3 AFFECTED ENVIRONMENT

Chapter 3 describes the environmental resources (physical, biological, cultural, recreational, and socioeconomic) that could be affected by the range of alternatives for implementing the Glen Canyon Dam Long-Term Experimental and Management Plan (LTEMP), as described in Chapters 1 and 2. The extent to which each specific resource may be affected by each alternative is discussed in Chapter 4, Environmental Consequences.[1]

3.1 PROJECT AREA

The project area includes the area potentially affected by implementation of the LTEMP (including normal management and experimental operations of Glen Canyon Dam and non-flow actions). This area includes Lake Powell, Glen Canyon Dam, and the river downstream to Lake Mead (Figure 3.1-1). More specifically, the scope primarily encompasses the Colorado River Ecosystem, which includes the Colorado River mainstream corridor and interacting resources in associated riparian and terrace zones, located primarily from the forebay of Glen Canyon Dam to the western boundary of Grand Canyon National Park (GCNP). It includes the area where dam operations impact physical, biological, recreational, cultural, and other resources. This section of the river runs through Glen, Marble, and Grand Canyons in Coconino and Mohave Counties in northwestern Arizona.

Although this EIS focuses primarily on the Colorado River Ecosystem, the affected area varies by resources and extends outside of the immediate river corridor for some resources and cumulative impacts. Portions of Glen Canyon National Recreation Area (GCNRA), GCNP, and Lake Mead National Recreation Area (LMNRA) outside the Colorado River Ecosystem are also included in the affected region for certain resources due to the potential effects of LTEMP operations. For resources such as socioeconomics, air quality, and hydropower, the affected region was larger and included areas potentially affected by indirect impacts of the LTEMP.

3.1.1 Colorado River Setting

The Colorado River rises in the Rocky Mountains of Colorado, flows southwesterly about 1,450 mi, and terminates in the Gulf of California. Its drainage area of 242,000 mi^2 in the United States represents one-fifteenth of the area of the country. As presented in the Colorado River Basin Water Supply and Demand Study (Reclamation 2012h), almost 40 million people in the seven western states of Arizona, California, and Nevada (Lower Division States), and

1 Pre-dam conditions are discussed in this chapter to provide historical context on certain resources that exist in an already altered environment; however, such references are not intended to form the basis for comparison of the alternatives in this Environmental Impact Statement (EIS), or to provide goals for achieving resource conditions. The action alternatives are compared to the No Action Alternative (Alternative A), as is the standard practice for National Environmental Policy Act of 1969 as amended (NEPA), compliance.

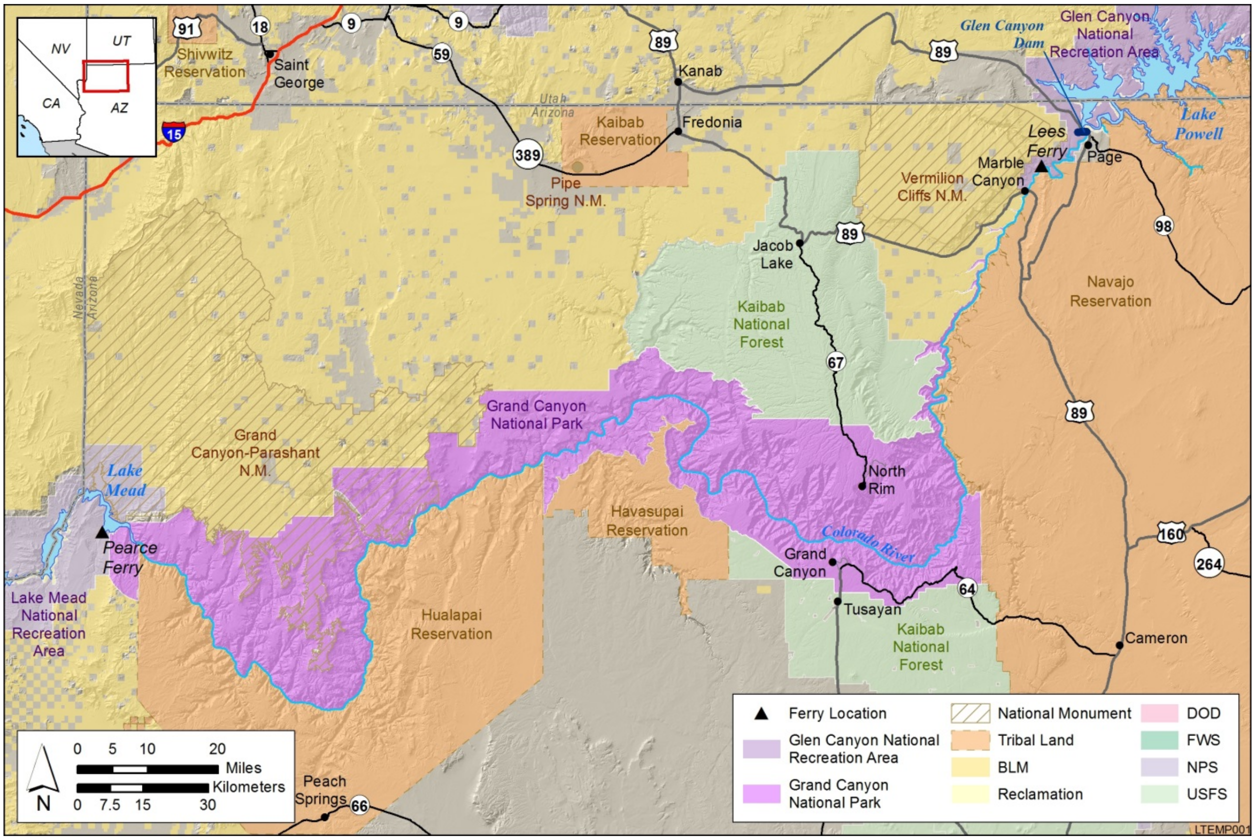

FIGURE 3.1-1 LTEMP Project Area and Surrounding Lands (This map is for illustrative purposes, not for jurisdictional determinations; potential area of effects varies by resource as described in this chapter and in Chapter 4.)

Colorado, New Mexico, Utah, and Wyoming (Upper Division States) rely on the Colorado River and its tributaries to provide some or all of their municipal water needs. Colorado River water is used to irrigate nearly 5.5 million ac of land in the Basin, which produces about 15% of the nation's crops and about 13% of its livestock. The Colorado River is the lifeblood for at least 22 federally recognized American Indian Tribes , 7 National Wildlife Refuges, 4 National Recreation Areas, and 11 National Parks.

Hydropower facilities along the Colorado River supply more than 4,200 megawatts (MW) of electrical capacity to help meet the power needs of the West and reduce the use of fossil fuels (Reclamation 2012h). The primary units of the Colorado River Storage Project (CRSP)—Glen Canyon, Flaming Gorge, Blue Mesa, Morrow Point, and Crystal—provide the majority of the hydroelectric power for the Upper Basin. CRSP has a combined installed capacity of more than 1,800 MW, with Glen Canyon accounting for approximately 73% of the CRSP facilities' total generating capacity.

Given the many and varied uses that depend on Colorado River water, as well as the significant public interest in the region, it is important yet difficult to achieve a suitable balance in the use of the Colorado River. Out of the 1,450-mi length of the Colorado River, it is the

284-mi reach that flows through Glen Canyon Dam and the Grand Canyon that is the affected reach under discussion in this EIS. It is against this background that the resources of the Colorado River Ecosystem are discussed and evaluated.

3.1.2 Geologic Setting

For more than 5 million years, the forces of geologic uplift, weathering, and downcutting of the Colorado River and its tributaries 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 mi at the rim. The erosive forces of the river cut only a narrow gorge; other geologic forces, including flowing water over the canyon walls, freezing and thawing temperatures, and abrasion of rock against rock cut the wider canyon. The Colorado River acts like a huge conveyor belt transporting finer sediment particles to the ocean.

In cutting the canyon, the river has exposed rocks of all geologic eras, covering a span of nearly 2 billion years. The rocks of the Grand Canyon are part of the Colorado Plateau, a 130,000-mi^2 area covering most of the Colorado River Basin. The elevation of the canyon rim varies between about 5,000 and 8,000 ft above mean sea level (AMSL), with the North Rim being about 1,000 ft higher than the South Rim.

Glen Canyon cuts through the massive Navajo Sandstone of the Mesozoic Era and is about 200 million years old. Downstream from Lees Ferry, a sequence of nearly horizontal sedimentary rocks of the Paleozoic Era appears at river level, beginning with the Kaibab Formation that caps much of the canyon rim. In Marble Canyon, the river passes through cavernous Redwall Limestone. The river is narrower here and in other places where the Paleozoic rocks are relatively hard, but becomes wider through the more easily eroded formations. The shelves of Tapeats Sandstone (more than 500 million years old) at the base of the Paleozoics appear near the mouth of the Little Colorado River. Farther downstream, 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, the youngest rocks in the canyon are exposed, which are 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 river flow at Lava Falls Rapid. The Grand Wash Cliffs mark the southwestern edge of the Colorado Plateau and the mouth of the Grand Canyon at the headwaters of Lake Mead.

3.1.2.1 Tribal Perspectives on Geologic Setting[2]

The Colorado River, through the Glen Canyon, Marble Canyon, and Grand Canyon (Canyons), has a prominent place in the traditional cosmology of the Havasupai Tribe, Hopi

2 Sections in this EIS entitled “Tribal Perspectives” are intended to represent the viewpoints of the Tribes who participated as Cooperating Agencies based on their input. The text was provided by the Tribes, and only minor typographic modifications were made prior to insertion into the EIS.

Tribe, Hualapai Tribe, Navajo Nation, Pueblo of Zuni, and the Southern Paiute Tribes and continues to have an important place in their contemporary cultures and economies. For example, Navajo oral history concerning the Grand Canyon and its tributaries states that it was developed during the time of creation of this world. Water was everywhere, and the world was named Ni′ Hodisq—the Glittering World. The people were given this world to live in after a series of trials with the native inhabitants (Chiishta Dootl′ izh, Chiishta Litso, and Chiishta Ligaii). The people discussed ways to make the world habitable; after much talk, they decided that rivers, creeks, and streams would be created to drain the world, which in turn would become the veins of the earth. The Colorado River is one of those veins. Haashch′ eeh yalt′ i′ i, the Talking God, and Haasch′ eehoghaan, the Evening God, became the advisors to the people, and under their direction, the world was created as it is today. In other oral histories, people say that Ghaa′ ask′idii, the Humpback God, created the Grand Canyon. After this world was given to humans by the Holy People, they cleared the water away. The Humpback God stood in the center of the world and dragged his cane from east to west and created the canyon. The water drained and created the rivers, creeks, and streams, which became the veins of the earth. The essence of the Humpback God is manifested by bighorn sheep and mountain goats as seen in the Grand Canyon today (Roberts et al. 1995).

3.1.3 Climatic Setting

Climatic conditions in the area vary considerably with elevation. At Bright Angel Campground (elevation 2,400 ft) near Phantom Ranch, the climate is characterized by mild winters, hot summers, and low rainfall. Average high temperatures range from about 15°C (59°F) in winter to 39°C (103°F) in summer. Low temperatures range from about 4 to 24°C (39 to 76°F). Average annual precipitation, mostly in the form of rain, is about 11.2 in.

In contrast, the climate at the North Rim (elevation 7,800 to 8,800 ft) is characterized by cold winters, cool summers, and abundant precipitation with snowfall. Average high temperatures range from 4°C (39°F) in winter to 24°C (75°F) in summer; low temperatures range from about –8 to 6°C (18 to 43°F). Average annual precipitation is 33.6 in. The South Rim (elevation 7,000 ft) receives about 16 in. of precipitation annually. Average high temperatures range from 5°C (41°F) in winter to 29°C (84°F) in summer; average low temperatures range from –8°C (18°F) in winter to 12°C (54°F) in summer.

The Upper Colorado River Basin (drainage basin above Lee Ferry[3]) is generally classified as semiarid and the Lower Basin (drainage basin below Lee Ferry) 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

3 "Lee" Ferry is the reference point that marks the division between the Upper and Lower Colorado River basins. The point is located in the mainstream of the Colorado River 1 mi below the mouth of the Paria River in Arizona. "Lees" Ferry is the historic location of Colorado River ferry crossings (1873 to 1928) and the current site of the U.S. Geological Survey (USGS) stream gage above the Paria River confluence.

results in as much as 60 in. 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 in., mostly from cloudburst storms during the late summer and early fall.

3.1.4 Glen Canyon Dam Releases and Flow

The major function of Glen Canyon Dam (and Lake Powell) is water storage to support a multitude of uses. In this EIS, river flows below the dam are referred to as releases or flows. River flow is measured in cubic feet per second (cfs). Annual and monthly volumes are measured in acre-feet (ac-ft). The amount of water and its pattern of release directly or indirectly affect physical, biological, cultural, and recreational resources within the Colorado River Ecosystem.

Hydropower generated from Glen Canyon Dam is cleaner in terms of air emissions, and its generation is more flexible and more responsive than many other forms of electrical generation. As such, the 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 (i.e., the maximum electric output of the eight generating units) of 1,320 MW. When possible, higher releases are scheduled in high-demand winter and summer months to generate electricity when demand is greatest.

Water releases from Glen Canyon Dam fluctuate on a daily and hourly basis 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 5,000 to 31,500 cfs, but actual daily fluctuations have been constrained to less than this maximum range as a result of implementing the 1996 Record of Decision (ROD) (Reclamation 1996). These constrained fluctuations result in a downstream “fluctuation zone” between low and high river stages (i.e., the water level associated with a given flow) that is inundated and exposed on a daily basis.

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 in the Colorado River between Glen Canyon Dam and Lake Mead. Before the dam, water temperature varied on a seasonal basis from highs around 27°C (80°F) to lows near freezing. Now, water released from Glen Canyon Dam averages 9°C (48°F) year round, although release temperatures vary depending on the water level in Lake Powell and other factors, and water temperature warms by about 1°C (1.8°F) for every 30 mi traveled downstream during warmer months of the year (Reclamation 1999b). Lake Powell traps sediment that historically was transported downstream. The dam releases clear water, and the river becomes muddy when downstream tributaries contribute sediment, as during summer monsoon storms.

3.1.5 Colorado River Ecosystem Resource Linkages

The Colorado River Ecosystem formed in a sediment-laden, seasonally flooded environment. Virtually all of the Colorado River Ecosystem resources are associated with or dependent upon water and sediment. Interactions among water volume and releases patterns, sediment transport, and downstream resources support a complex ecosystem. The construction of Glen Canyon Dam altered the natural dynamics of the Colorado River. It is understood that Glen Canyon Dam collects and stores water for beneficial purposes and in the process traps sediment and associated nutrients that previously traveled down the Colorado River. The regulated releases from Glen Canyon Dam and Lake Powell have resulted in an altered aquatic and terrestrial ecosystem compared to that which existed before Glen Canyon Dam.

