second largest reservoir in the Western United States. Glen Canyon Dam and Powerplant were constructed to operate between the elevations of 3490 and 3700 feet above sea level. Within this range, the lake has a water surface area of 52,000 to 163,000 acres and a shoreline of 990 to 1,960 miles. Lake Powell provides public recreation in several major categories of activities: lakeshore and backcountry camping, campground use, fishing, boating, beach use, and picnicking.

Normal fluctuations are a part of the nature and role of Lake Powell, with highest water levels generally occurring during the April-June spring runoff and lowest levels during February and March, when the reservoir is drawn down to provide flood storage capacity.

Facilities. Lake Powell currently has five developed marinas, with some expansions and additions planned. Existing facilities (marinas, boat docks, launch ramps, etc.) were constructed when Lake Powell was near its maximum surface elevation of 3700 feet. Normal lake fluctuations influence recreational boating because changing water levels affect access to the water via developed facilities. Change in reservoir levels requires adjusting facilities including marinas, docks, buoys and buoy lines, breakwater barriers, channel markers, and possibly ramps.

Boating. The amount of water storage in Lake Powell directly influences surface area, which in turn dictates boating capacity. At the 3700-foot level, the lake has 163,000 water surface acres. Using the safety standard developed in 1977 by the Bureau of Outdoor Recreation for open lake boating at unlimited power, a 1987 Lake Powell carrying capacity study applied a 9-acre-per-boat density limit, resulting in a safe boating density of approximately 17,932 boats. As shown in table III-14, less water surface results in increased boating density.

Table III-14.—Density as a function of lake surface area (Combrink and Collins, 1992)

Elevation (feet)	Lake surface area (acres)	Safe boating density (No. of boats)
3660	134,280	14,920
3680	147,490	16,387
3700	161,390	17,932

Recreational boating is the largest type of boating activity on the lake surface, with an estimated 1.5 million boater nights per year. While use of the major marinas at Wahweap, Hall's Crossing, and Bull Frog decreased during the low water period of 1989, the total number of boats reported on Lake Powell as of July 31 had increased 14.5 percent compared to the same period in 1988.

Camping. Ninety-five percent of Lake Powell boaters spend at least 1 night on the lakeshore (Combrink and Collins, 1992). As lake level decreases, so does the amount of shoreline and, thus, the number of suitable campsites. Competition for prime camping areas may result in unavoidable crowding, which in turn may influence the recreational experience.

Lake Level and River Rafting. Lake levels have an influence on commercial raft trips taken on the San Juan River and on the Colorado River through Cataract Canyon. The lake is considered a take-out point for raft trips, and most operators are more concerned about lack of water volume in the San Juan and through Cataract Canyon than they are about low lake levels. Lake levels do have an influence on operating costs (in the form of wear and tear on equipment and increased labor costs) and on trip duration.

Navigability of Upper Lake Mead

Boats usually are launched at Pierce basin, South Cove, or Temple Bar for excursions into Grand Canyon. Rental houseboats also travel to the Grand Wash Cliffs area on their week-long trips. Because there are no gas facilities on the lake upstream from Temple Bar, boaters must carry enough fuel to complete a round trip to their destination. Sightseeing in the Lower Gorge is a popular activity for boaters on upper Lake Mead. Popular points of interest on these trips are Columbine Falls, Bat Cave, Spencer Creek, and Separation Canyon. Overnight beach camping is often a part of the itinerary for people enjoying the lower Grand Canyon by powerboat.

Before construction of Glen Canyon Dam, spring runoff carried heavy loads of sediment down the Colorado River to Lake Mead, where the sediment dropped out and settled at the lake bottom in the vicinity of Grand Wash to Pierce basin. After the dam was completed, sediment continued to be transported down the river, but in smaller quantities from side canyons and the beaches below the dam. Over the years, these sediment deposits have built up and are now exposed as broad mud flats in the vicinity of Pierce basin when lake levels fall below 1180 feet. Because no well-defined river channel has been established through these flats, the river is too shallow at low flows for boaters to navigate up to the Grand Wash Cliffs and into the lower reaches of Grand Canyon. Also, the channel changes with fluctuating flows, making it hard for even small boats to stay in the channel.

Economics of Recreational Use

This section describes the existing quantity, distribution, and economic impact of recreation in the study area. Two economic measures—the net economic value of recreation and the regional economic impact of recreation—are introduced. These measures are used to illustrate the national and regional economic impacts of the proposed alternatives.

The net economic value of an activity is the net addition to the Nation's output of goods and services measured in dollar terms. The term "net economic value" is used to emphasize that it is a measure of the value over and above the costs of participating in a recreational activity. The costs of participation in a recreational activity are simply the expenditures made by recreationists.

Regional economic impact is a measure of the importance to the local economy of the expenditures made by recreators. Since such expenditures reflect the costs of participation, they are not considered benefits from the national point of view and are excluded from the calculation of net economic value.

Recreation Use

The amount and distribution of recreational use in the study area have important implications both for estimating regional economic impact and for estimating the net economic value of recreation. The distribution of visitation during calendar year 1991 by recreational activity is shown in figure III-40. As shown, much of the white-water boating use occurs during the summer months when most Americans take their vacations. Most of the angling use occurs during the spring and fall. This pattern of use has an important effect on the generation of net economic benefits. To the extent that net economic benefits are directly determined by flow, changes in flow during periods of high recreational use produce larger