This EIS is focused on potential changes to current operations at Glen Canyon Dam, the impacts they may have on Colorado River Ecosystem resources, water management and hydropower generation, and the determination of whether such changes can further improve resource conditions in the Colorado River Ecosystem. Specifically, the question is whether the alternative actions and experiments identified in this EIS can lead to changes in the current Modified Low Fluctuating Flow (MLFF) operation in a manner that improves resource conditions in the Colorado River Ecosystem consistent with existing laws.

The following discussion addresses the current resources of the affected environment and how dam operations affect them either directly or through linkages among resources.

3.2 WATER RESOURCES

This section presents information about the water resources of the affected area, including Lake Powell, the Colorado River and portions of its tributaries below Glen Canyon Dam, and Lake Mead (especially the inflow area of the reservoir). Information is organized within the broad topics of hydrology and water quality and includes information on the operation of Glen Canyon Dam and current conditions in these topical areas.

The hydrology of the Colorado River, as discussed in this EIS, refers to the water volumes, flow rates, and open channel hydraulics (i.e., characteristics of the conveyed flow such as depths and velocities) of the reservoirs, the river, and its tributaries. These aspects of Colorado River hydrology are directly affected by the proposed action of changes in operations at Glen Canyon Dam. Hydrology directly affects water quality variables in the downstream river environment such as temperature, salinity, and turbidity. Sediment transport and channel and floodplain morphology (e.g., pools, rapids, sandbars, and terraces) are controlled and shaped by the river's hydrologic properties.

From a human needs perspective, the construction and operation of Glen Canyon Dam, in addition to other dams in the basin, allow the distribution of Colorado River water as envisioned by the Colorado River Compact and the related Law of the River. These dams also provide the opportunity to deliver water to the farms, ranches, and communities that depend on Colorado River water.

From an ecosystem and habitat perspective, dam operations define and can change the Colorado River Ecosystem attributes that support aquatic and terrestrial species and communities. This EIS examines whether current operations at Glen Canyon Dam can be modified in a manner, consistent with existing law, to protect and improve these resources as contemplated in the Grand Canyon Protection Act of 1992 (GCPA).

From a recreational perspective, the dam and dam operations provide both flat water and river-based recreational opportunities. Dam operations provide predictable and relatively stable flow conditions that allow a viable year-round recreational opportunity that might otherwise not have existed. Certain dam operations impact the quality of a river recreational experience, such as fewer or smaller sandbars to recreate on and fewer high flows for whitewater rafters. But, with the addition of flat water recreation on the reservoir and predictable dam operations, there are also recognizable benefits to recreation and the regional economy.

From a power generation perspective, hydropower provides a cleaner (in terms of air emissions) and flexible renewable energy source that provides peaking power to help maintain a stable power grid. In the case of Glen Canyon Dam, the major component of the CRSP, revenues from power generation provide funds for repayment of the federal investment in the CRSP facilities, the infrastructure to support existing and additional water development in the Upper Basin, as well as environmental programs such as the Upper Colorado and San Juan Recovery Implementation Programs for the four Colorado River Endangered Fish, and the Glen Canyon Adaptive Management Program.

From a Tribal perspective, the Colorado River is considered the lifeblood of ancestral Tribal lands. The Fort Mojave Tribe, Havasupai, Hopi, Hualapai, Navajo Nation, Pueblo of Zuni, and Southern Paiute Tribes depend upon the Colorado River and the land it supports for water supply; economic growth; business; and historical, cultural, and spiritual connection.

3.2.1 Hydrology

The primary source for the total annual water flow in the Colorado River Basin is mountain snowmelt emanating from the Rocky Mountains in the Upper Colorado River Basin. Therefore, unregulated river flows are typically very high in the late spring and early summer and diminish rapidly by midsummer, although flows in late summer through autumn sometimes increase following monsoonal rain events (Reclamation 2007a). In general, the average annual natural flow of the Colorado River at Lees Ferry over the 105-year period (water years 1906 through 2010) has averaged around 15 million acre-feet (maf), but has ranged between approximately 5.4 and 25.4 maf (Reclamation 2007a, 2013a). The period from water years 2000 to 2010 was the driest 11-year period in the more than 100-year historical record for the Colorado River Basin (average annual flow of 12.1 maf); the period from water years 1999 to 2010 was the second-driest 12-year period (12.5 maf) on record (Holdren et al. 2012; GCMRC 2015a). Based on historical (1922–2015) Lees Ferry flow data from Grand Canyon Monitoring and Research Center (GCMRC) (2015a), the most recent 10-year period (2006–2015) was drier than 77% of all 10-year periods since 1922, and the most recent 20-year period (1996–2015) was drier than 73% of all 20-year periods since 1922. These two periods had average annual cumulative flows of 9.0 maf and 9.6 maf, respectively. Average annual natural flow is forecast to decline in the future (Seager et al. 2007; Vano et al. 2013; Reclamation 2012e).

3.2.1.1 Lake Powell Hydrology

Lake Powell, illustrated in Figure 3.2-1, along with its associated major tributaries, is the second-largest man-made reservoir on the Colorado River (Lake Mead is the largest) and the largest reservoir constructed by the Bureau of Reclamation (Reclamation) under the authority of the Colorado River Storage Project Act of 1956 (CRSPA). Lake Powell has a maximum live storage capacity of around 24.3 maf. At full pool capacity, the mean depth is approximately 165 ft, with a maximum depth of about 560 ft in the forebay area of the dam. Lake Powell provides water storage for use in meeting the compact obligations consistent with the Law of the River (Reclamation 2007a). Specifically, Lake Powell provides storage needed to assist the Upper Division States in meeting their Colorado River Compact obligations. Releases from Glen

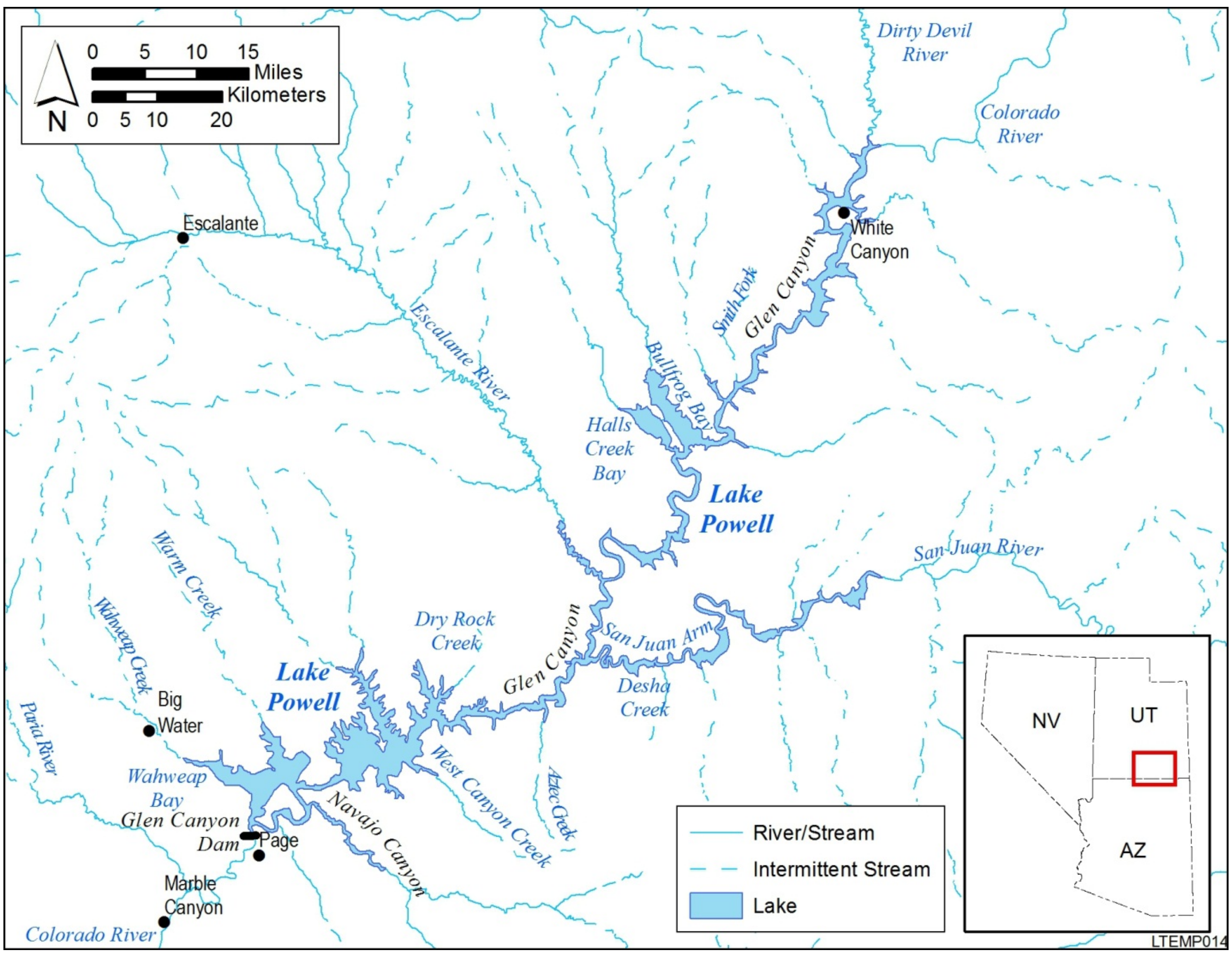

FIGURE 3.2-1 Map of Lake Powell and Associated Major Tributaries

Canyon Dam made pursuant to the Long-Range Operating Criteria (LROC), and its current implementation through the Interim Guidelines, provide the operational guidance needed to currently comply with the Colorado River Compact and related Law of the River. Water released from Lake Powell for compliance with the provisions of the Colorado River Compact also generates hydroelectric power through the Glen Canyon Dam powerplant and provides benefits to recreation. The reservoir is also used as a municipal water source for the City of Page, Navajo Community, Chapter of LeChee, and industrial water for the Navajo Generating Station.

The reservoir is long and narrow, more than 180 mi long and often less than a mile wide at the surface. Glen Canyon Dam is designed to operate between the outlet works intakes at elevation 3,370 ft AMSL and the top of the live storage pool at elevation 3,700 ft AMSL. Hydropower production would cease if Lake Powell drops below approximately 3,490 ft in elevation, or minimum power pool. As the water level changes, the surface of Lake Powell varies in size from about 52,000 ac at the top of the minimum power pool to 163,000 ac at the top of live storage, and the corresponding shoreline fluctuates from approximately 990 to 1,960 mi long. At the full pool elevation of Lake Powell, this reach includes approximately 25 mi of Cataract Canyon, more than 50 mi of the San Juan River, and approximately 170 mi of Glen Canyon (Reclamation 1995, 2007a). Almost half of the reservoir's capacity lies in its upper 100 ft, a zone where the lake overtops many local plateau surfaces. The floor of the reservoir is the incised bed of the former Colorado River, ranging from around 500 to 800 ft in width at its bottom, with a nearly uniform grade of 0.038% (Johnson and Merritt 1979). Lake Powell contains more than 90 major side canyons that have unique orientations and morphologies owing to differences in size, orientation, inflow contributions (springs and tributary flows), mixing processes, and visitor activities; however, it appears that side canyon portions of the reservoir generally have the same chemical and physical stratification as that of the main reservoir body (Taylor et al. 2004).

The hydrology of Lake Powell is primarily influenced by basin-wide hydrology and subsequently annual inflow into the reservoir. The elevation of Lake Powell and the timing, volume, and water quality of inflow into the reservoir influence the water quality of releases from Glen Canyon Dam, which has subsequent effects on the downstream water quality of the Colorado River in Glen and Grand Canyons and Lake Mead. The proposed action cannot affect Lake Powell inflow patterns.

One of the most important factors driving short-term and long-term processes in Lake Powell is the inflow hydrology, characterized by the volume and quality of inflows to the reservoir and their seasonal variation (Vernieu and Hueftle 1998). Overall, approximately 95% of the reservoir's inflow originates from the mainstream of the Colorado River and two major tributaries, the San Juan and Green Rivers (Stanford and Ward 1991; Reclamation 1995, 2007a; Wildman et al. 2011). Specifically, since water year 2005, the Upper Colorado River Basin has experienced significant year-to-year hydrologic variability. The unregulated inflow (i.e., the inflow that would occur if no upstream reservoir storage regulation existed) to Lake Powell has averaged a water year volume of 10.22 maf (94% of 30-year average for the 1981–2010 period) during the period from 2005 through 2012. The hydrologic variability during this same period (from 2005 to 2012) resulted from a low water year unregulated inflow volume of 4.91 maf

(45% of the 30-year average) in water year 2012 and a high water year unregulated inflow volume of 15.97 maf (147% of the 30-year average) in water year 2011 (Reclamation 2013c).

The majority of the inflow into Lake Powell, around 60%, occurs in late spring and early summer as a result of snowmelt in the Rocky Mountains and Upper Colorado River Basin (Iorns et al. 1965; Evans and Paulson 1983; Vernieu et al. 2005). This runoff tends to be warm, low in salinity, and turbid (i.e., sediment laden) as a result of its passage through the canyonlands and, because of its temperature, it represents the lowest-density water entering the reservoir during the year. Consequently, this water travels along the top of the reservoir as an overflow density current, leaving the waters below the penstock level (i.e., elevation 3,470 ft) essentially untouched (Johnson and Merritt 1979; Vernieu and Hueftle 1998; Vernieu et al. 2005; Reclamation 1995).

Winter inflows are cold and saline and represent the highest-density inflows to the reservoir during the year. Depending on the relative density of the existing hypolimnion (i.e., the lower layer of water in a stratified lake) in Lake Powell, winter inflows may flow along the bottom of the reservoir as an underflow-density current (Johnson and Merritt 1979), routing fresh water to the hypolimnion and displacing older oxygen-poor saline water upward toward the dam release structures. During the spring of each year from 1999 to 2008, winter inflows moving through Lake Powell had sufficient density to flow along the bottom of the reservoir (Vernieu 2010). If winter inflows are less dense than the water in the hypolimnion, as might happen following years of low runoff that establish saline conditions, they will flow into intermediate layers as an interflow-density current, eventually being discharged through the penstock outlet and leaving deeper waters stagnant (Vernieu and Hueftle 1998; Reclamation 1995; Vernieu et al. 2005). This condition was observed at Lake Powell from 1991 to 1998 (Vernieu 2010). Regardless of whether the winter inflow density current overrides or displaces the hypolimnion, there is a consistent annual pattern of colder and more saline water around the penstock withdrawal zone during the winter months.