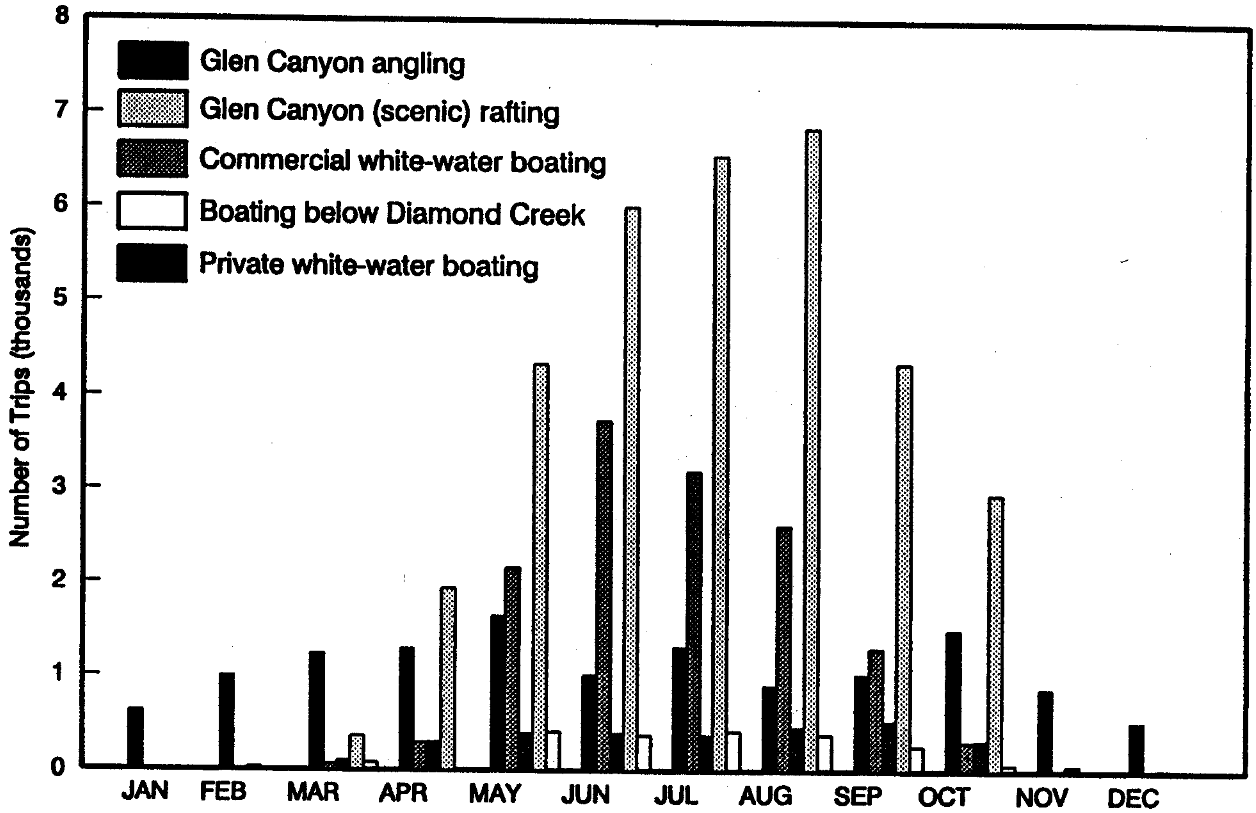


Figure III-40.—Recreational use in Glen and Grand Canyons, 1991.

changes in net economic value than similar changes in flow occurring at other times of the year.

NPS limits commercial and private white-water boating in Grand Canyon to 115,500 and 54,450 visitor days per year, respectively. White-water boating use is limited to 166 visitors per day during the primary season, May 1 through September 30. These use limitations were designed to increase boating safety, reduce crowding on the river, and minimize resource damage. These regulations are important since they preclude any increase in white-water boating use.

Presently, there are no constraints on the number of anglers permitted to fish in Glen Canyon. The number of fishing trips to the area in any given year is expected to vary with general economic conditions, fishing regulations, and the quality of the fishery.

Net Economic Value of Recreation

River-based recreation activities in Glen and Grand Canyons are nationally and internationally renowned for their quality and scope. Because of this significance, it was hypothesized that the net economic value of these activities was substantial. However, the magnitude of this value and the degree to which it depends on flow were not investigated until relatively recently.

In 1987, a study of river-based recreation in the study area was completed by Bishop et al. The goals of this intensive study were:

- To document quantity and pattern of river-based recreational use
- To identify factors having a significant impact on the net economic value of recreational use

- To estimate net economic value of river-based recreation in the study area

The authors identified four major categories of river-based recreational use:

1. Day (scenic) rafting in Glen Canyon
2. Angling in Glen Canyon
3. Commercial white-water boating in Grand Canyon
4. Private white-water boating in Grand Canyon

The study by Bishop et al. (1987) was based on the contingent valuation technique, a survey method for estimating the net economic value of recreation use. The study found that the value of angling and white-water boating was related to flow and that there were significant differences between the effects of flow on commercial white-water boaters and private white-water boaters. In contrast, the authors reported that they were unable to identify a correlation between the value of day use rafting and flow. For this reason, no estimates of the net economic benefits of day rafting are presented.

White-water boating below Diamond Creek was not investigated by Bishop et al. (1987), and the potential influence of flow on the net economic value of white-water boating in this reach has not been empirically determined. For this reason, estimates of net economic benefit in this reach were made by prorating the net economic benefits from Bishop et al. (1987) on a per-day basis. Table III-15 presents the estimated net economic value of recreation use based on 1991 use and price levels and on flow patterns for representative years.

It should be noted that the estimates of net economic benefit presented here and in chapter IV represent a "snapshot" in time. These estimates are based on the statistical relationship between flow and recreation with all other factors held constant at the time of the study. Therefore, these benefit estimates do not account for any long-term flow impacts on the environment. If, for example, camping beaches eroded over time, the estimated net economic benefit presented here would not reflect any negative impact that this might have on the value of the recreation experience. Conversely, if the number and size of camping beaches were to increase under some alternative, this too would not be reflected in the estimates of net economic benefit presented here.

Regional Economic Activity

River-based recreational users, such as anglers and white-water boaters, spend large sums of money in the Glen/Grand Canyon region. These recreators purchase gas, food and drink, lodging, guide services, and outdoor equipment while visiting the region. Expenditures represent participation costs and thus **do not** represent a benefit measure from the national viewpoint. Direct expenditures are nonetheless important since they support local businesses and provide employment for local residents. In this sense, such expenditures provide some measure of the local impacts of recreational users.

However, direct expenditures alone do not fully measure the impacts of spending by visitors to the region. Local businesses and residents spend part of the money they receive from anglers and white-water boaters to purchase goods and services

Table III-15.—Net economic value of recreation (Benefits in nominal 1991 $ millions)

Type of release year	Anglers	Commercial white-water boating	Commercial white-water boating below Diamond Creek	Private white-water boating	Total
Low (1989)	1.3	5.4	0.1	1.1	7.9
Moderate (1987)	1.2	6.4	0.1	1.2	8.9
High (1984)	1.1	12.4	0.2	2.0	15.7

from other individuals and local businesses. These individuals and businesses, in turn, spend a portion of their revenue in the region, and so on. A portion of each dollar spent by nonresident recreators is re-spent over and over in the region, and the impact of each dollar of direct expenditure by visitors is greater than $1.

An example can be used to demonstrate this concept more clearly. Suppose that all of the businesses, government agencies, and households in a hypothetical county spent 40 percent of the money they receive from nonresident expenditures on goods and services in the local area. They spent the other 60 percent of the money to buy goods and services outside of the region. Each dollar spent by nonresident visitors will stimulate an initial $1 worth of local economic activity. That $1 is re-spent by businesses, government agencies, and households. Of that $1, $0.60 is spent outside the county and $0.40 is spent inside the county. Of that $0.40, $0.40 x 40 percent = $0.16 is re-spent in the region and $0.40 x 60 percent = $0.24 is spent outside of the county. After six successive re-spendings, the money that circulates inside the hypothetical county is less than $0.01. In this example, the effect of each $1 of direct expenditures by nonresident visitors is:

Initial expenditure	= $1.00
$1.00 x 40%	= $0.40
$0.40 x 40%	= $0.16
$0.16 x 40%	= $0.06
$0.06 x 40%	= $0.03
$0.03 x 40%	= $0.01
Total impact	= $1.66

This example illustrates that each additional dollar of direct expenditure by a nonresident visitor produces $1.66 in local economic activity. A simple multiplier is calculated from this result: ($1.66/$1.00) = $1.66.

A multiplier relates the amount of direct nonresident expenditure to the total amount of local economic activity produced by the visitor's spending. The size of a multiplier differs depending on the economic structure of the region. In general, the more complex the economy, the larger the multiplier and the more the impact on the local economy from each dollar of nonresident expenditure. Multipliers allow the impact of nonresident expenditures to be more fully assessed. For instance, suppose that a nonresident visitor spent a total of $101.00 in the hypothetical county discussed previously. Using the multiplier of 1.66, this direct expenditure would create $101.00 x 1.66 = $167.77 in local economic activity.

The U.S. Forest Service's Impact Analysis for Planning (IMPLAN) model (Taylor et al., 1992), a sophisticated framework for assessing regional impacts, was used to estimate multipliers for this analysis. These multipliers are based on the concept described above. However, unlike the example discussed, IMPLAN multipliers are disaggregated into business sectors.

Two Arizona counties, Coconino and Mohave, were assumed to capture the bulk of the local economic impacts generated by river-based recreation in Glen and Grand Canyons. River-based recreators who reside outside of these two counties are described as nonresidents for the purposes of this analysis. River-based recreators who reside in either Coconino or Mohave Counties were classified as residents.

Using IMPLAN, multipliers were developed for the local impact region and were used to develop the results reported in table III-16.

Estimates of average expenditures by anglers and white-water boaters were obtained by Bishop et al. (1987). Expenditures by white-water boaters below Diamond Creek are unknown. Estimates of their expenditures were derived by apportioning the trip costs found in Bishop et al. (1987) on a daily basis and by substituting their commercial trip fees as appropriate.

As shown, commercial white-water boaters generate most of the economic activity in the region. In total, river-based recreational users generated approximately $23 million in local economic activity in 1991.

Table III-16.–Number of nonresident trips, direct expenditures by nonresident river-based recreators, and estimated local economic activity generated in the region in 1991

	Number of 1991 trips by nonresidents	Estimated regional expenditures per trip (1991 $)	Total direct expenditures by nonresidents (1991 $)	Local economic activity generated (1991 $)
Glen Canyon (scenic) rafting	32,816	72		
Glen Canyon anglers	10,270	122	1,252,000	,833,000
Private white-water boating in Grand Canyon	2,926	255	747,000	124,000
Commercial white-water boating in Grand Canyon	13,478	71	9,581,000	15,420,000
Commercial white-water boating below Diamond Creek	1,504	299	450,000	735,000
Private white-water boating below Diamond Creek	467	103	48,000	75,000
Total	61,461		14,452,000	23,115,000

Recreation, Economics, and Indian Tribes

Hualapai Tribe. Recreation access fees and commercial recreation enterprises generate a significant percentage of the total revenue earned by the Hualapai Tribe. This revenue supports the reservation's economy and creates employment for tribal members.

Recreational use of Hualapai resources in Grand Canyon has increased in the past decade and is anticipated to increase over time. Figure III-41 illustrates this trend. As shown, recreational use has increased substantially over the period that data is available.

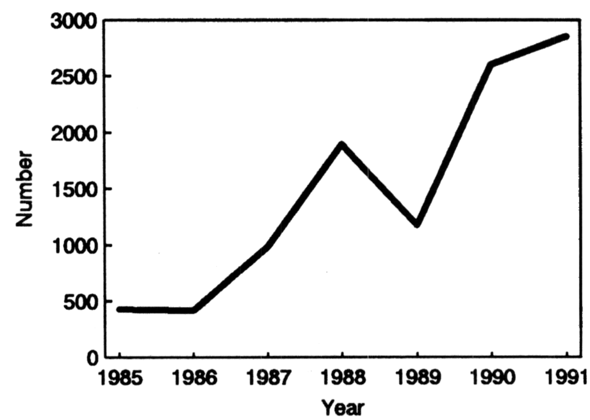


Figure III-41.—Total recreation permits sold by Hualapai Tribe, 1985-91.

The revenues generated by recreational activities on the Hualapai Reservation are earned by tribally owned enterprises. The Hualapai Tribe's recreational enterprises can be classified into two types:

- River-based recreational activities
- River-related recreational activities

River-based recreational enterprises are those that are directly flow dependent, including such activities as fishing and white-water boating. Conversely, river-related activities such as sightseeing and camping take place in the river corridor but are not directly influenced by flow.

Commercial white-water boating below Diamond Creek may have net economic value and regional economic impact. However, Bishop et al. (1987) did not investigate the net economic value of white-water boating in this reach.

Based on use data provided by the Hualapai Tribe and several assumptions about boater expenditure patterns, estimates of the regional economic impact of boating below Diamond Creek were developed. These estimated impacts are shown in table III-16.

River-Based Recreation.–A substantial portion of the Hualapai Tribe's gross revenue is derived from river-based recreational activities. The largest of these activities is white-water boating. The Hualapai Tribe owns and operates Hualapai River Runners, a commercial white-water boating company. Hualapai River Runners is one of four tribal enterprises and was the major source of tribal income in the 1980's. In addition to offering white-water boating trips, Hualapai River Runners provides shuttle services, tows across Lake Mead, and access for river takeouts at Diamond Creek. In 1987, Hualapai River Runners earned 49 percent or approximately half of the Hualapai's total gross income.

The tribe has diversified its business interests and now depends less on river-based recreation activities than it did in the past. Nevertheless, the tribe earned about 33 percent of its total 1991 income from such activities.

River-Related Recreation.–The Hualapai Tribe also owns and operates Grand Canyon West, an enterprise based on the natural beauty of Grand Canyon and the Colorado River. This enterprise offers guided tours of the Hualapai Reservation at the west end of the canyon. Currently, Grand Canyon West only provides river-related activities that are not directly flow dependent.

The Hualapais sell permits for sightseeing and camping on the reservation. Much of this river-related use is concentrated along the river corridor. In addition, the Hualapai Tribe derives approximately one-fourth of its gross revenue from the sale of permits to hunt desert bighorn sheep. Some of these sheep are known to use riparian zones in Grand Canyon.

Navajo Nation. The Navajo Reservation borders portions of Glen Canyon National Recreation Area and Grand Canyon National Park. There has been little development of business enterprises in this region due largely to the "Bennett Freeze." Imposed by the Federal Government in 1966, this statutory freeze precluded construction or development on this portion of the reservation pending resolution of a territorial dispute. The Bennett Freeze has recently been lifted, and river-based enterprises may develop in the near future. At the present time, however, no river-based enterprises owned or operated by the Navajo Nation have been documented.

At various times, the Navajo Nation has planned to construct a marina at Antelope Point on Lake Powell. Should such a marina be constructed, it would be subject to the same impacts as existing NPS facilities on the lake. These impacts are described under "Lake Activities and Facilities."

A number of tribally owned or operated businesses in Cameron, Tuba City, Grey Mountain, and elsewhere on the reservation are dependent on Grand Canyon visitors. The many jewelry stands along Arizona Highway 89 and other approaches to the park are especially prominent examples. Owned and operated by individual Navajo families, these small enterprises are frequented by visitors to the region.

Other Tribes. Portions of the Havasupai Reservation border Grand Canyon National Park. No river-based enterprises owned or operated by the Havasupai Tribe have been documented. The Hopi Tribe, Pueblo of Zuni, and Southern Paiute

Tribe have both current and historical ties to Grand Canyon and the surrounding region. No river-based enterprises owned or operated by these tribes have been documented.

HYDROPOWER

This section describes hydropower resources as they affect, or are affected by, Glen Canyon Dam operations. The discussion is presented under two major headings:

- Power operations
- Power marketing

Power generated at Glen Canyon Dam is marketed mostly in six Western States by the Department of Energy's (DOE) Western Area Power Administration (Western). Western's primary mission is to sell power from Federal water project powerplants under statutory criteria in the Reclamation Project Act of 1939, the Flood Control Act of 1944, and the Colorado River Storage Project Act of 1956. These criteria include:

- Preference in the sale of power must go to municipalities, public corporations, cooperatives, and other nonprofit organizations.
- Power must be marketed at the lowest possible rates consistent with sound business practices.
- Revenues generated from power sales must pay for power generation and all allocated investment costs under the original Colorado River Storage Project (CRSP) Act.
- Projects should generate the greatest amount of power and energy that can be sold at firm power and energy rates, consistent with other project purposes.