Early dam operations were pursuant to the 1970 Criteria for Coordinated Long-Range Operation of Colorado River Reservoirs and influenced by the Filling Criteria for Lake Powell, which were formally terminated when the reservoir filled on June 22, 1980. Operations during the relatively full period from 1980 to 1987 were controlled by the LROC, focusing on water delivery and power generation. Beginning in 1988, operations returned to the objective minimum release of 8.23 maf, as specified in the LROC. Since the early 1990s, operations have continued to focus on meeting water allocation requirements and producing power, but they were modified to address and comply with environmental values and constraints designed to minimize the effects of Glen Canyon Dam on downstream resources (Reclamation 1995). The 1996 Glen Canyon Dam ROD identified MLFF as the operating regime for Glen Canyon Dam and adopted an adaptive management framework to monitor and assess changes in operations to Glen Canyon Dam (Reclamation 1996). MLFF set monthly release ranges, minimum and maximum daily release limits, daily fluctuation limits, and ramping rates to minimize the effects of Glen Canyon Dam releases on downstream resources (Reclamation 1995). During the period following adoption of the MLFF, numerous experimental flows and non-flow actions for scientific and environmental purposes were conducted.

3.2.1.2 Hydrology of the Colorado River Downstream of Glen Canyon Dam

Annual water release volumes are established pursuant to the LROC, which is currently implemented through the Interim Guidelines for Coordinated Operations of Lake Powell and Lake Mead (Reclamation 2007a). The interim guidelines for coordinated operations of Lake Powell and Lake Mead define four operation tiers: (1) the Equalization Tier, (2) the Upper Elevation Balancing Tier, (3) the Mid-Elevation Release Tier, and (4) the Lower Elevation Balancing Tier. Releases are based upon the elevations of Lake Powell and Lake Mead as identified in Appendix D. Notably, when operating in the Equalization Tier, the Upper Elevation Balancing Tier, or the Lower Elevation Balancing Tier, scheduled water year releases from Lake Powell would be adjusted each month based on forecast inflow and projected September 30 elevations at Lakes Powell and Mead.

The annual releases since the dam was completed have included annual volumes above 8.23 maf numerous times. In general, each period of higher release was followed by a reduction in the salinity of the hypolimnion (Vernieu and Hueftle 1998). Monthly release volumes accomplish the annual releases implemented pursuant to the LROC and are based on anticipated power demands, forecasted inflows, and other factors such as storage equalization between Lake Powell and Lake Mead. High release volumes do not always coincide with peaks in reservoir inflow; instead, they coincide with times of increased power demands (e.g., January and August). Therefore, the timing of these high releases may or may not facilitate the drawing and replacement of hypolimnetic waters near the dam (Vernieu and Hueftle 1998).

The Lees Ferry gaging station (river mile [RM] 0), which has been operated by the U.S. Geological Survey (USGS) since May 1921, is approximately 15.5 mi downstream from the Glen Canyon Dam and approximately 1 mi upstream of the Paria River mouth. Its location allows a comparison of pre-dam flows with post-dam flows downstream of Glen Canyon Dam because it is located close to the dam, but is unaffected by the presence of tributary inflows. This section primarily utilizes the Lees Ferry data and analysis. Figure 3.2-2 illustrates the changes in the pattern of annual flows at Lees Ferry for the pre-dam period (from 1922, when continuous records began, through 1962) and post-dam period (1963 through 2015) (GCMRC 2015a).

The average pre-dam peak annual discharge was found to be approximately 92,000 cfs (Topping et al. 2003). The largest recorded peak flow during the pre-dam period (data record from 1921 to 1963) occurred in June 1921, soon after the installation of the Lees Ferry gage. This flood was estimated to have a peak flow of 170,000 ± 20,000 cfs; the return period of this event was estimated to be 40 years (Topping et al. 2003; O’Connor et al. 1994). The average 2-year recurrence interval flood peak was calculated from the discharge record to be 85,000 cfs (Topping et al. 2003). There is also evidence of a flood in 1884 that peaked at approximately 213,500 cfs (+ 14,500 cfs) at Lees Ferry (Topping et al. 2003). Paleoflood research has determined that during the last 4,500 years, 15 floods at Lees Ferry had peak discharges larger than 120,000 cfs. Of these floods, 10 had peak discharges greater than 140,000 to 150,000 cfs during the last 2,100 to 2,300 years, and one flood that occurred 1,200 to 1,600 years ago had a peak discharge exceeding about 300,000 cfs (Topping et al. 2003).

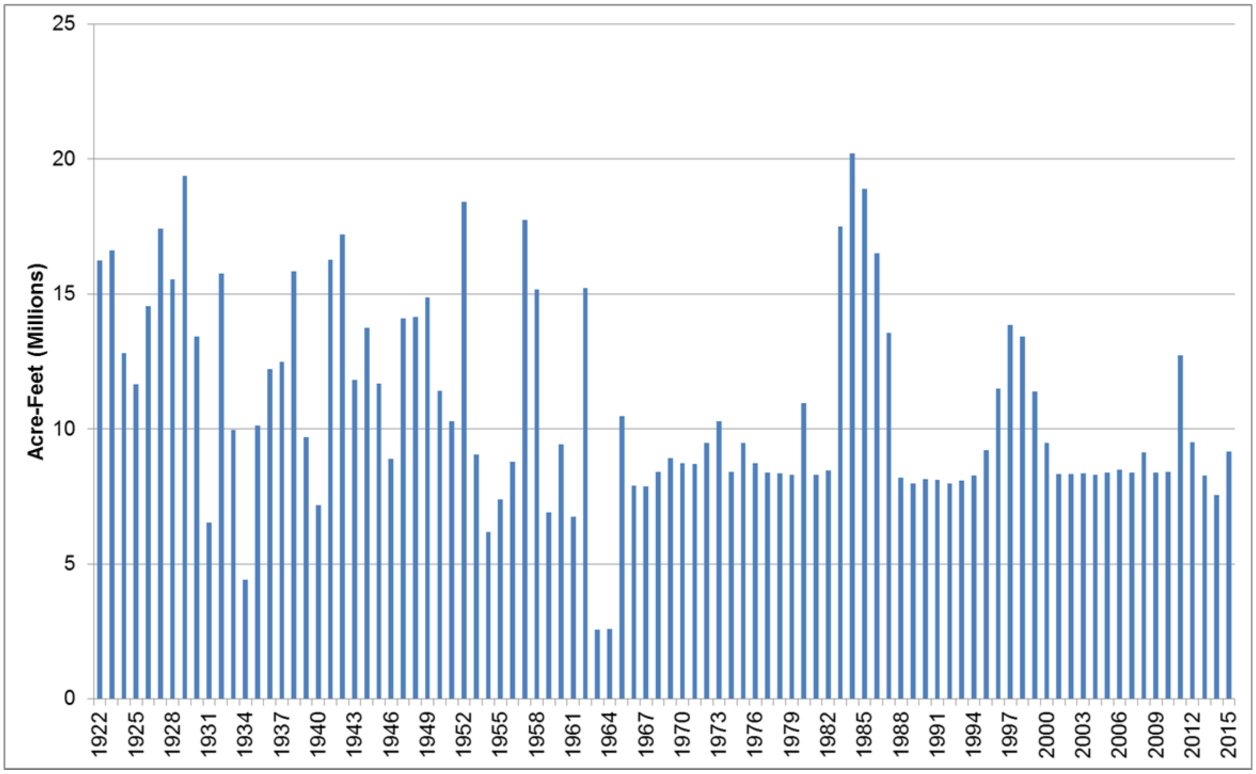

FIGURE 3.2-2 Pattern of Annual Historic Flows at Lees Ferry (Source: GCMRC 2015a)

Compared to pre-dam flows, post-dam flows exhibited a reduction in the percentage of very high flows (i.e., flows >40,000 cfs) and very low flows (flows <5,000 cfs). Post-dam monthly median flow has ranged from 10,200 cfs in October to 16,400 cfs in August (Topping et al. 2003). No post-dam months have had a median flow less than 9,000 cfs (Topping et al. 2003). The median post-dam within-day flow variation was 8,580 cfs; the within-day range exceeded 10,000 cfs on 43% of all days (Topping et al. 2003). Note that since the 1996 ROD, maximum within-day flow variation has been limited to 8,000 cfs (except during high-flow experiments [HFEs]). Within-day flow variation in releases continues downstream for the entire length of the Colorado River between Glen Canyon Dam and the headwaters of Lake Mead, but decreases as flows pass through Marble and Grand Canyons. For example, the difference between the peak and base release on October 1, 2014, was 5,470 cfs. This resulted in a difference from peak to base of approximately 3,930 cfs 13 hours later at RM 61 (just upstream of the confluence with the Little Colorado) and approximately 3,100 cfs 43 hours later at RM 225 (near Diamond Creek at the western end of Grand Canyon).

Periodic releases of relatively short duration that bypass the hydropower plant have also occurred at the Glen Canyon Dam. Recent examples of releases that have utilized the bypass outlet works or the spillways include mid-1980s flood years (using outlet works and spillways); and HFEs conducted in 1996, 2004, 2008, 2012, 2013, and 2014 (using outlet works only).

3.2.1.3 Lake Mead Hydrology

Lake Mead, illustrated in Figure 3.2-3, along with its associated major tributaries, is located approximately 30 mi east of Las Vegas, Nevada, in the Mojave Desert. It is the second of four major reservoirs on the mainstem Colorado River and was formed by the Hoover Dam, which first began impounding water in 1935 (Turner et al. 2011; Reclamation 2008a). Lake Mead has a live capacity of 26.399 maf at elevation 1,221.4 ft, and can store twice the average annual flow of the Colorado River (Reclamation 2012a). Lake Mead provides water storage to regulate the water supply and meet the water demands of the Lower Division states and Mexico consistent with the Law of the River (Reclamation 2007a). Similar to Lake Powell, its waters are also used for recreation and generation of hydroelectric power, through the Hoover Dam powerplant. Hoover Dam also provides flood control benefits. The reservoir is located within the LMNRA, which is administered by the National Park Service (NPS); however, Reclamation retains authority and discretion for the operation of both Hoover Dam and Lake Mead (Reclamation 2007a).

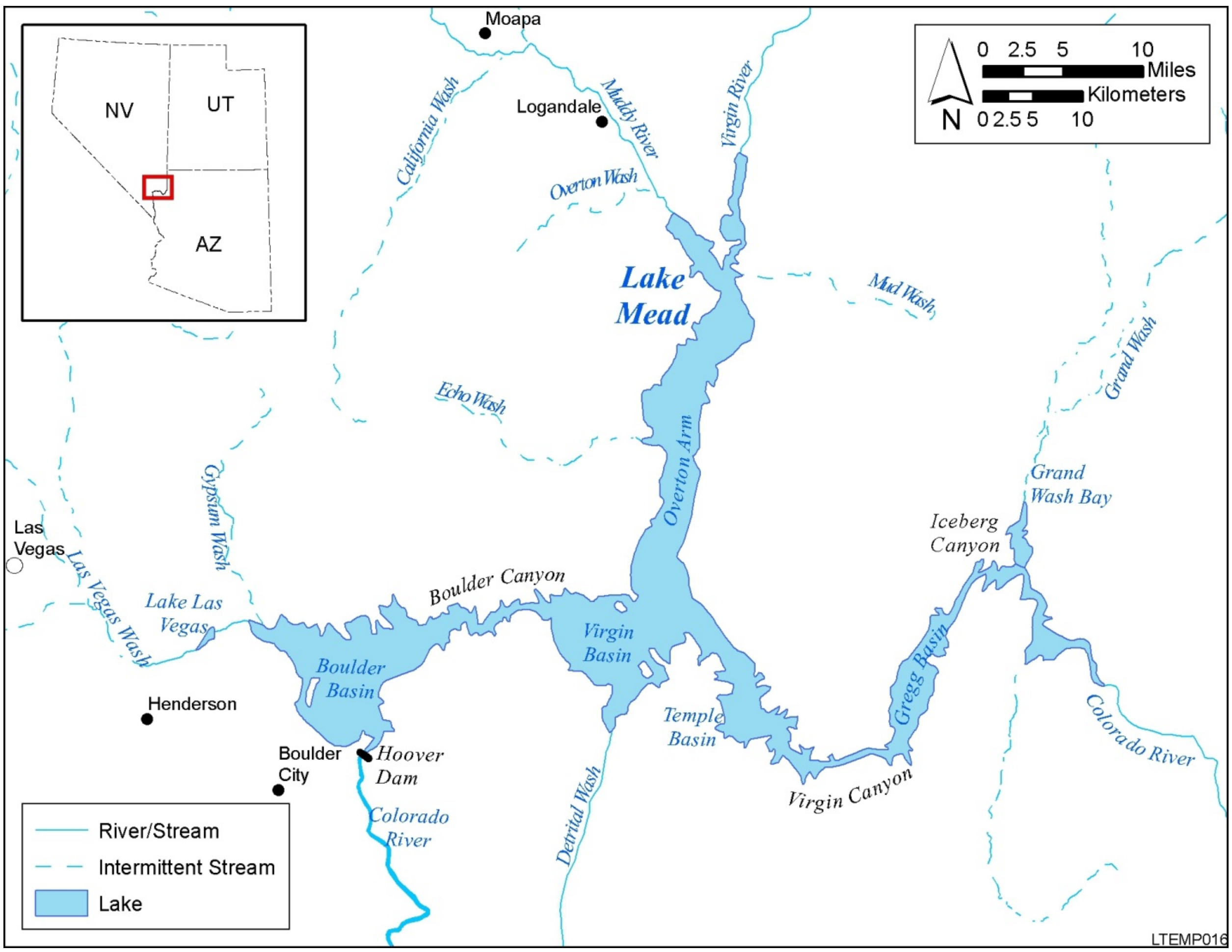

FIGURE 3.2-3 Map of Lake Mead and Associated Major Tributaries

Lake Mead is a large, deep-storage reservoir with a maximum depth of approximately 490 ft and a mean depth of nearly 170 ft. It is approximately 110 mi long, extending from the mouth of the Grand Canyon at Pearce Ferry to Hoover Dam in Black Canyon. With a width that varies from several hundred feet in the Canyons to more than 9 mi, Lake Mead has the largest surface area of any reservoir in the Northern Hemisphere, covering about 160,000 ac (250 mi^2) with a shoreline that is more than 550 mi long (Reclamation 2012a; Turner et al. 2011; Evans and Paulson 1983). The hydraulic residence time of Lake Mead depends upon reservoir release and inflow patterns (which are dependent upon Glen Canyon Dam releases). Estimates have calculated residence times on the order of about 2.6 years, based on average inflows and reservoir volumes (Turner et al. 2012; Holdren 2012). When the reservoir is thermally stratified, the epilimnion (i.e., the surface layer of water in a stratified lake) occurs from approximately 0 to 65 ft, the metalimnion (i.e., middle layer of water in a stratified lake) occurs from approximately 65 to 100 ft, and the deep hypolimnion occurs from approximately 100 ft to the bottom of the reservoir.

Lake Mead can be divided along the historical Colorado River channel into four large sub-basins: Boulder, Virgin, Temple, and Gregg; four narrow canyons: Black, Boulder, Virgin, and Iceberg; and the 30-mi-long Overton Arm, which extends from the Virgin and Muddy Rivers to the Virgin Basin (Figure 3.2-3). The Colorado River enters the eastern end of Lake Mead at the upper end of Gregg Basin.

Prior to closure of Glen Canyon Dam in 1963, Colorado River inflow into Lake Mead was unregulated and reflected natural hydrologic variability; volumes depended upon the annual snowmelt and rainfall received on the west side of the Rocky Mountains. Regulation of inflow began in 1963, when Glen Canyon Dam was constructed approximately 280 mi upstream. The formation of Lake Powell and operation of Glen Canyon Dam have altered the physical characteristics of the Colorado River inflow to Lake Mead. In general, gaged annual inflows to Lake Mead averaged about 10.9 maf between 1935 and 2001, with a pre-dam (1935–1963) value of 11.3 maf and a post-dam (1963–2001) value of 10.6 maf (Ferrari 2008). Flows decreased from 1999 through 2010 as the entire Colorado River Basin experienced drought conditions. Annual inflows to Lake Mead for the period of 1999–2010 have averaged approximately 9.0 maf, which included about 8.23 maf, with additional inflow of approximately 0.7 maf contributed by other tributaries, thus providing a total average operational inflow into Lake Mead of 9.0 maf (Holdren et al. 2012; Turner et al. 2012).

3.2.1.4 Seeps and Springs

Although the Colorado River flows through the Grand Canyon, its waters do not originate there. The Grand Canyon's only native waters (i.e., waters derived in place) come from the more than 1,000 springs and seeps that are recharged by precipitation on the high plateaus surrounding the canyon (i.e., Coconino on the South Rim and Kaibab on the North Rim) and discharged along the walls below the rim. Some springs, such as Pumpkin Spring and Fence Spring, are within the area of the Colorado River Ecosystem that is potentially affected by the proposed action.

Although springs make up less than 0.01% of the Grand Canyon's landscape, they are ecologically important (Rice 2013). Each spring is unique and supports a distinctive array of flora and fauna, many of which are endangered and endemic (i.e., found nowhere else) (NPS 2014a). It has been estimated that species diversity is 100 to 500 times greater in the vicinity of the springs than in the surrounding areas (NPS 2014a). Any changes or declines in flow of a small spring or seep may change a perennial system into an intermittent one, or dry the system out completely. Thus, species such as riparian plants, fish, amphibians, and invertebrates that rely on these water sources may be lost because they do not often have a mechanism to move across the desert landscape to a new water source (Rice 2013).

Tribal Perspectives on Seeps and Springs

Many springs and seeps also hold cultural significance for Native Americans in the region. For example, from the Zuni perspective, the earth is circular in shape and is surrounded on all sides by ocean. Under the earth is a system of covered waterways, all ultimately connecting with the surrounding oceans, springs, and lakes, which are the openings to this system (Bunzel 1932) and are regarded as sacred to the Zuni because they provide water, a life-giving substance that is necessary to maintain life within the Southwest's harsh environment. Springs are specifically "considered to be the most precious things on Earth" (Hart 1980). The Grand Canyon contains numerous springs that are utilized among all religious groups for traditional and religious practices and play an integral role in water collecting by the Zuni people for ceremonial use.

The Hualapai consider *Ha'thi-el* (Salty Spring), a sacred spring within the Canyon, to contain a petroglyph site that tells of the creation of the Hualapai and other Pai peoples (HDCR 2010). Other springs, such as Pumpkin Spring at RM 213 and Medicine Spring at the downstream end of Lava Falls Rapid, are warm mineral springs and are considered to have healing properties. Pumpkin Spring is immediately above the level of typical operational flows, although in the pre-dam past it would have regularly been inundated and flushed during the frequent flood episodes. During periods when it has not been frequently inundated and flushed, concentrations of algae, bacteria, and minerals may affect the health of the spring.

All springs in the Canyons have a spiritual importance to the Hopi; water in general is a central feature in all of Hopi philosophy, and springs in particular are considered to be altars (Hough 1906). Water is collected at a number of springs in the Canyons for ceremonial use by Hopi, and prayers are offered to all of the spring locations. The Sipapuni, the origin location for the Hopi people, is a spring. Springs provide habitat for culturally important plants and animals that are rare in the otherwise arid region. Finally, springs have a key historical importance as water sources for the Hopi ancestors who resided in the Canyons.

The Havasupai are dependent on the springs that emit from the shallow and deep aquifers on their reservation and in GCNP. The spring water that flows through the Village of Supai and over the spectacular waterfalls on the reservation delivers approximately 49,000 ac-ft per year to the Colorado River. The Havasupai consider all springs to be sacred, with some having particular significance in tribal religious and cultural practices. They have also historically farmed at the major springs, including what is now called Indian Garden in GCNP (Hirst 1985).

3.2.2 Water Quality

3.2.2.1 Lake Powell Water Quality

The stratification of Lake Powell influences many chemical and biological processes in the reservoirs and, as a result, influences the characteristics and quality of water that is released to the Colorado River below the dam (Hart and Sherman 1996). As described previously, Lake Powell is thermally and chemically stratified into density layers that differ vertically and longitudinally. In general, vertical stratification varies seasonally and is determined by the relative density of different layers of the reservoir; longitudinal variation in water quality is the result of currents moving through the reservoir (Vernieu et al. 2005). The physical, chemical, and biological characteristics of Lake Powell have a direct effect on the quality of water drawn from and released below Glen Canyon Dam.

Lake Powell is thermally stratified through much of the spring, summer, and early fall (typically April–October) (Figure 3.2-4). In general, the epilimnion of Lake Powell, which

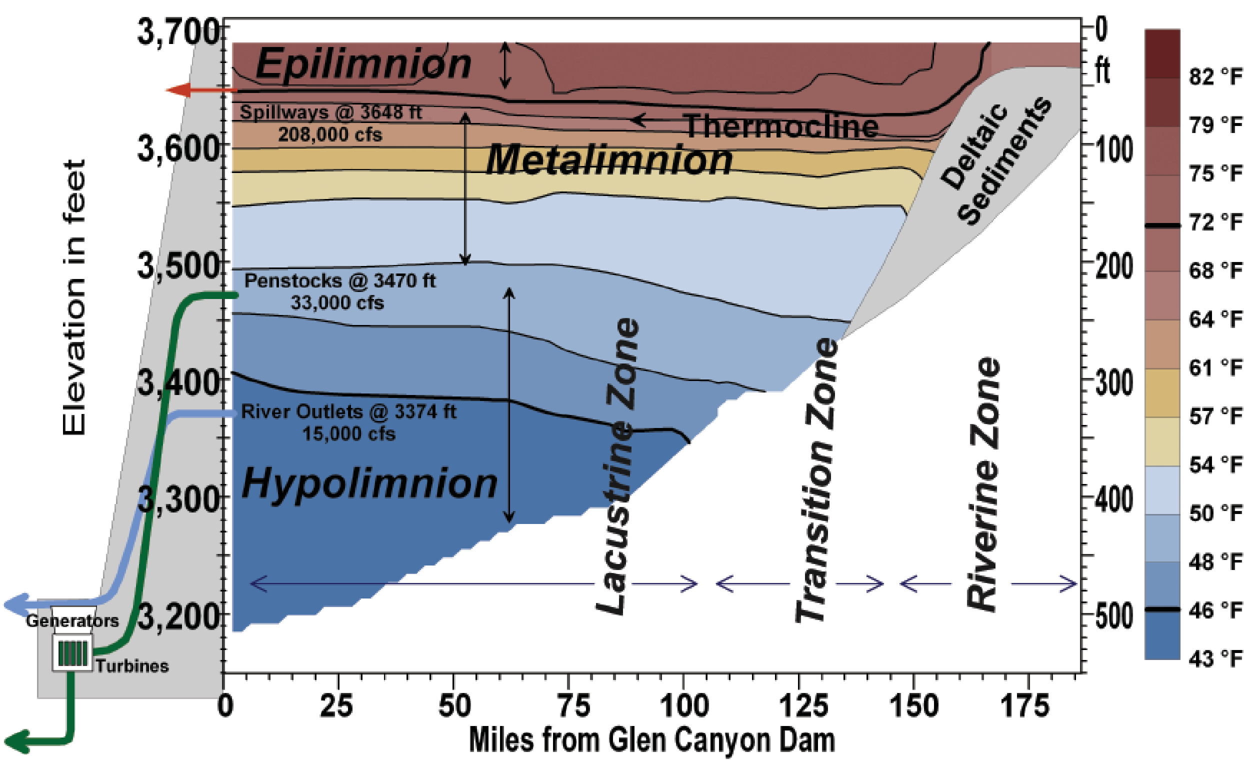

FIGURE 3.2-4 Profile of Lake Powell from Glen Canyon Dam to the Inflow of the Colorado River (Source: Vernieu et al. 2005)

ranges from the reservoir surface to a depth of about 60 ft, depending on season and location (Hart and Sherman 1996; Vernieu et al. 2005), exhibits the highest temperatures within the reservoir and varies little with depth. Warmed by spring inflows, ambient air temperature, and solar radiation, summer temperatures can reach around 25–30°C (77–86°F), while winter temperatures may drop to 6–10°C (45–50°F) (Stanford and Ward 1991; Vernieu et al. 2005; Reclamation 1995, 1999b). The metalimnion typically ranges from 60 to 180 ft in depth and exhibits decreasing water temperatures with depth because sunlight's ability to warm water also decreases with depth (Hart and Sherman 1996; Reclamation 1995). The hypolimnion, which begins around 180 ft below the surface of the reservoir, is typically too deep for sunlight to reach, and water temperatures are lower and remain nearly constant at about 6–9°C (43–48°F) (Vernieu et al. 2005; Hart and Sherman 1996; Reclamation 1995).

During the winter period (November–March), the thermal stratification breaks down as cooling surface waters are mixed with deeper water by the wind and vertical currents. By the end of the calendar year, mixing typically progresses to the depth of the penstock withdrawals. At this point, the release waters begin to exhibit characteristics of the epilimnion, which contains the warmest water in the reservoir at that time of year, despite the cooler weather conditions (Vernieu et al. 2005). Thus, the warmest release temperatures of the year occur in late fall to early winter, then temperatures begin to cool again as vertical currents mix the reservoir down to the penstocks depth, which occurs before thermal stratification begins to reestablish.

During the ongoing drought in the 2000s, Lake Powell levels generally declined and release temperatures gradually began to warm (Vernieu et al. 2005). Since then, total Colorado Basin storage has experienced year-to-year fluctuations in response to wet and dry hydrology, but water temperatures have continued on a general warming trend compared to the early 1990s (refer to Section 3.2.2.3 for further details on Colorado River water temperature). Figure 3.2-5 presents the water temperatures measured at the Lees Ferry gage (the official point of measurement for satisfying compact obligations is at Lee Ferry, Arizona) from 1991–2013, illustrating the aforementioned warming of the Glen Canyon Dam releases. Note that in water year 2011, there was a higher snowpack in the Colorado Mountains which resulted in higher inflows to Lake Powell and unusually large releases of warmwater.

Because of the position of the penstocks (i.e., elevation 3,470 ft), water temperatures can vary both annually and throughout the course of a year because the locations of the epilimnion, metalimnion, and hypolimnion (Figure 3.2-4) depend on season, reservoir level, hydrodynamics, timing and strength of stratification, and magnitude of withdrawals (Vernieu et al. 2005). When reservoir levels are high, releases tend to originate from within the hypolimnion and releases are cooler; when levels are low, withdrawals may come from the metalimnion or upper hypolimnion and releases are warmer (Hart and Sherman 1996). It appears that the water quality of Lake Powell above the dam has been largely unaffected by dam operations, particularly since 1991. Instead, the water quality of the reservoir appears to be more strongly linked to annual to decadal climatological variations, inflow hydrodynamics, and continuing basin-wide depletions (Lovich and Melis 2007; Hueftle and Stevens 2001; Vernieu and Hueftle 1998).

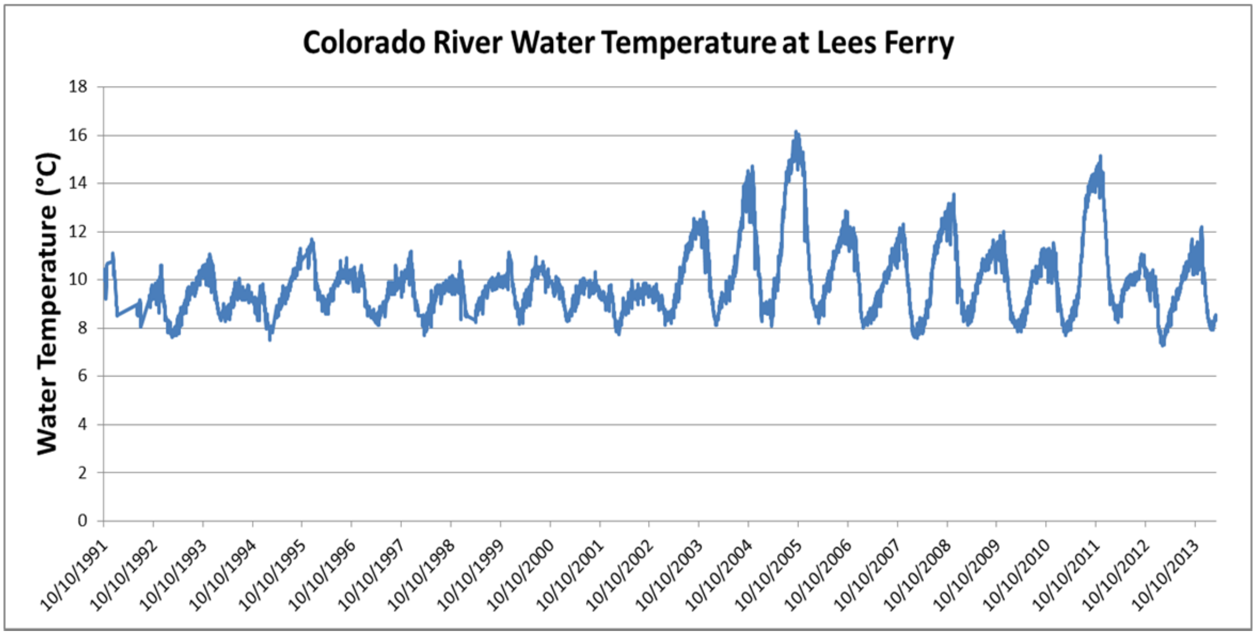

FIGURE 3.2-5 Water Temperature at Lees Ferry (Source: GCMRC 2015a)

Releases from Glen Canyon Dam can have minor effects on water quality and stratification in Lake Powell; such effects can include changes in temperature, salinity, and dissolved oxygen (DO) (Vernieu 2010). The effects on Lake Powell are dependent on the volume and duration of discharges from the dam and on preexisting conditions associated with stratification patterns, location of the layers relative to the release structures, and the fate of inflow currents in the reservoir. In general, the various discharges can cause increased mixing in the reservoir and result in increased movement of horizontal currents through the reservoir, at withdrawal-structure elevations (Vernieu 2010).