Western's other statutory responsibilities include construction, operation, and maintenance of transmission lines and attendant facilities.

In this document, power refers to both capacity and energy.[2] Capacity refers to the total powerplant generation capability. Energy is electric capacity generated and/or used over time. Capacity and energy both can be sold on a firm (guaranteed by contract) or nonfirm (provided as available, not guaranteed) basis.

Glen Canyon Dam and Powerplant are part of the CRSP, one of the Federal projects from which Western markets capacity. Western's Salt Lake City Area Integrated Projects (SLCA/IP) is part of an interconnected generation and transmission system that includes Federal, public, and private power generating facilities. Other Federal projects and facilities from which SLCA/IP markets power are presented in Appendix E, Hydropower.

To ensure timely repayment of Federal project construction debt and coordinate electric power rate-setting and marketing efforts, the Colorado River Storage, Collbran, and Rio Grande Projects were administratively integrated into the SLCA/IP in 1987 (figure III-42).

Actual operating capacity for each powerplant depends on generating unit capabilities and efficiencies, reservoir elevation, and maximum water releases through the powerplant. CRSP powerplants, together with Fontenelle Powerplant, provide approximately 98 percent of SLCA/IP's total capacity and 97.5 percent of the energy.

Power Operations

Power operations refer to the physical operations of a large electrical power system, including power generation, control, and transmission. Power operations form the basis of all power sales and services, referred to as marketable resources.

To ensure system reliability, Western is required to meet operational and reliability guidelines of the North American Electric Reliability Council (NERC), the Western System Coordinating Council (WSCC), and the Inland Power Pool (IPP).

[2] Capacity vs. energy: megawatts and kilowatts represent power, while megawatthours and kilowatthours represent energy. Reclamation and Western can deliver kilowatts (power) from Glen Canyon Dam as a function of generator size and the capability of the hydroelectric network. Kilowatthours (energy) are delivered by employing capacity over time.

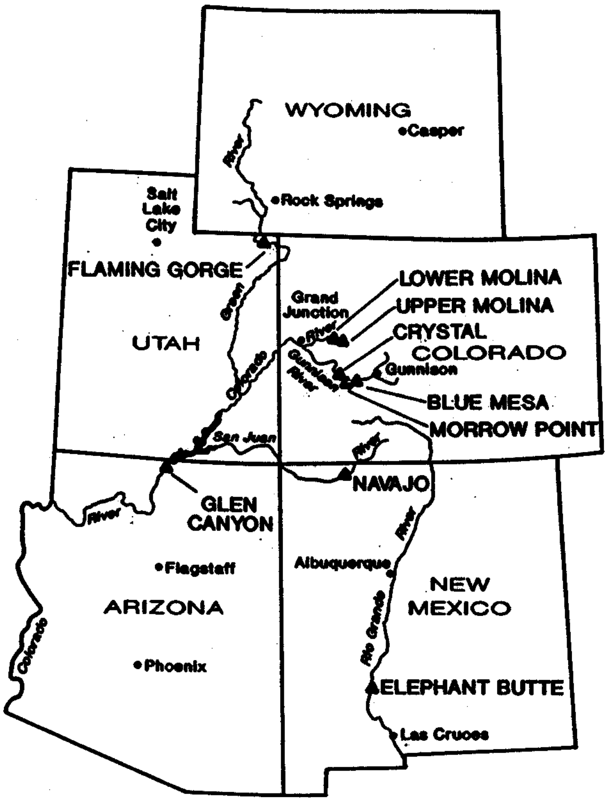


Figure III-42.—Location of Salt Lake City Area Integrated Projects.

Each WSCC utility must be within a load control area, and one utility serves as load control area operator. Western is a load control area operator, responsible for ensuring that each utility within the area:

- Serves its own internal load (demand) and meets its power obligations
- Maintains enough generating reserve to respond to its internal load changes and disturbances (such as loss of a generator or a transmission line) on the interconnected system

Within the Western Area Upper Colorado (WAUC) load control area, the flexibility and quick response of CRSP hydroelectric powerplants—particularly Glen Canyon—are important in meeting reliability criteria.

The WAUC load control area was combined with the Western Area Lower Missouri load control area in April 1993; however, since management and procedures for the larger load control area are still being refined, discussion of Glen Canyon Dam operations will be limited to the WAUC.

Operational Flexibility

One of the major benefits of a hydroelectric powerplant is flexibility—it can quickly and efficiently increase or decrease generation as needed. The following events typically require powerplant responses:

- Changes in customer demand
- Generating unit or transmission line outage
- Special requests for assistance
- Unscheduled customer deviation from power schedules

The previous factors are made more complex by the following variables:

- How often an event occurs
- Season and time of day the event occurs
- Restrictions at other CRSP generating facilities
- Availability and price of alternative power resources

Individual components of operational flexibility are described in the rest of this section.

Scheduling. Scheduling is the process of matching each day's system energy and capacity needs with available generation. Many factors affect the daily scheduling of energy and capacity from Glen Canyon Dam:

- Monthly water volumes and how water allocations are distributed over the month
- Water release patterns (maximum and minimum flows, allowable daily change in flows, up and down ramp rates)
- Availability of Glen Canyon units and other generation units in the system
- Customer allocations and special requests
- On-peak and off-peak periods
- Weather forecasts
- Market prices

Generally, scheduling to meet power requirements means making higher water releases in peak load months (December, January, July, and August) and lower water releases when electric power demand is less. This allows Western to take advantage of market conditions for cost-effective sales and purchases.

Interchange occurs when one utility delivers energy or capacity to another utility, which the second utility agrees to return at a later time in agreed-upon quantities. Western uses interchange, when financially feasible, to ensure system reliability and acquire additional power when available water releases can't generate enough to meet loads. Flexibility to change water releases—between seasons and days and during each day—determines how effectively interchange can be used.

Load Following. Power generation rises and falls instantaneously with the load (or demand)—a pattern called load following. The amount of load on the system is determined by how many electrical devices are using power.

Glen Canyon Dam can immediately increase or decrease water releases, thus changing power generation instantaneously. As load control area operator, Western provides immediate response to changes in control area load up to a maximum of plus or minus 2-½ percent of its total load, or about 56 megawatts (MW). (A release of 1,000 cfs through the powerplant turbines generally equates to generation of approximately 35 MW, depending on the elevation of Lake Powell.) By comparison, coal- and nuclear-based resources are less efficient and have a relatively slow response time; consequently, they generally are not used for load following. Oil- and gas-based powerplants fall between hydro and coal/nuclear in efficiency and response time and can be used for load following.

Under normal conditions, the system load pattern throughout the region stays about the same Monday through Friday. On Saturday and Sunday, load drops considerably as companies with a heavy commercial or industrial load shut down. System load also varies with seasonal conditions.

Minimum and maximum water release levels determine the minimum and maximum power generation capability. Both scheduled and unscheduled ramping are crucial in load following, emergency situations, and variations in real-time (what actually happens compared to what was scheduled) operations.