DO concentrations in reservoirs are affected by variations in inflow volume and temperature, seasonal reservoir circulation, and biological production and decomposition. In years of high inflows and when the reservoir elevations are low, flows cut through deltaic sediments, resuspending organic matter and nutrients that contribute to both chemical and biological oxygen demand as the inflow water passes down through the reservoir water column. The resulting plumes of low-oxygen water drive water column concentrations lower. When deltaic sediments and organic matter are not resuspended, oxygen demand is decreased and DO concentrations remain higher. Downstream of dams, turbulence, exposure to the atmosphere, and primary productivity reaerate the water column. The DO concentration reaches saturation downstream of Glen Canyon Dam before the confluence with the Little Colorado River (Hall et al. 2012) after passing through several major rapids.

Releases utilizing the bypass structures are made from depths beneath the powerplant intakes. The release waters tend to have lower temperatures, higher salinity, and lower oxygen levels than the water discharged from the dam during normal operations (Lovich and Melis 2007; Hueftle and Stevens 2001).

3.2.2.2 Colorado River Water Quality

The limnology and stratification of Lake Powell, particularly with respect to the location of the penstock intakes, defines the quality of Glen Canyon Dam releases. In general, outflow waters are drawn from the deep zone of the forebay metalimnion into the hypolimnion and characterized as generally even in quality throughout the year, being uniformly cold, clear, below saturation in DO, and low in nutrients (refer to individual Lake Powell parameters in Section 3.2.2.1 for more details). In addition, operation of the dam for peaking power generation has resulted in the removal of much of the seasonal and annual variability that occurred under natural conditions, replacing it with daily fluctuations constrained by set ramping rates (Vernieu and Hueftle 1998; Lovich and Melis 2007). After its release from the dam, changes to the chemical and physical quality of the water are affected by ambient meteorological conditions, primary production and respiration from the aquatic environment, aeration from rapids, inputs from other tributary sources and overland flow, and various aspects of dam operations (Vernieu et al. 2005).

Previous HFEs have been shown to affect the water quality of Lake Powell, the release waters, and Colorado River below Glen Canyon Dam, resulting in slight reductions in downstream temperature and slight increases in salinity, as well as a temporary increase in turbidity (i.e., suspended sediment) from scouring (Reclamation 2011b). In addition, under normal powerplant discharges, limited aeration of the river occurs in the tailwater reach of the river just below the dam compared to reaches farther downstream. However, during HFEs (e.g., high flows in 1996, 2004, 2008, 2012, 2013, and 2014), the effects of the spray and resulting turbulence were sufficient to bring the undersaturated release water up to full or supersaturation oxygen levels immediately below the dam and through the tailwater (Hueftle and Stevens 2001; Vernieu et al. 2005; Vernieu 2010; GCMRC 2015a). During HFEs, diurnal DO patterns were still present but were overshadowed by jet tube aeration. These fluctuations recover quickly (within hours) when there is a return to lower flows, although net respiration is typically reduced from pre-flood levels due to the sheared biomass (Hueftle and Stevens 2001). The magnitude of the dam discharges also influences the amount of sediment in suspension, and high water volumes can greatly affect the degree of downstream distribution. Large or widely fluctuating releases draw water from a thicker withdrawal zone than do low or steady releases. Thus, during these events, water has the potential to be either cooler and more saline (if drawn from below the thermocline or released through the jet tubes), or warmer and less saline (if drawn from above) than that typically released (Vernieu et al. 2005).

Downstream of the dam, larger tributaries (e.g., Little Colorado River and Paria River) that enter the Grand Canyon can affect water quality of the Colorado River below Glen Canyon Dam. In general, these tributaries tend to carry water at higher temperatures than the mainstem river, thus warming the regions where they join. In addition, tributaries, such as the Paria River and Little Colorado River, can carry large amounts of fine sediment and organic materials during flood events, which limit light availability for primary production and may enhance conditions for native fish that use turbid water for cover from predation (Cole and Kubly 1976; Shannon et al. 1994; Topping et al. 2000a,b; Vernieu et al. 2005). Some tributaries, such as the Little Colorado River, are also significant sources of salinity for the mainstem Colorado River, while other tributaries are more dilute (Cole and Kubly 1976; Vernieu et al. 2005). There are also a number of smaller spring-fed tributaries that originate within the Grand Canyon reach, which tend to have very different physicochemical properties than the mainstem; however, their mean flows are so low that their contribution to water quality during base flow is not significant.

Colorado River Temperature

Prior to the construction of Glen Canyon Dam, the water temperatures of the Colorado River in the Grand Canyon would range from near freezing (0°C, or 32°F) in the winter to around 30°C (86°F) in the late summer, with a mean of approximately 14°C (57°F) (Cole and Kubly 1976; Johnson and Merritt 1979; Reclamation 1995; Vernieu and Hueftle 1998; Lovich and Melis 2007; Stevens 2007). Before 1973, during the reservoir's initial filling stage, release temperatures were greatly affected by surface or epilimnetic withdrawals because of the proximity of the reservoir's surface to the penstock withdrawal zone. Thus, the maximum release temperatures during that period occurred during the months of August and September, reflecting the surface warming of the reservoir (Vernieu et al. 2005).

Trends in tailwater temperature stabilized from 1973 to 2003, when the reservoir surface elevations were above 3,600 ft. During this time, overall seasonal fluctuations diminished to approximately 5°C (9°F), and release temperatures were greatly reduced because the penstocks of the dam were located well below the surface of Lake Powell in the hypolimnion. The Glen Canyon Dam tailwater temperatures ranged between about 7 and 12°C (45 and 54°F) and averaged about 9°C (49°F) as measured at Lees Ferry, with minor excursions beyond this range during periods of spillway releases (Reclamation 1995, 1999b; Vernieu et al. 2005; Hamill 2009). In addition, an asymmetric annual temperature pattern developed over this period, with tailwater temperature measurements reflecting the seasonal changes of the water at the penstock depth. In general, the highest river temperatures immediately below the dam occurred in late fall or early winter (e.g., December), most likely a result of winter vertical mixing in the upper layers of the reservoir. This is followed by a sudden drop of the river's minimum temperature within a few months, with the lowest temperatures occurring in late winter (e.g., February or March), that likely occurs due to reservoir mixing (Vernieu and Hueftle 1998). Daily warming of the tailwater has also been observed, with the maximum warming (about 1.3°C, or 2.3°F) during the day occurring in June, near the summer solstice (Flynn et al. 2001).

Since the early 2000s, total Colorado Basin storage has experienced year-to-year increases and decreases in response to wet and dry hydrology. However, Lake Powell water levels have generally declined as a result of basin-wide drought conditions, and subsequently release temperatures warmed. For example, in November 2004, the annual maximum mean daily temperature reached its height at around 15°C (59°F) (Vernieu et al. 2005) at the Little Colorado River. Beginning in water year 2005, overall reservoir storage in the Colorado River Basin has increased (Reclamation 2013c), which has apparently caused river temperatures to decline slightly, although they still range between around 8 and 12°C (46 and 57°F) at Lees Ferry. Figure 3.2-5 (in Section 3.2.2.1) presents the water temperatures measured at Lees Ferry from 1991 to 2013, which illustrates the aforementioned warming trend of dam releases.

River temperatures increase as the water moves slowly downstream. This correlation is a function of the distance and time from Lake Powell, as well as the input from tributaries (which are usually warmer than the mainstem) (Cole and Kubly 1976). However, it has been generally estimated that water temperatures increase about 1°C (1.8°F) for every 30 mi traveled downstream (Reclamation 1999b). This downstream warming trend can be seen in Figure 3.2-6, which presents Colorado River water temperatures at four stations along the river from Lees Ferry to Diamond Creek.

The greatest warming occurs during the period from June through August because of the transfer of heat from the warmer surrounding air mass, heat stored in the canyon walls adjacent to the river, and solar radiation. The mean annual downstream river temperatures ranged between 9 and 18°C (48 and 64°F), depending on year and distance downstream of the dam (Reclamation 1995, 1999b; Hamill 2009). In general, water temperature in lower reaches of the river is affected by three physical properties: discharge rate, which affects residence time (Anderson and Wright 2007; Wright, Anderson et al. 2008); channel aspect, which affects light availability; and air temperature, which is generally greater in the western portion of the Grand Canyon (Yard et al. 2005; Ralston 2011). Mainstem water temperatures near the mouth of the

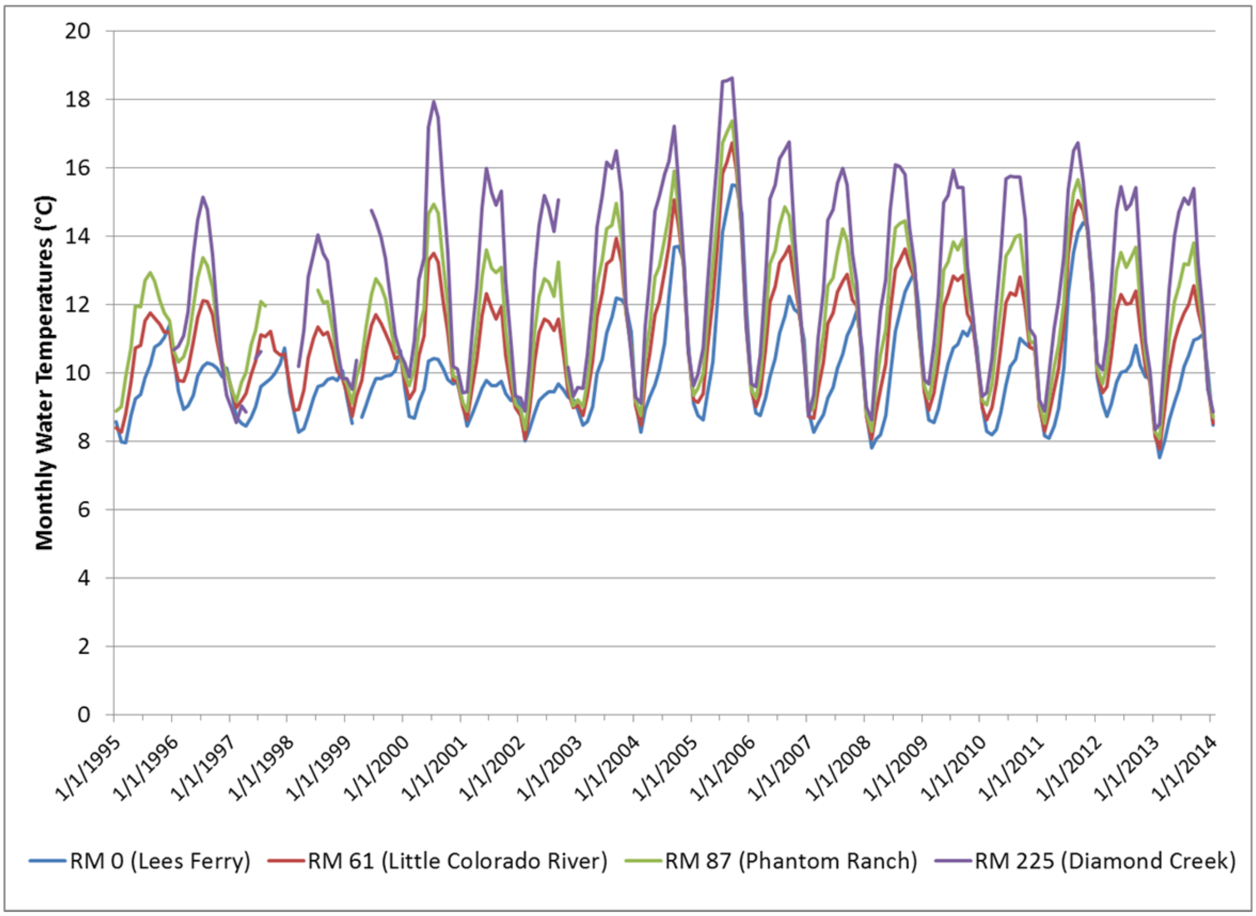

FIGURE 3.2-6 Water Temperatures at Four Stations along the Colorado River from Lees Ferry to Diamond Creek, 1995–2014 (Source: GCMRC 2015a)

Little Colorado River have not reached 16°C (61°F) in July and August unless release temperatures approached 14°C (57°F) (Wright, Anderson et al. 2008). Warmer mainstem temperatures are attainable in the western part of the Colorado River in July, when releases from Glen Canyon Dam are 12°C (54°F), because of the longer residence time of water in the river channel (Ralston 2011).

As illustrated in Figure 3.2-7, a comparison of the increase in weekly average water temperature between Glen Canyon Dam and Diamond Creek to the average weekly flow during mid-June from 1994 to 2004 demonstrates the effect of Glen Canyon Dam releases on warming patterns in the Colorado River in the Grand Canyon. For example, the 1997 high steady flows of approximately 26,000 cfs resulted in 5°C (9°F) warming at Diamond Creek, whereas the low steady flows of 8,000 cfs in 2000 exhibited a 10°C (18°F) warming. This difference is because large volumes of water have greater mass and a lower surface area to volume ratio, as well as less residence time for atmospheric heat exchange that is due to higher velocity, reducing the amount of warming from ambient temperatures and solar radiation. The warming occurring at low discharges also affects water temperatures in the lower Grand Canyon to a greater degree than the elevated release temperatures (Vernieu et al. 2005).