Regulation and Control. Regulation and control maintain electrical system stability, frequency, and voltage. These actions can occur either automatically (through automated generation control as explained in chapter II) or manually by dispatcher actions. Regulation depends on being able to ramp up or down quickly in response to system conditions. SLCA/IP powerplants provide regulation services to the city of Farmington, Tri-State Generation and Transmission Association, and Deseret Generation and Transmission Cooperative. Glen Canyon Powerplant provides the majority of system regulation and control for the WAUC control area.

Reserves. Each utility is required to have sufficient generating capacity—in varying forms of readiness—to continue serving its customer load, even if the utility loses all or part of its own largest generating unit or largest capacity transmission line. This reserve capacity ensures electrical service reliability and uninterrupted power supply. Reserve requirements are based on total available capacity—which, in turn, is determined by the minimum and maximum allowable releases through the generators.

Due to its flexibility and rapid response, Glen Canyon Powerplant provides excellent reserves. Spinning reserves are used to quickly replace lost electrical generation resulting from a forced outage, such as the sudden loss of a major transmission line or generating unit. Operating reserves also are used to replace generation shortages but cannot be provided as quickly as spinning reserves.

Emergencies and Outage Assistance. Western's operating procedures meet North American Electric Reliability Council guidelines for emergency operating criteria. NERC guidelines state that under emergencies, generation must be available to quickly restore the transmission system and start the return to normal operating conditions within 10 minutes. Generally, emergency services are needed only for short periods (1 hour or less).

Glen Canyon Powerplant is important in responding to interconnected transmission system emergencies. Western has existing contractual agreements to use Glen Canyon capacity to restart thermal powerplants in the area in the unlikely event of a widespread power outage.

Emergency assistance is similar to emergency operations, but generally involves smaller outages that last longer. Under this service, each IPP member utility is obligated to provide up to its spinning reserve amount of capacity and energy for 72 hours if an unplanned outage occurs. Western's ability to supply IPP emergency assistance is limited by two factors: available transmission capacity and generation capability.

Western's ability to deliver emergency assistance varies on an hourly basis, depending on firm load obligations and available generation from project resources. Under historic operations, with a full reservoir and average loads, Glen Canyon Powerplant has provided emergency assistance beyond its required reserves.

When an unplanned outage extends beyond 72 hours, the affected utility may arrange to purchase or exchange firm capacity and/or energy with another utility. SLCA/IP often provides scheduled outage assistance due to its central location within IPP and the flexibility of its hydroelectric resources.

Transmission System. The CRSP/WAUC transmission system has approximately 2,300 miles of transmission lines. The following map shows the CRSP Interconnected Transmission System. The CRSP transmission system stretches from southern Wyoming through western Colorado and eastern Utah, down to northern New Mexico, across northern Arizona, and finally into the south-central Arizona area. The WAUC is interconnected with six other Federal and private load control areas:

- Public Service Company of Colorado
- PacifiCorp (including Utah Power and Light)
- Public Service Company of New Mexico
- Western Area—Lower Missouri
- Arizona Public Service Company
- Western Area—Lower Colorado

Western's transmission lines transport electricity from Glen Canyon Dam and other generating sources to customer utilities that serve end users, such as residential, irrigation district, and commercial and industrial consumers.

Both hydroelectric and thermal generation are affected by transmission limitations when lines do not have enough capacity to transport electricity from the point of generation to the point of demand. At times, Western can mitigate existing limitations on Glen Canyon's eastern transmission line by exchanging power with the Salt River Project (SRP), as explained later in this section.

The amount of power scheduled for transmission varies from season to season, day to day, and hour to hour. Scheduling limits are derived from physical limits and determine how many transactions may occur. Actual transmission refers to the actual measured flow of power on the line. NERC requires monitoring of the actual and schedule power flow for system operation.

Transmission Service.–Western, like many utilities, offers both firm and nonfirm transmission service. Firm transmission service is contractually guaranteed for the term of the agreement. Nonfirm transmission service is provided as available and is not guaranteed. Western participates in electricity transfers through "wheeling," which occurs when two indirectly connected utilities agree to purchase or sell power to each other. The purchaser or seller must make arrangements to use the transmission system that electrically connects them. Western offers wheeling service over particular CRSP transmission paths, including lines carrying power from Glen Canyon. Nonfirm transmission service, like nonfirm power sales, can be interrupted on short notice.

SRP Exchange Agreement.–Seventy-five percent of SLCA/IP generating resources are located at Glen Canyon, while many of SLCA/IP loads are located in Utah, Colorado, and New Mexico. All capacity needed to satisfy load in these areas cannot be sent directly from Glen Canyon because of the limited capacity of the Glen Canyon-Kayenta-Shiprock transmission line, which links the powerplant to these major load areas.

To compensate, Reclamation and the SRP Agricultural Improvement and Power District entered into a long-term contract in 1962 to exchange Glen Canyon generation for SRP generation at coal-fired powerplants in Craig and Hayden in Colorado, and at Four Corners, New Mexico. The SRP exchange, amended in 1974, also provides for limited transmission of SRP capacity during times when a full hydrothermal exchange is not possible. The SRP exchange agreement has operated successfully for many years, with proven benefits to both parties. This arrangement maximizes efficiency and has reduced overall environmental impacts.

Power Marketing

Power marketing involves determining appropriate levels of long-term firm capacity and energy commitments based on the long-term firm capacity and energy available from SLCA/IP powerplants. It also involves establishing contractual arrangements to provide long-term, firm electrical service—on a wholesale basis—to electrical utility customers.

Several laws govern the marketing of capacity and energy. Section 9(c) of the Reclamation Project Act of 1939 discusses principles of power rates in terms of the minimum charges for power. The law also makes it clear that the United States markets power to serve the public interest, not to make a profit. Section 7 of the CRSP Act of 1956 instructs Western to generate the most power practicable without interfering with other authorized project purposes.

Ninety-five percent of CRSP costs must be repaid to the U.S. Treasury by power and water users. Reimbursable costs include:

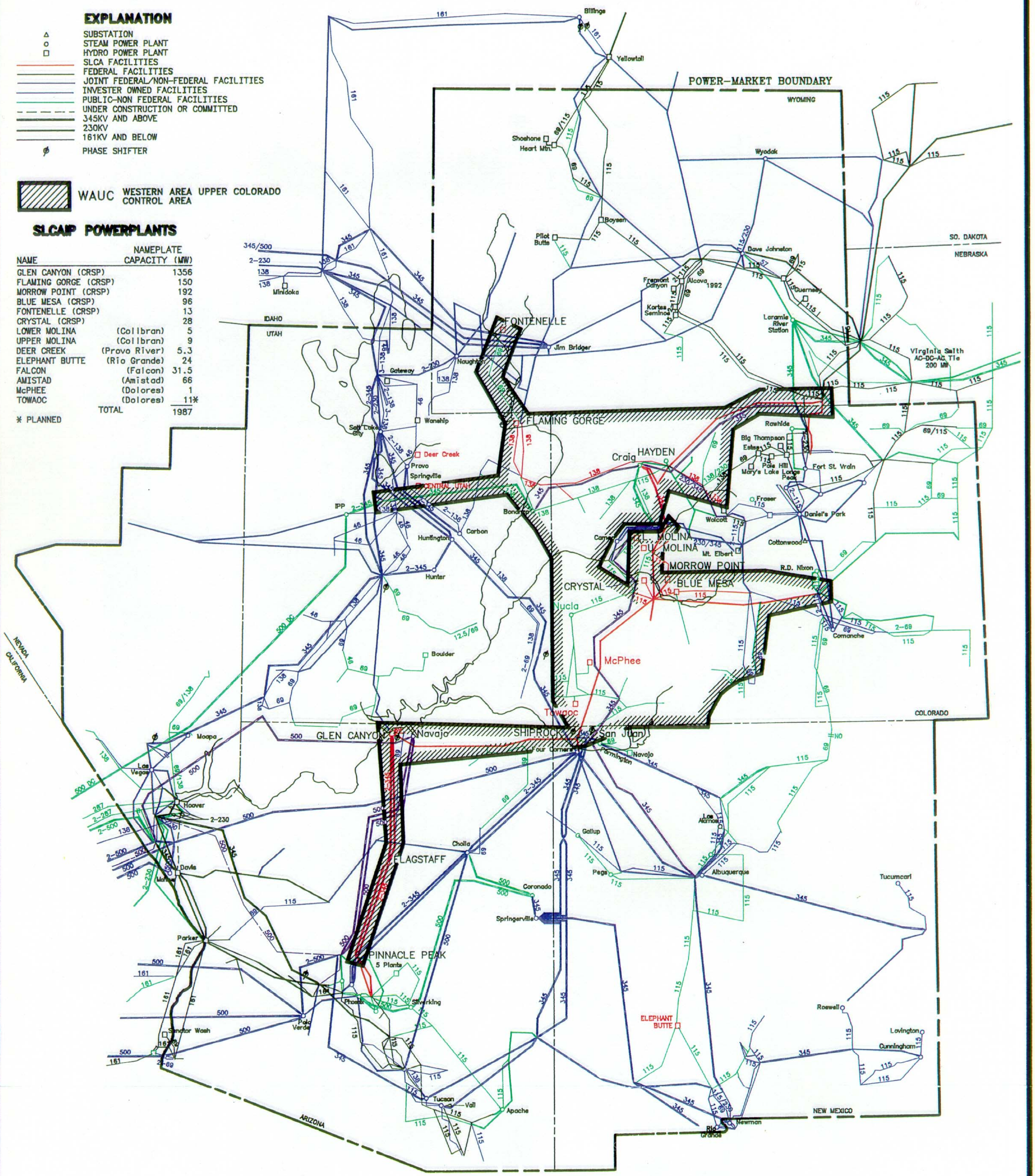
- One hundred percent of the Federal investment in power facilities, plus interest
- One hundred percent of annual operation and maintenance costs for power facilities
- Federal investment in irrigation facilities beyond the irrigators' ability to repay

The remaining 5 percent of CRSP costs are nonreimbursable, paid by monies appropriated primarily through Federal taxes. Additional background on project cost repayment can be found in appendix E.

Western markets a number of electric power services such as long-term firm capacity and energy, short-term firm capacity and energy, and nonfirm energy. Loads are made up of firm load, nonfirm sales, and interchanges out of the control area. Firm load includes long- and short-term firm sales, Reclamation project use loads, system losses, control area regulation, firm load reserves, and scheduled outage assistance. By law, capacity must be reserved to operate CRSP, participating projects, and Reclamation's irrigation and drainage pumping plants before marketing long-term firm capacity. Western's ability to make nonfirm sales depends on SLCA/IP's flexibility to take advantage of the difference in the off- and on-peak spot energy markets.

Long-Term Firm Power

Generally, long-term firm contracts are for 10 years or more and are based on estimates of the long-term availability of capacity and energy. Determining the amount of resources that can be sold on a long-term basis requires a balance between the mandate to market the greatest practicable amount of firm resources and the risk of occasionally being unable to meet firm contract commitments due to periods of drought. Generally, Western must meet its firm contract



UNITED STATES

DEPARTMENT OF ENERGY

WESTERN AREA POWER ADMINISTRATION

SALT LAKE CITY AREA OFFICE

COLORADO RIVER STORAGE PROJECT
INTERCONNECTED TRANSMISSION SYSTEM

APRIL 1993

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commitments, either through generation alone or by generation combined with purchases. Long-term firm commitments vary seasonally according to project loads and customer requirements.

Seven of SLCA/IP's customers are considered to be "large" systems—utilities that buy capacity and energy to supplement their own generating resources. The rest of Western's customers are "small" systems that have little or no generating capacity and rely on purchases for most or all of their capacity and energy needs. Almost all SLCA/IP customers have supplemental suppliers to meet additional capacity needs.

The SLCA/IP marketing area and some of the many customers are shown on customer service maps in appendix E, along with a detailed listing of their firm capacity and energy allocations.

Short-Term Firm Power

Short-term firm sales of capacity or energy can be made seasonally or monthly. Short-term firm sales are based on resource availability projections that exceed long-term firm commitments. Prior to each 6-month marketing season, Western determines whether excess capacity or energy will be available for a season or a month. This short-term firm resource is made available first to Reclamation for project needs, then to preference customers (municipalities, public corporations, cooperatives, and other nonprofit organizations). Any remaining resources are offered to nonpreference customers. Prices are based on long-term firm power rates.

Nonfirm Energy

Nonfirm sales are short duration energy transactions, always less than 1 year. Normally scheduled 1 day in advance, they can be determined up to the hour of transaction. The flexibility of hydropower operations allows actual deliveries to be modified hourly, as system conditions warrant. Western may market nonfirm energy and arrange for interchange transactions, depending on revised water release estimates. Nonfirm energy sales are not guaranteed and may be interrupted with advance notice. The price for this service is based on market conditions.

Nonfirm sales also are known as economy energy or fuel replacement sales, terms related to substitution of hydroelectric generation for oil- and gas-fueled generation. The fuel replacement program began in the early 1980's to encourage this substitution. Economy energy sales are scheduled as market and hydrologic conditions allow.

SLCA/IP Post-1989 Power Marketing Criteria

In 1980, Western began to review and modify its marketing and allocation criteria because existing power contracts were due to expire on September 30, 1989. The associated public process in 1986 resulted in the post-1989 marketing criteria. Western is preparing an EIS on the post-1989 marketing criteria (Western Area Power Administration, 1994).

Marketable Resources

The SLCA/IP hydropower resources supply the marketable energy and capacity under the post-1989 power marketing criteria. Capacity and energy are marketed on a seasonal basis—winter season (October-March) and summer season (April-September). Under the post-1989 marketing plan, SLCA/IP has contractual commitments for 1,407 MW of capacity and 3,105,848 megawatthours (MWh) of energy in the winter season and 1,315 MW of capacity and 2,904,403 MWh of energy in the summer season. These amounts are explained in greater detail in the following sections.

Capacity. The CRSP and Fontenelle Powerplant components of the SLCA/IP total long-term firm capacity values are based on the amount of capacity available 9 of every 10 years.[3] Critical

[3] Marketable firm capacity and energy are based on attempts to ensure a reliable level of capacity and energy, while maintaining an acceptable level of risk. This level of acceptable risk was approved by Western's customers following review of the September 1984 "Revised Proposed General Power Marketing and Allocation Criteria" (U.S. Department of Energy, 1985).

seasonal loads occur in winter (December-January) and summer (July-August). Critical seasonal capacity values are based on the heaviest load month in each of those two seasons.

Energy. Marketable CRSP energy is based on projected annual seasonal averages, plus 400 gigawatthours (GWh). The rationale for selecting approximate average seasonal energy, plus 400 GWh, is similar to the rationale for selecting capacity levels.

Average generation, plus 400 GWh, corresponds to the level that would be equaled or exceeded about 4 of every 10 years on an average annual basis. Western must purchase any shortfalls below the annual average, plus 400 GWh. Historically, Western has purchased up to 2,000 GWh annually to make up for generation shortfalls, as well as interchange and on- and off-peak economy transactions.

Net Marketable Capacity and Energy. Net marketable capacity is determined by subtracting project use loads, system losses, control area regulation needs, firm load reserves, and scheduled outage assistance loads from generation. The resulting winter and summer capacities are 1,407 MW and 1,315 MW, respectively. Net marketable energy is determined by adding purchases to the combined powerplant resources and subtracting losses and project use. The winter and summer marketable firm energy is 3,106 GWh and 2,904 GWh, respectively. These amounts vary seasonally due to differences in project use loads and exchanges. Approximately 12 percent of this energy and capacity is delivered to customers within the WAUC control area; the remainder is exported to six adjoining control areas (listed under "Transmission System") for delivery to SLCA/IP customers.

Wholesale and Retail Power Rates

Western's customers typically are municipal utilities, Federal or State public power projects, or rural electric cooperatives paying wholesale rates to purchase power for resale to their customers. Retail rates are those paid by end users (residential, commercial, and industrial clients of Western's wholesale customers). Changes in Glen Canyon operations could impact both wholesale and retail power rates; therefore, wholesale and retail rates are used as indicators of power marketing impacts.

Wholesale Rates and Repayment. Power repayment studies are used to ensure project power revenues will be sufficient to pay all costs assigned to power within the prescribed time periods. Payment criteria are based on law and on policies established in DOE Order RA 6120.2.

Power revenues also pay annual power operation and maintenance, purchased power, transmission service, and interest expenses, as well as various miscellaneous costs. CRSP power revenues also must contribute toward salinity control costs under the Colorado River Basin Salinity Control Act and construction costs of CRSP participating projects.

By law, firm power rates are based on recovering costs—i.e., only what it takes to keep the system operating and pay its obligations. Therefore, Western's ratesetting procedures differ from those of profit-making utilities.

SLCA/IP revenues are used first to pay annual operation and maintenance, purchased power, transmission service, and other annual expenses, then to pay interest expense. Any remaining annual revenues are applied to the investment costs assigned to power, so that each investment can be paid within the time allowed. Normally, the highest interest-bearing investments are repaid first, because this usually results in a lower overall power rate.

Since the CRSP and the Rio Grande and Collbran Projects were integrated, parts of their power repayment studies also were combined. The resources of all three projects are summed to arrive at an estimate of the total available. The gross power-related revenue required for the smaller projects is added as another expense to the CRSP. The power repayment study then helps determine the combined rate needed to meet the total revenue requirements of each SLCA/IP project.

Retail Rates. Approximately 180 public power utilities currently purchase electric power from the SLCA/IP. Most of these utilities are located in Arizona, Colorado, Nevada, New Mexico, Utah, and Wyoming (figure III-43), though some extend into California, Nebraska, and Texas.

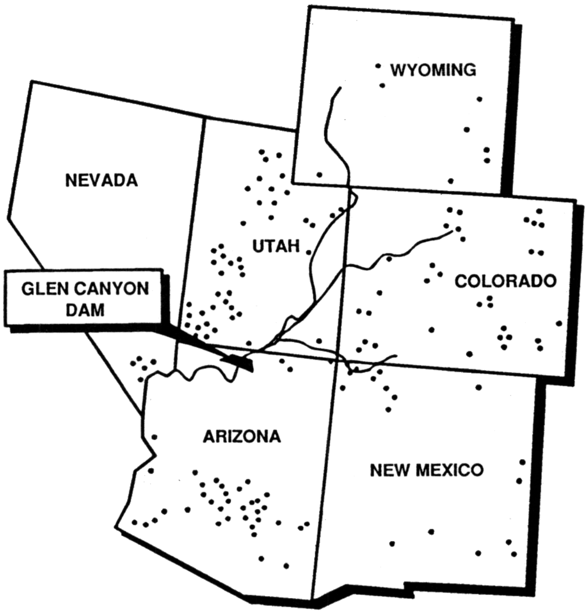

Figure III-43.—The SLCA/IP markets power to approximately 180 utilities, mostly in six States.

The retail rates charged by these public power entities normally are set to cover system operation and capital costs. The largest portion of these obligations, in the case of Glen Canyon, is attributed to operating expenses. As costs of these individual components change, the retail rates are adjusted to ensure enough revenue is collected to meet the utility's financial obligations.

There are approximately 5.6 million residential, industrial, and commercial power customers in the six-State area where power from Glen Canyon Dam is sold (U.S. Department of Energy, 1994). The majority of these end users, approximately 3.9 million (70 percent), do not receive power from the dam. The remaining 1.7 million (30 percent) end-use customers receive power directly or indirectly from Glen Canyon Dam (Electric World, 1993). The power rates paid by these users potentially could increase as a result of changes in dam operations.

Regional Economic Activity

All (or the vast majority) of the power produced in the region is consumed in the region.

As the supply of peaking power falls, for any given level of demand the price of electricity rises. Supply-induced price changes may affect the production of final goods and services and the demand for many other goods in the impact region. To further complicate matters, loss of capacity at Glen Canyon Dam is likely to result in the construction of new powerplants in the region earlier than would otherwise be the case. Large-scale construction projects may create employment and stimulate local economic activity.

NON-USE VALUE

The previous sections on recreation and hydropower focused on the human uses for Colorado River flows in Grand Canyon. These uses include fishing, white-water boating, and the production of electric power. Analyses of the impact of riverflows on all of these uses are presented in chapter IV. Until recently, most descriptions of these uses of resources probably would have ended there.

However, social scientists have long acknowledged the possibility that humans could be affected by changes in the status of features of the natural environment even if they never visit or otherwise use these features. These individuals may be classified as non-users, and expression of their preferences regarding the status of the natural environment may be termed "non-use value." Non-use value is the term used in this EIS to describe the monetary value non-users place on the status of the natural environment.

This section details the concept of non-use economic value and describes the ongoing non-use value study for this EIS.

Market Value, Non-Market Value, and Non-Use Value

Use values for marketed goods are one traditional measure of impacts to the human environment. Theoretically similar measures of use values for nonmarketed goods also are routinely used to support decisionmaking (Water Resources Council, 1983). Non-use value is a special case in which the nonmarket good is the status of particular attributes of the physical environment.

Measures of non-use value rarely have been considered in evaluations of impacts to the human environment. However, applications of non-use value have become more numerous in recent years. Proposed Department of the Interior regulations allow estimates of non-use value to be used in natural resource damage assessment cases (U.S. Department of the Interior, 1991), and the Department of Commerce is now considering the use of non-use value for damage assessment in cases involving oil spills and toxic releases (U.S. Department of Commerce, 1990, 1991, 1992). As part of this consideration, the Department of Commerce commissioned a panel chaired by two Nobel laureates to study the concept, underlying theory, and related estimation techniques. The findings of this "blue ribbon committee" support the application of non-use value in these prescribed situations (U.S. Department of Commerce, 1993). Recently, non-use value was estimated and reported in the FWS's EIS on grey wolf reintroduction (U.S. Fish and Wildlife Service, 1994).