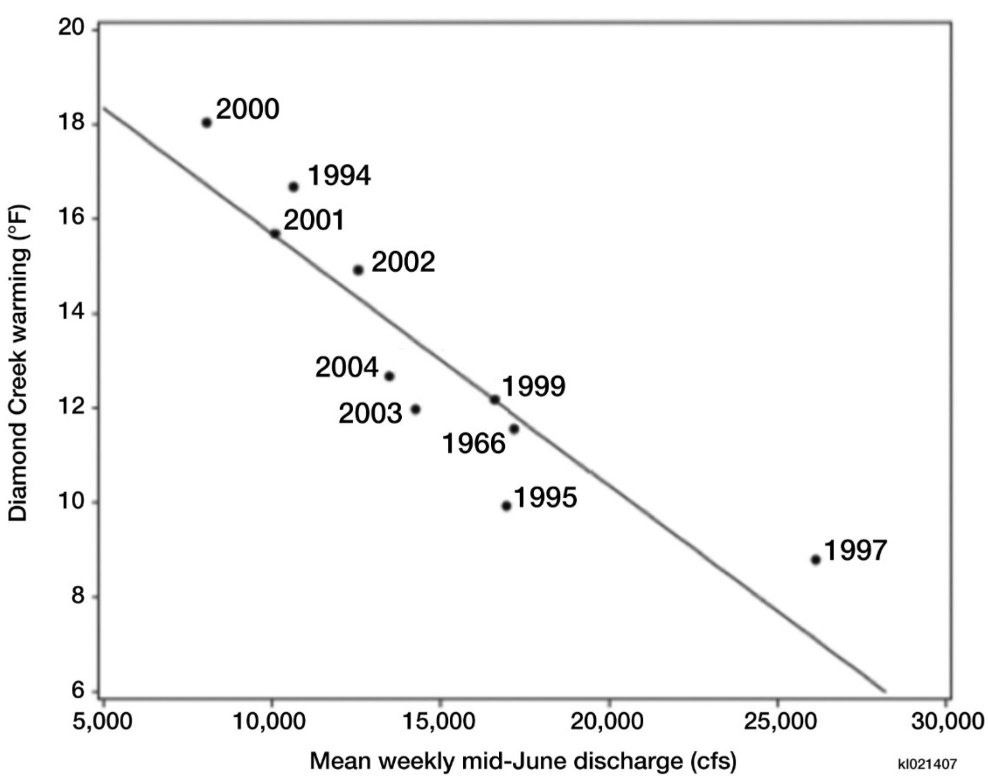

FIGURE 3.2-7 Mid-June Warming above Release Temperatures Measured at Diamond Creek, 1994–2004, as a Function of Mean Weekly Discharge (Source: Vernieu et al. 2005)

Lateral variation in river temperature has also been found to occur throughout the Grand Canyon. Substantial warming takes place in various near-shore environments, ranging from shallow, open-water areas to enclosed backwaters. Water in these environments becomes isolated from mixing with the main channel current and warms (depending on the season) as a result of solar radiation and equilibration with ambient air temperatures (Vernieu et al. 2005; Ralston 2011). According to 2000 data, water-surface temperatures along the shorelines varied from 9 to 28°C (48 to 82°F), with temperatures between 13 and 14°C (55 and 57°F) accounting for the largest proportion of all shoreline areas (Davis 2002; Ralston 2011). Backwaters specifically showed the largest contiguous areas with surface temperatures greater than 16°C (61°F) during the warmest periods. In addition, the area near the confluence with the Little Colorado River shows significant local warming as a result of the tributary inflow. According to 2000 data, mainstem surface temperatures near the Little Colorado River averaged about 13.5°C (56°F), because the cooler mainstem temperatures (typically 12°C [54°F], even in the summer months) are mixed with those of the warmer tributary (typically greater than or equal to 16°C [61°F]) (Voichick and Wright 2007; Protiva et al. 2010; Ralston 2011). In contrast to the mainstem, the Little Colorado River and other tributaries do not appear to have much interannual variation in the range of natural variability after 1990, when regular monitoring began (Stevens 2007).

Colorado River Salinity

Historically, salinity has been a major concern, not only to ecological habitats, but also to water users in both the United States and Mexico. In June 1974, Congress passed the Colorado River Salinity Control Act, which directed the Secretary of the Interior, acting through Reclamation, to implement a basin-wide salinity control program to protect and enhance the water quality of the Colorado River. Since 1974, significant salinity control measures have been implemented and substantial reductions in salinity have been achieved throughout the basin (Reclamation 2013c).

Since the construction of Glen Canyon Dam, the existence of Lake Powell and the amount of water passing through the system has acted to moderate and stabilize salinity levels in both the reservoir and the tailwater (Reclamation 1999b). Salinity below Glen Canyon Dam is typically in the range of 300 to 600 mg/L for total dissolved solids (TDS), with sodium and calcium as the dominant cations and sulfate as the dominant anion (Hart and Sherman 1996; Taylor et al. 1996; Vernieu et al. 2005; Reclamation 1999b, 2005a, 2011c; CRBSCF 2011).

The specific conductance of the Colorado River between the Glen Canyon Dam and Lake Mead has been found to range from 310 to 4,600 µS/cm (approximately 200–2,700 mg/L TDS), with the lowest levels near the mouth of Bright Angel Creek and the highest concentration near the mouth of the Little Colorado River (Taylor et al. 1996; Voichick 2008; Hart and Sherman 1996).

Research has indicated that salinity below the dam changes little with the seasons and shows no regular daily pattern (Flynn et al. 2001; Reclamation 1995). In fact, post-dam salinity fluctuations downstream vary less over several years than the pre-dam cycles changed on the order of months (Reclamation 1995). However, large or widely fluctuating releases draw water from a thicker withdrawal zone than do low or steady releases. Thus, during these events, water has the potential to be either cooler and more saline (if drawn from below the thermocline or released through the jet tubes), or warmer and less saline (if drawn from above) than that typically released (Vernieu et al. 2005).

Colorado River Turbidity

Turbidity levels are of interest in the downstream environment because water clarity affects the amount of light available for photosynthesis for downstream algal communities, which are an important part of the overall food base for native and nonnative fishes. Turbidity also affects the behavior and distribution of various native and nonnative fishes in providing cover from various predators or by affecting sight-feeding abilities (Vernieu et al. 2005). Turbidity is related to several characteristics of suspended sediment (as noted above in Section 3.2.2.2); thus, suspended-sediment measurements have been used as a proxy for determining turbidity in the system. Voichick and Topping (2010) specifically correlated these two values for the Grand Canyon section of the Colorado River and determined a statistically significant relationship between them.

Prior to construction of Glen Canyon Dam, the Colorado River has historically had very turbid water with suspended load averaging between 1,450 and 6,140 mg/L, depending on month, at Lees Ferry (data for the years 1930–1964) (USGS 2013a) and around 8,000 mg/L downstream 80 mi (Cottonwood Creek), with a maximum historical record of more than 150,000 mg/L measured between the mouth of the Little Colorado River and Bright Angel Creek (Cole and Kubly 1976; Johnson and Merritt 1979).

In the post-dam river, the annual supply of sediment has been altered and reduced. More recent measurements have found the concentration of suspended sediment at Lees Ferry to range from approximately 1 to 150 mg/L (data for the years 1996–2012) (Reclamation 2002; USGS 2013b). The amount of suspended sediment downstream of the dam depends primarily on tributary runoff into the Colorado River below Lees Ferry, which can contribute high concentrations to the mainstem during large floods on those tributaries (Voichick and Topping 2010). It also depends on the magnitude and frequency of planned HFEs, which can temporarily increase suspended sediment as a result of scouring in the reach downstream of the dam. Consequently, suspended sediment varies over an even larger range now than it did prior to the completion of Glen Canyon Dam. Post-dam suspended sediment concentrations near the mouth of the Little Colorado River range from approximately 20 to 133,000 mg/L depending on season and year (Cole and Kubly 1976; Taylor et al. 1996). At Phantom Ranch, approximately 87 RM below Lees Ferry and below several tributaries (Paria River, Little Colorado River, and Clear Creek), the suspended sediment concentrations have been found to range from 6 to 47,100 mg/L (Reclamation 2002).

Colorado River Nutrients

Nutrients like nitrogen and phosphorous are necessary for healthy waters, but high levels of nutrients can cause a number of problems, ranging from nuisance algae blooms and cloudy water to threatening drinking water quality and harming aquatic life. In general, releases from Glen Canyon Dam and downstream Colorado River waters are relatively low in nutrients. Tributaries below the dam (e.g., Paria River, Little Colorado River) have somewhat higher nutrient contents than the mainstem, but they appear to contribute little to overall mainstem nutrient concentrations (Reclamation 1995).

Dense populations of the New Zealand mudsnail (*Potamopyrgus antipodarum*) may also affect available nutrients. Dense populations can consume nutrients, and, because they are relatively immune to predation, sequester those nutrients making them unavailable to other species in the food chain (Sorensen 2010). Sections 3.5.1.4 and F.2.1.3 (Appendix F) provide additional information on the New Zealand mudsnail.

The high biomass of filamentous green algae (dominated by *Cladophora glomerata* until 1995; currently *Ulothrix zonata* and *Spirogyra* spp. dominate) observed in the Glen Canyon stretch of the Colorado River below the dam suggests that nutrients may not be a limiting factor. The uptake and cycling of nutrients may be quick enough that there is very little opportunity to sample free dissolved nutrients in the water column of the river; alternately, constant delivery of low concentration nutrient levels are sufficient for the algae to grow (Reclamation 1999b).

Colorado River Dissolved Oxygen

The ideal DO for fish, particularly those in early life stages, is between 7 and 9 mg/L. Most fish cannot survive when DO falls below 3 mg/L (i.e., acute stress), and DO values less than 5 mg/L are considered a chronic stress for fish. DO concentrations in the Glen Canyon Dam tailwater at Lees Ferry typically range from a low of around 6 mg/L in the fall (e.g., October–November) up to a high between 9 and 11 mg/L in the spring (e.g., April–May) (GCMRC 2015a). However, it is significant to note that unintentional fish kills in the Glen Canyon reach were documented in 2005 as a result of low DO levels (approximately 3.5 mg/L), and DO levels in 2014 approached the lethal limit for trout (Arizona Council of Trout Unlimited, Inc. 2015). Thus, while DO levels over the long term do not typically affect the aquatic ecosystem in Glen Canyon, occasional short-term low DO events can negatively impact fish (Kennedy 2016).

The seasonal variation in DO of the Glen Canyon reach of the Colorado River reflects changes in the DO concentration in the water of Lake Powell at the depth of the penstocks (Flynn et al. 2001). In general, Lake Powell DO concentrations are at their highest near the surface of the reservoir in the spring to early summer when inflows are well oxygenated and photosynthetic activities, atmospheric reaeration, and wind-induced mixing are high. During the summer and into the fall, the DO concentrations decrease, primarily as a result of biological reactions. Then, by early winter when the temperatures drop, DO concentrations gradually increase as a result of the higher oxygen-carrying capacity of coldwater and natural mixing processes created by the winter underflow current (Johnson and Merritt 1979; Vernieu and

Hueftle 1998). In addition, as the reservoir ages or if there are periods of extended drought, resuspension of decaying organic matter in upstream deltas can lead to low-DO (less than 5 mg/L) water being released from the dam increase (Vernieu et al. 2005).

DO concentrations increase with distance downstream as a result of aeration, particularly in rapids. Concentrations typically reach full saturation downstream of House Rock Rapid in Marble Canyon (Hall et al. 2012). As previously noted, HFEs can also act to increase oxygen levels immediately below the dam and through the tailwater; however, these effects will recover quickly when there is a return to lower flows (Hueftle and Stevens 2001; Vernieu et al. 2005; Vernieu 2010; GCMRC 2015a). Daily oscillations in DO in the tailwater have also been observed at Lees Ferry as a result of activity by the Colorado River algal community. During daylight hours, DO concentrations increase through photosynthesis; at night, a decrease in DO occurs when respiratory processes become dominant (Flynn et al. 2001; Vernieu et al. 2005). The amplitude of the daily DO change at Lees Ferry ranges from around 0.5 mg/L to more than 3.0 mg/L depending on season, with the lowest fluctuations occurring in winter and greatest in spring and summer (GCMRC 2015a).

Colorado River Bacteria and Pathogens

The Grand Canyon's water quality varies greatly in terms of bacteria and pathogens. As development and recreation along the river continue, the potential for an increase of bacterial contamination will continue. Coliform bacteria are a large group of bacterial species that are most commonly associated with water quality. *Escherichia coli* (*E. coli*), one species of fecal coliform bacteria present in the fecal matter of warm-blooded animals, is commonly used in recreational water quality sampling as an indicator of fecal contamination and the potential presence of other harmful organisms (ADEQ 2006a). For fresh recreational waters, the *E. coli* standard criteria is set at 126/100 mL (3.38 oz), with Arizona further defining a single sample maximum of 235 for full body contact and 576 for partial body contact (EPA 2003).

Research has indicated that episodic precipitation cycles and arid watershed hydrology are the principal factors influencing occurrence of bacteria in the river system. Bacterial testing has not indicated a chronic problem in the river, although local occurrences of high coliform bacterial count can and have occurred (ADEQ 2006a; NPS 2005a; Dodson 1995; Tinkler 1992). Fecal coliform in the river and in most tributaries were found to range from 10 to 20 counts/100 mL (3.38 oz) during drought cycles. During wet cycles and storm flows, fecal coliform densities were highly variable and often exceeded recreational contact standards (Tunniclif and Brickler 1984).

Most of the tributaries have high bacterial counts at least some of the time. This bacteria may not be of human origin, but may still result in illnesses. Any stream exhibiting high fecal coliform or fecal streptococcus counts may also carry *Giardia* (NPS 2012a).

3.2.2.3 Lake Mead Water Quality

This section describes the historic and existing water quality constituents that could potentially be affected by the proposed federal action. These water quality constituents of concern include salinity, temperature, sediment, and DO. Other water-quality-related issues and parameters were also considered, but they were determined unlikely to be affected by the LTEMP alternatives, or there was insufficient data to provide an assessment and they are therefore not discussed here.

The Colorado River is the primary hydrologic input into Lake Mead, providing approximately 97% of the total annual inflow. Thus, it is reasonable to assume that the quality of the Colorado River water flowing into the reservoir will have a significant and direct influence on the resulting water quality of Lake Mead. Although a suite of water quality parameters was evaluated for this EIS, four water quality variables were found to be important relative to the effects of Glen Canyon Dam operations. Temperature, salinity, turbidity, and DO of the inflow of the Colorado River into Lake Mead can be affected, particularly by large-volume flows such as HFEs. Because Lake Mead serves as a water supply for Las Vegas and large regions of Arizona, California, and Mexico, changes in Lake Mead water quality have the potential to affect the quality of this water supply.