Conceptual Basis for Non-Use Value

Individual consumers use their incomes to purchase marketed goods and combine these marketed goods with time, human knowledge, and available nonmarketed goods to produce a particular quality of life. In these terms, it is clear that an individual's perception of well-being is determined by the interaction of the individual's preferences and the available marketed and nonmarketed goods. It is equally clear that consideration of only the value of marketed goods could overlook important impacts of various alternatives if the alternatives affect nonmarket goods about which individuals care.

The state of the natural environment affects people both in how they use the environment and how they would prefer the environment to be. Thus, both use and non-use values need to be considered when assessing impacts to the human environment.

Given that non-use values are relevant in the decisionmaking process, it is worthwhile to review the factors that might give rise to non-use values. Frequently mentioned origins of non-use values are:

- Desire to preserve the functioning of specific ecosystems
- Desire to preserve the natural ecosystem to maintain the option for future use
- Feeling of environmental responsibility or altruism toward plants and animals

The most commonly accepted classification of these motives is the division of non-use value into bequest value and existence value, with option value sometimes considered as a third component. Bequest value is the value individuals place on preserving the resource for use by their heirs. Existence value is the benefit generated by knowing that a resource will continue to exist in the future even if no onsite use is contemplated. Option value is the value of preserving a resource so that the option to use the resource in the future is maintained.

The literature on non-use value emphasizes the uniqueness or specialness of the resource in question and the irreversibility of the loss or injury. Indicators of non-use value are described in the proposed Department of the Interior rules for damage assessment (U.S. Department of the Interior, 1991) which state:

. . . an injury to a common natural resource with many substitutes (e.g., a typical small stream), may not generate large non-use values, particularly for those residing outside the area where the injury occurred, even if the recovery takes a long time. However, a permanent injury to a unique resource (e.g., Grand Canyon) may generate significant non-use values, even for those residing in areas far removed geographically from the site where the injury occurred.

Evidence of Relative Magnitude of Use and Non-Use Value

Since the role that non-use value might play in a decision regarding dam operations at least partly depends on the magnitude of the value, it is worthwhile to review how non-use values were measured in other contexts. Particularly relevant are two studies that explored the non-use value associated with water resources.

Sanders et al. (1990) estimated the total value of preserving 15 wild and scenic rivers in Colorado. They reported that Colorado residents expressed a use value of $19.16 and a non-use value of $81.96 per household per year. The total (use and non-use) value of protecting 15 Colorado rivers aggregated over these 1.2 million households is approximately $120 million annually. As noted by the authors, non-use value was approximately four times the recreation use value.

Loomis (1987a, 1987b) estimated both use and non-use value for Mono Lake in California. Based on an analysis of open-ended responses, he reported that use value was approximately $40 per visit. Aggregated over 145,000 visits, total use value was approximately $5.8 million annually (Loomis, 1987a). For households, estimated non-use value was approximately $42.71 per year. Aggregated over 10 million households in California, total non-use value was approximately $422 million annually (Loomis, 1987a). In this case, too, estimates of non-use value greatly exceeded estimates of use value.

Non-use value estimates cited in the examples above are for "with and without" analyses. As described elsewhere in this document, this EIS focuses on how alternative Glen Canyon Dam operations will impact affected resources. Since these impacts are incremental in nature, non-use value estimates in this EIS will reflect only these incremental changes and may or may not approach the magnitude of the two examples.

As these examples demonstrate, if interest in the affected resources is widespread, then even a small per person or per household value can be very large when extrapolated across the population holding non-use value. It is possible that interest in the resources affected by Glen Canyon Dam operations could extend to all areas of the United States. If this is found to be the case, the non-use value of operational changes might be quite large.

Potential Non-Use Value for Hydroelectric Power

The discussion of non-use value presented thus far has focused exclusively on nonmarket goods. During this EIS process, the question arose as to whether there is some non-use value associated with hydroelectric power—a good sold in the market.

In the literature to date, there is only one example suggesting that non-use value might be associated with market goods (Lockwood et al., 1994). Nonetheless, the question of whether there is non-use value for hydropower generated at Glen Canyon Dam is one of more than purely academic interest.

Implications of Non-Use Value

Estimating non-use value for the alternatives may have important implications for the decision-making process. To the extent that non-use value is comparable with other estimates of economic impact presented in this EIS, including non-use value, potentially could alter the outcome of the economic evaluation of alternatives.

If estimates of non-use value are not comparable to other economic impact estimates—perhaps because of concern about their precision—they nevertheless provide an invaluable quantitative gauge of public sentiment. It seems likely that decisionmakers would carefully assess such a quantitative measure of public preference.

Estimating Non-Use Value for This EIS

The Glen and Grand Canyon resources are known throughout the Nation and world. The Grand Canyon is, in fact, used as an example of a resource for which non-use value may be significant. The National Academy of Science Committee to Review the Glen Canyon Environmental Studies recognized this significance and noted that the GCES Phase I economic studies failed to consider non-use value (National Research Council, 1987).

Reclamation retained HBRS, Inc., an independent consulting company, to complete an analysis of the feasibility of estimating non-use value for the Glen Canyon Dam EIS. As part of this analysis, a panel of well-known economists was convened to review the HBRS, Inc. report, to provide written commentary on the technical adequacy of the work, and to provide their views on prospects for successfully completing a non-use value study for this EIS. While some technical and practical difficulties were noted, the findings of this panel were in favor of initiating a non-use value investigation (Bishop et al., 1991). As a result, the cooperating agencies decided to investigate the feasibility of estimating non-use value for this EIS.

Representatives of the cooperating agencies and other interested individuals met to discuss all aspects of the non-use value study and to provide suggestions, technical comments, and critique throughout the study process. Chaired by the Bureau of Reclamation, all interested parties were encouraged to attend committee meetings. Representatives from AGFD, Colorado River Energy Distributors Association, FWS, Hualapai Tribe, NPS, Reclamation, and Western attended regularly. This open committee forum ensured that interested individuals and organizations could obtain information on the study and its progress as desired. Further, the exchange of views at committee meetings helped to improve all facets of the study.

Focus Group Investigation

In the initial stages of this investigation, a series of focus groups (group discussions) was held in various locations around the country to explore the feasibility of estimating non-use value for the specific resources affected by dam operations. Focus groups were held in New York, Tennessee, Nebraska, Arizona, New Mexico, and Utah (HBRS, Inc., 1992).

Focus group participants were able to predict, in a general way, the impacts of dam releases on the downstream environment. Participants indicated that they care most about impacts to vegetation and associated wildlife, native fish, Native Americans currently living near Grand Canyon, and archeological sites. The discussions indicated that participants were able to distinguish between impacts to the river corridor and those to the Grand Canyon in general. Participants also expressed a clear desire to undertake actions to reduce or eliminate these impacts.

Most importantly, results of the focus group investigation indicated that the non-use value for operational changes could be estimated. The cooperating agencies collectively decided to continue the investigation in a stepwise manner. The next step in the investigation was a pilot-test research phase. The nature and findings of the pilot test, methodologies employed, plan for future study, and a qualitative description of the likely outcome of this study are presented in chapter IV.