The temperature of the Colorado River water that enters Lake Mead is influenced by the temperature of water in Lake Powell and to a lesser degree, by monthly and daily release patterns from Glen Canyon Dam. Colorado River inflow temperature is a contributing factor to the small, isolated algae blooms that have occurred in Lake Mead. Two examples of uncommon algal blooms are discussed below to demonstrate how inflow temperatures may affect biological productivity in Lake Mead.

Between February and July of 2001, a reservoir-wide algae bloom occurred and consisted of predominantly the non-toxic green algae *Pyramichlamys dissecta*. The Lake Mead Water Quality Forum's Algae Task Force reviewed the potential factors contributing to the reservoir-wide bloom in 2001, but they could not point to a direct cause of the bloom. Instead, the Algae Task Force indicated four factors that potentially contributed to the 2001 bloom: (1) excessive nutrient runoff from above average winter and early spring rain events; (2) warmwater inflows from the Las Vegas Wash that flowed on the surface of Lake Mead; (3) biological mobilization of phosphorus-rich sediment at the confluence of the Las Vegas Wash and Lake Mead; and (4) seasonally high phosphorus inflows from wastewater treatment plants discharging to the Las Vegas Wash. Although the *Paramichlamys* bloom was not considered a human health risk, the bloom was a deterrent to recreational uses in Lake Mead and contributed to low DO concentrations detrimental to fish. The extent to which the Colorado River flowing into Lake Mead influenced the 2001 algae bloom is unknown, including the attempt to warm river temperatures during the June–September low steady flow experiment conducted the year before the bloom.

Most recently, in 2015, increases in the temperature of water entering Lake Mead contributed to dispersed and periodic blooms of blue-green algae (i.e., cyanobacteria, *Microcystis*) throughout the reservoir, including Gregg's Basin. This type of algae produces multiple toxins, including microcystin and anatoxin, which can affect humans and wildlife. *Microcystis* toxins in water samples from Lake Mead were measured for the first time in 2015.

Colorado River water has a higher density due to its lower temperature and, to some extent, its suspended sediment load. As a result, the Colorado River most often enters Gregg Basin as an underflow, which at times can be seen all the way into Boulder Basin and at the Hoover Dam (Turner et al. 2011; Holdren et al. 2012). This phenomenon also limits nutrient delivery and productivity in the upper levels of the reservoir. During summer months when the temperature differential between Lake Mead and the Colorado River is at its greatest, water entering Lake Mead from the Colorado River plunges to a depth of 65–100 ft in the reservoir's metalimnion, approximately 6 mi downstream of Pearce Ferry (Grand Wash). From this point on, water from the Colorado River exists as a metalimnion interflow and retains its identity, as characterized by lower conductivity, for much of the distance through the reservoir. During winter months, a similar flow pattern occurs; however, the plunge line moves downstream several miles. Cooler winter water temperatures in Lake Mead provide greater mixing due to the decreased amount of energy needed to mix the Colorado River water into the reservoir.

Once Colorado River water plunges, instead of riding the metalimnion just below the thermocline, it drops to a depth of about 260–330 ft, at which point it reaches equilibrium with the reservoir water. The distance traveled before the plume loses its identity is also shorter in the winter due to the greater mixing that occurs, and because of the reduced temperature differential between the two bodies of water (Horn and LaBounty 1997).

Effects on Lake Mead water quality that can occur as a result of changes at Glen Canyon Dam or Hoover Dam, could include changes in salinity, turbidity, and DO in the reservoir (Tietjen 2013), as well as the temperature and water column dynamics influenced by the inflow. In general, higher inflow temperatures have the potential to alter the stratification of the water column, which has resulted in the formation of anoxic conditions in the past. Higher temperatures will also increase metabolic activity in Lake Mead and its sediments. The loading of dissolved and total organic matter to Lake Mead by the Colorado River further influences water quality in the upper reservoir. This material drives oxygen consumption in the sediments and water column in the riverine zone of most reservoirs, and, as such, contributes to observed hypoxia and anoxia.

In Lake Mead, DO concentrations periodically decrease in the bottom waters of Las Vegas Bay, as a result of nutrient and organic matter contributions from Las Vegas Wash and algal growth. In the past and in recent years, low DO conditions have been documented in some isolated parts of Lake Mead near the Colorado River inflow. Ongoing monitoring and investigations are being conducted to determine the cause of such decreases. Currently, elevated temperatures in the Colorado River inflow are the most likely driver. Through an ongoing, multi-agency water quality monitoring program, anoxic conditions were observed in the upper region of Lake Mead in 2014 for a period of 2 months. The warmer Colorado River inflow to Lake Mead altered the typical inflow dynamic, resulting in the river water entering the middle of the water column. This reduced the addition of oxygen to the sediment-water interface and resulted in the development of a 14-mi hypoxic and anoxic region in upper Lake Mead. As with Lake Powell, the stratification of Lake Mead influences many processes in the reservoir, and, consequently, influences characteristics and quality of the water that is released to the Colorado River below the Hoover Dam. Further, DO has not been documented as an issue in downstream reaches.

The formation of Lake Powell in 1963 resulted in marked reductions in suspended sediment loading to Lake Mead, by trapping nearly all of the upstream Colorado River suspended sediment and effectively removing around two-thirds of Lake Mead's previous sediment-contributing drainage area (Ferrari 2008). It has been estimated that between 1935 and 1963, about 0.091 maf of sediment was deposited in Lake Mead each year. However, with the construction of Glen Canyon Dam and the great reduction in suspended sediment load, the life of Lake Mead is now essentially indefinite (Reclamation 2012c). A rough estimate of Lake Mead's current annual sediment accumulation from the Colorado River in the very upper delta portion of the reservoir is less than 7,200 ac-ft (assumes the continual trapping of sediments in Lake Powell and ongoing consolidation of the finer sediments entering Lake Mead) (Ferrari 2008). The amount of finer material entering and settling in the lower reaches of the reservoir is unknown. Dam operations can affect turbidity of the Colorado River inflow to Lake Mead. HFEs may produce increased turbidity in the inflow, although this is also influenced by Lake Mead elevation, stratification, and inflow temperature (Tietjen et al. 2012). Changes in turbidity in upper Lake Mead following HFEs have been observed to persist for weeks following the event and to span more than 25 mi. While the short-term nutrient impacts have been limited, changes in sediment loading to Lake Mead may increase biological productivity in the long term, which may exacerbate the occasional low DO conditions that are already observed. However, HFEs have also been shown to help eliminate low oxygen concentrations or the anoxic region that may develop in the Greggs Basin region of Lake Mead.

The salinity (or specific conductance) of the water in Lake Mead is controlled by a set of interrelated factors, including relatively low values originating from the Colorado River, higher values in the small Muddy and Virgin River inflows; concentration of salts by the evaporation of surface waters, and the influence of water column stratification in seasonally limiting water column mixing and dilution. As a result, salinity concentrations have cycled during this time period (conductivity values were spread over an approximate 100 μS/cm range), specifically in response to the volume and quality of Colorado River water being released from Lake Powell (Tietjen et al. 2012). For example, as Lake Powell releases water of lower or higher salinity into the Colorado River downstream, the average salinity levels of Lake Mead's water column will similarly decrease or increase, respectively.

3.2.3 Tribal Perspectives on Water Resources

It is important to note that, in the broadest sense, all sources of water (e.g., springs, washes, ponds, pools, lakes, and rivers) are culturally and spiritually important to the Fort Mojave Tribe, Havasupai Tribe, Hopi Tribe, Hualapai Tribe, Navajo Nation, Pueblo of Zuni, and the Southern Paiute Tribes.

For the Hopi, water is the most precious resource, because it is the basis of life. The cycle of water is at the core of all Hopi ceremonies, and all things related to water—including the plants and animals associated with it—need to be respected and protected. It is a link between current Hopis and their ancestors. It forms the basis for the farming lifestyle that has sustained the Hopi people for thousands of years. Finally, the Colorado and Little Colorado Rivers figure prominently in Hopi clan and ceremonial history.

The Havasupai are the Havsu w 'Baaja, the people of the blue-green water in their native language. Both the Havasupai and Hualapai consider the river the backbone, or *Ha'yiđađa*, of the landscape and to have healing powers (NPS 2006a). The importance of water is evident for the both Tribes as evidenced by inclusion of water in their Tribal seals. The Hualapai worldview holds that the Colorado River provides a life connection to the Hualapai as it flows through the landscape, connecting the canyon and the riparian ecosystems that sustain the Tribe. The historic trails in the Canyons and across the Coconino Plateau include sacred springs as stopping points. The Havasupai religion and culture are closely connected to springs through songs and stories (Hirst 1985).

Excerpt from a Ne'we:kwe Medicine Society's ceremonial prayer (shared by Seowtewa)

When the world was created, within the four Great Oceans and waterways (North Pole, South Pole, and Atlantic, Pacific Oceans)
Our Father that stayed behind and flourished
The Feathered Serpent
The Water Snakes
The Fish
The Turtle
The Tadpoles
The Toads
The Frog
The Water Boatman and all aquatic life . . .

And all the protectors of the waters
The Crane
The Geese
The Ducks
The Coots
The Grebes
The Orioles
The Mockingbirds
The Nuthatch
The Wren
The Egrets
The Father Sun – Mother Moon
The Creator
These are the Givers of the Breath of Life
The Aged and the Wisdom
The Water of Life
The Seed of Life
The Belongings of Life
The Offsprings of Life
The Strength
And the rest of the Givers of Life

I ask for their breath
If all goes accordingly and the breath of our fathers are respected
We will all see our fathers rising and setting sun
Arm in Arm
Strength in connection
We will all grow old in wisdom
Now I ask the fathers for that Breath
For the Breath of Life for all

The Zuni religion is focused on the blessings of water, a gift that is considered to be the ancestors themselves (Chimoni and Hart 1994). The waters of the Colorado River are described as "definitely sacred," according to Alex Seowtewa. Even dry washes are important. The Zunis deem them "passageways" for water, whether or not water flows there year-round. Long before the Americans first ever saw and named the Colorado River, the Zuni named this watercourse *K'yawan' A:honanne*. The name itself speaks to a time before the U.S. government dammed the river, when its waters flowed red from the crimson-hued soils its currents carried. Zunis feel a general sense of sacredness for this body of water. As Octavius Seowtewa explained, "Our respect, our heritage and traditions believe this river has significance for our religion and way of life."

The river is associated with the Zuni people's emergence and first migrations; it is home to aquatic life that is important to Zuni traditions; the water from the river is used in ceremonies; and the waterway is a literal trail and a metaphorical umbilical cord that is linked directly to the Zuni home area via the Little Colorado River (Hart 1995). Seowtewa continued, "My medicine society talks about all the water life; it's all mentioned in my prayers. So any disturbance of water life impacts my religion and way of life. I was taught to respect all life and now damming the river and pumping water [creates…] a spiritual impact on our medicine practices. When you are a religious head you have to take care of even the lowliest form of life, even the stink bug, even the rocks, anything that is on the land." This statement parallels previously documented Zuni values of the river. As Dongoske et al. (2010) wrote, "The Colorado River itself is regarded as an important conscious living being that has feelings, and is expressive of calmness and anger. The river can offer happiness, sadness, strength, life, sustenance, and the threat of death. According to many of the Tribal beliefs, if a land and its resources are not used in an appropriate manner, the Creator will become disappointed or angry and withhold food, health, and power from humans."

Zunis pray for water; they pray at water sources; and they use water in religious ceremonies. Cushing wrote that the Zuni "consider water as the prime source of life" (Green 1979). As Dickie Shack, a Zuni religious leader and cultural advisor, explained, "The whole world has water and it's all precious to us. We get it and bring it here for our religious stuff. We use it in paint for our prayer sticks—it's so important to get rain. So this water is precious to us. If I go to the Grand Canyon, I'll get me water there. I believe the rain is our fathers. Anywhere there are springs we hold out hand and say, 'come with us to Zuni village' and we pour the water on our heads." Mr. Shack added, "In my Rain Priest doings, we pray for all directions, to the ocean, to our grandfather, Ko'lowisi, the serpent, in all directions. We say prayers so that they'll help us with rain. So all this water around the world, even the ponds, it's very important to us, for us to say prayers because we need rain in Zuni" (Colwell-Chanthaphonh et al. 2011).

Further emphasizing the importance of all water life to the Ne'we:kwe Medicine Society, the textbox provides an excerpt from one of the ceremonial prayers shared by Seowtewa. Speaking about Glen Canyon Dam, Seowtewa stated, "They put the dam in without consultation, and ... the dam restricted the umbilical cord. It's like when you're in your mother's womb and there's a knot in the cord, then there's a problem" (Colwell-Chanthaphonh et al. 2011).

The present Navajo world begins at Hajiinai, the Place of Emergence. The people began their journey through several underworlds until they finally emerged into this world filled with water. After this world was given to us by the Holy People, they cleared the water away. The Humpback God stood in the center of the world and dragged his cane from east to west and created the canyon. The water drained and created rivers and creeks which then became the veins of the earth. In the canyon there are also places of clan origins and migrations, specifically for the Tl 'izilani (Manygoats) clan and a branch of the Anaasazi Tachii 'nii clan. Sodizin (prayers) are still offered at these places and will continue to be in the future. Plants from the Canyon are used for food and medicine, and minerals such as salt and red ocher are still gathered for use in ceremonies and in everyday life (Roberts et al. 1995).

3.2.4 Hydrology and Climate Change

Global climate models,[4] covering a range of possible future emissions scenarios, project that temperatures will increase globally by about 1.1 to 6.4°C (2 to 11.5°F) by the end of the 21st century (2090–2099; relative to 1980–1999 values) (Solomon et al. 2007). Although global predictions and trends cannot predict changes at the regional level with certainty, regional temperatures are also expected to increase. Average estimates for the Colorado River Basin indicate a projected 5 to 6°C (9 to 10.8°F) increase during the 21st century, with slightly higher increases projected in the upper Colorado Basin (Reclamation 2011e). Predictions also suggest a general drying trend (although the full range of predictions includes both wetter and drier conditions) for mid-latitude areas such as the Colorado River Basin (Reclamation 2007a; Vano et al. 2013; IPCC 2007).

Observations and studies have also shown that many natural systems are being affected by regional climate changes, particularly the aforementioned temperature increases, and that these changes will likely affect the hydrological cycle, with associated impacts on water resources. The following sections summarize the potential effects of increasing temperatures on the broad-scale features of Colorado River Basin hydrology and water resources; other aspects related to climate change (e.g., meteorology and air quality) are discussed in Section 3.16 of this EIS.

3.2.4.1 Basis for Runoff Estimates

The most likely hydrological changes expected as a direct consequence of warmer temperatures are linked to water variability and availability (described in more detail in Section 3.2.4.2), which is mostly influenced by the amount of runoff in the basin (Reclamation 2007c). The conventional assumption used in water resources planning is that the past record of runoff can be used to represent future conditions; in other words, that the future will look like the recent past. However, there are limitations to these assumptions; it is possible that future flows may include periods of wet or dry conditions that are outside the range of sequences observed in the historical record, particularly considering the effects of climate change and the potential for increased hydrologic variability. Furthermore, considerable evidence from paleontological records indicates that the observed record of the last 100 years does not capture the full range of variability of historical stream flows in the Colorado River (Reclamation 2007c; Vano et al. 2013). In fact, the early 20th century, which is the basis for water allocation decisions in the basin, was a period of unusually high flow (Vano et al. 2013). Tree ring records indicate that the Colorado River Basin has experienced severe droughts in the past and could do so again, even without human-caused climate change (Vano et al. 2013). Thus, although paleoclimatic information may not necessarily represent future climate conditions, this information is valuable

[4] Refer to Solomon et al. (2007) for further detail related to the global climate models used for the projected temperature rise.

and may be useful in understanding variability in future hydrologic sequences, particularly with respect to the potential for drought (Reclamation 2007a).

3.2.4.2 Water Variability and Availability

In general, the water supply of the Basin is strongly dependent on snowmelt from high-elevation portions of the Upper Basin, with about 15% of the watershed area producing about 85% of the entire basin's average annual runoff. Annual precipitation ranges from less than 4 in. in southwestern Arizona to nearly 63 in. in the headwaters in Colorado, Utah, and Wyoming (Reclamation 2011e). The western states have heated up more than the world as a whole has (Saunders et al. 2008). In 2003–2007, the global climate has averaged 1°F (0.56°C) warmer than the 20th century average. For the same period, the 11 western states averaged 1.7°F (0.94°C) warmer than the 20th century average. By state, average temperature increases range from 1.3°F (0.72°C) in New Mexico to 2.2°F (1.2°C) in Arizona. To date, decreases in snowpack, less snowfall, earlier snowmelt, more winter rain events, increased peak winter flows, and reduced summer flows have been documented (Saunders et al. 2008).

Water storage is very sensitive to changes in mean inflows and to sequences of wet and dry years. As noted previously, although precise regional estimates of the future impacts of climate change on runoff throughout the Colorado River Basin at appropriate spatial scales are not currently available, these impacts may include decreased mean annual flow and increased variability, including more frequent and severe droughts. Overall changes to precipitation would likely decrease the rain and snow that drains into the Colorado River Basin; however, estimates have suggested that by 2050, Upper Basin precipitation may increase slightly (i.e., 2.1%), while that in the lower basin declines similarly (i.e., 1.6%) (Reclamation 2011e). Furthermore, warmer temperatures alone would be expected to increase water losses (e.g., evapotranspiration from vegetation, evaporation from reservoirs, and sublimation) and reduce runoff flow (Reclamation 2007a; Vano et al. 2013; Reclamation 2012e).

Estimated declines of future runoff for the Colorado River Basin range from less than 3.5% to 45% by the mid-21st century (Vano et al. 2013; Reclamation 2011e). The wide range in projected flow decreases results from the following factors:

- Variability among climate models and future emissions scenarios used to generate the estimates;
- Spatial resolution of the model, which is important for capturing topography and its effect on the distribution of snow in the Colorado River's mountainous headwaters;
- Representation of land-surface hydrology, which determines how precipitation and temperature changes affect the land's ability to absorb, evaporate, or transport water;

- Methods used to statistically downscale from the roughly 124-mi resolution used by global climate models to the 6.2- to 12.4-mi resolution used by regional hydrology models; and

- Model uncertainties, including the uncertainty in the climate response, as well as the uncertainty due to differences in methodological approaches and model biases (Vano et al. 2013; Reclamation 2007a).

As discussed in the *Colorado River Basin Water Supply and Demand Study* (Reclamation 2012h), the general picture for climate change, as it relates to Colorado River Basin hydrology, includes decreased inflow to the reservoir system (due to lower precipitation), greater evaporation and evapotranspiration losses (due to higher temperatures), and increased demand (due to increased population size). Combined, these factors increase the probability and likely duration of delivery shortages in coming decades. It has been estimated that the shortfall created by future supply and demand imbalances could range from 2.3 to 4.1 maf per year, during any given deficit period (Reclamation 2012e). When climate change considerations are taken into account, this value increases to around 7.4 maf per year during the deficit period (Reclamation 2012e). These considerations would affect all of the LTEMP alternatives equally.

3.2.4.3 Seasonal Timing Shifts

Warmer conditions are also expected to lead to shifts in the precipitation events and seasonal timing of runoff (i.e., transitioning snowfall to rainfall) with increased winter runoff (December to March) and decreased summer runoff (April to July) (Reclamation 2011d,e, 2013c; Brekke et al. 2009). This shift in timing could present challenges in managing streamflow, especially under current reservoir operational constraints. Storage opportunities during the winter runoff season currently are limited by flood-control considerations, and increased winter runoff under climate change will not necessarily translate into increased storage of water leading into the spring season. Conversely, reservoir storage capture of snowmelt runoff traditionally has occurred during the late spring and early summer seasons. Reductions in runoff during this season likely would translate into reductions in storage capture and, likewise, reductions in water supply for warm season delivery (Reclamation 2013b). Increasing temperature may also increase potential evapotranspiration from vegetation and land surfaces and may thereby decrease the amount of water that then reaches streams, lakes, and reservoirs (Brekke et al. 2009).

There may also be changes in seasonal patterns in relation to extremes of precipitation. Depending on location, these possible changes can and have led to concerns that droughts and floods, defined relative to past experiences, will occur more frequently and/or be more severe under future climate conditions. However, because of uncertainties in climate models and flood record analyses, the nature of changes in specific locations remains uncertain and will require detailed study (Brekke et al. 2009).

3.2.4.4 Water Quality

Water quality is also greatly affected by the changing precipitation and temperature that result from climate change. For example, increasing air temperatures may lead to increased water temperature, which can affect the chemical properties of water and habitat suitability. Altered water temperature in the reservoirs also influences the potential for algal blooms, which can further reduce oxygen levels. In addition, changes to precipitation intensity and frequency (i.e., water availability) can also influence concentrations of suspended sediment, nutrients, and chemical contaminants originating from tributaries, as well as non-point-source pollution from runoff (e.g., agricultural fields, roads, and other land surfaces) (Brekke et al. 2009).

3.3 SEDIMENT RESOURCES

This section describes the sediment resources of the affected area. Sediment is defined as unconsolidated material derived from the weathering of rock that is transported and deposited by water or wind. Sediments can be described based on their particle size such as clay, silt, sand, gravel, cobble, and boulder (Section 3.3.2.1). In this EIS, the use of the term sediment refers to the full range of sediment sizes found in Glen, Marble, and Grand Canyons and references specific sediment size ranges using the terminology described in Section 3.3.2.1. For this EIS, the sediment size of greatest concern is sand. Dam operations have an important effect on sand distribution in the affected area, and sand transport and deposition are greatly affected by the characteristics of dam operations. Sand deposits above the elevation of normal operations provide for important areas for vegetation, wildlife, and visitors to GCNRA and GCNP.

3.3.1 Background: Geomorphology of the Colorado River

Geomorphology describes the geologic evolution and configuration of landforms and the processes that shape them. The processes by which sediment is formed, transported, and deposited within the system are largely functions of the geomorphic setting through which the Colorado River and its tributaries flow, and the characteristics of rock formations, faulting, and fluvial processes. These factors generate several distinct geomorphic features, such as turbulent rapids, tranquil pools, talus slopes (rock slides), channel-margin areas, terraces, canyon walls, debris-flow deposits, fan-eddy complexes, and sandbars (see Figure 3.3-1). There have been numerous studies regarding these geomorphic features within Glen, Marble, and Grand Canyons. This research has been used to develop conceptual models of how these geomorphic features interact with river hydraulic and sediment-transport processes.

The Colorado River follows a meandering path as it flows between the canyon walls. Below Glen Canyon Dam, the river varies with respect to its channel geometry (width, depth, and slope), sediment inputs, bed materials, and hillslope deposits, as well as the topography and geology of the surrounding watershed. Valley width is most affected by the type of rocks near the river level, such that resistant rocks exposed at or near river level (e.g., Vishnu Schist) create narrow valleys, and easily eroded rocks (e.g., Bright Angel Shale) create wide valleys. The level

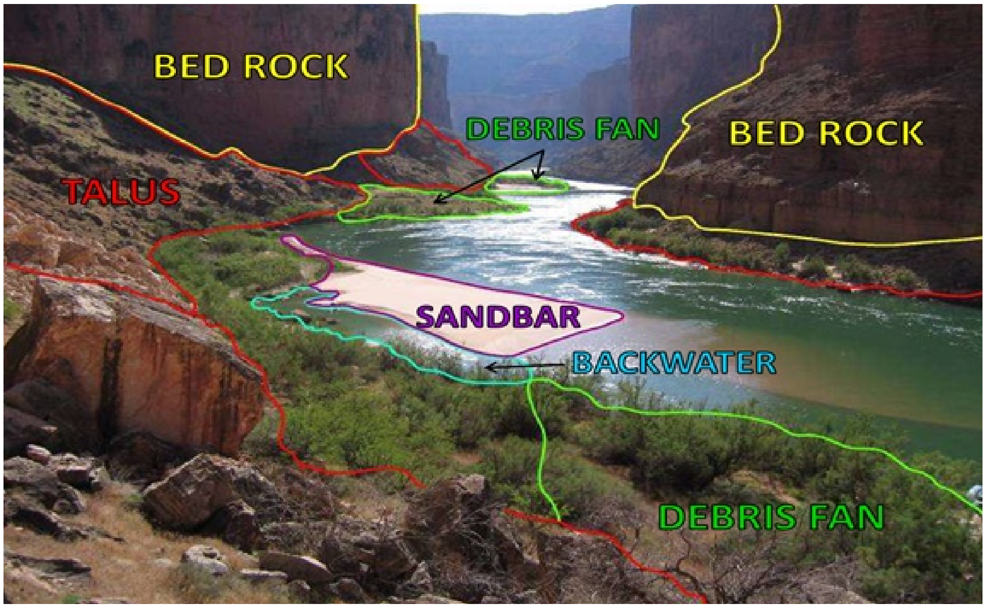

FIGURE 3.3-1 Geomorphic Features of the Colorado River

of bedrock fracturing, which is also a function of bedrock resistance, affects the frequency of tributary debris fans and deep pools (Howard and Dolan 1981).

Schmidt and Graf (1990) defined 11 geomorphic reaches within Marble and Grand Canyons based on parent geologic materials, width-to-depth ratios, slope, and relationship to the confluences with major tributaries. These 11 geomorphic reaches are often described as either narrow or wide reaches based on the width of the canyon in that region. A coarser view of the study area, as used in this EIS, considers three main sections bounded by Glen Canyon Dam, the Paria River, Little Colorado River, and Lake Mead. Beginning at Glen Canyon Dam, the first portion of the river is the 15-mi stretch that runs downstream through Glen Canyon to just upstream of the Paria River at Lees Ferry (RM 0). Glen Canyon has a substantially different geomorphic structure compared to the reaches farther downstream, and it has a limited sediment supply. The next section of river is the approximately 62-mi stretch that runs through Marble Canyon. This stretch starts at the mouth of the Paria River at Lees Ferry (RM 0) and extends to just upstream of the Little Colorado River (RM 61.5). The sediment load of this reach is dominated by Paria River inputs. The third section runs through the Grand Canyon and comprises the remainder of the river downstream of the Little Colorado River. The sediment load of this third portion is the cumulative supply provided by contributions from the Paria River reach, the Little Colorado River, and various other small tributaries.

3.3.1.1 Geomorphic Features of the Colorado River

Fan-Eddy Complexes

The areas along the river where a tributary debris fan partially blocks the flow are commonly referred to as fan-eddy complexes (Schmidt and Rubin 1995; Schmidt et al. 2004). Formed at the mouths of tributary canyons, debris fans are sloping deposits of poorly sorted sediment ranging in size from clays and silts to larger boulders. Deposited by tributary debris flows, debris fans and their associated processes play a significant role in defining the geomorphic characteristics of the Colorado River in Marble and Grand Canyons (Webb et al. 1988; Reclamation 1995; Yanites et al. 2006).

Debris fans extending into the Colorado River obstruct the channel, making it narrower and raising the bed elevation, which forms rapids (or riffles) through the point of constriction, and the downstream-directed current becomes separated from the riverbank (Griffiths et al. 1996) (see Figure 3.3-2). Downstream from the constriction, the channel is typically wider, the main current reattaches to the riverbank, and some of the water is redirected upstream (Schmidt and Graf 1990). This change in flow direction forms a zone of low-velocity recirculating water (i.e., an eddy) between the points of separation and reattachment and between the main channel and riverbank (Rubin et al. 1998). These conditions allow for sediment to become entrained within the recirculation zone where the lower velocities enhance the potential for sediment deposition (Schmidt and Graf 1990; Schmidt and Rubin 1995). Figure 3.3-3 presents a cross-sectional diagram demonstrating how these complexes can trap sediment and work to build sandbars. In this instance, 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 (Reclamation 1995).

The deep pools that form upstream from rapids (see Figure 3.3-2) provide space for the temporary storage of substantial amounts of riverbed sediment (e.g., sand and gravel). 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.

Nearly all sandbars in the Grand Canyon are associated with fan-eddy complexes. In general, these complexes generate consistent sandbar features, which include separation bars and reattachment bars, based on their specific locations within the recirculation zone (Schmidt and Grams 2011a). They continuously exchange sand with the river. Thus, the sandbars commonly found along the banks of the Colorado River are generally dynamic and unstable. Separation bars form along the downstream face of a debris fan, and reattachment bars form outward from the downstream point where the recirculation zone meets the channel bank (see Figure 3.3-2).

Sandbars form a fundamental element of the river landscape (Figure 3.3-1) and are important for vegetation, riparian habitat for fish and wildlife, cultural resources, and recreation (Wright, Schmidt, et al. 2008; Reclamation 1995). For example, they form the substrate for

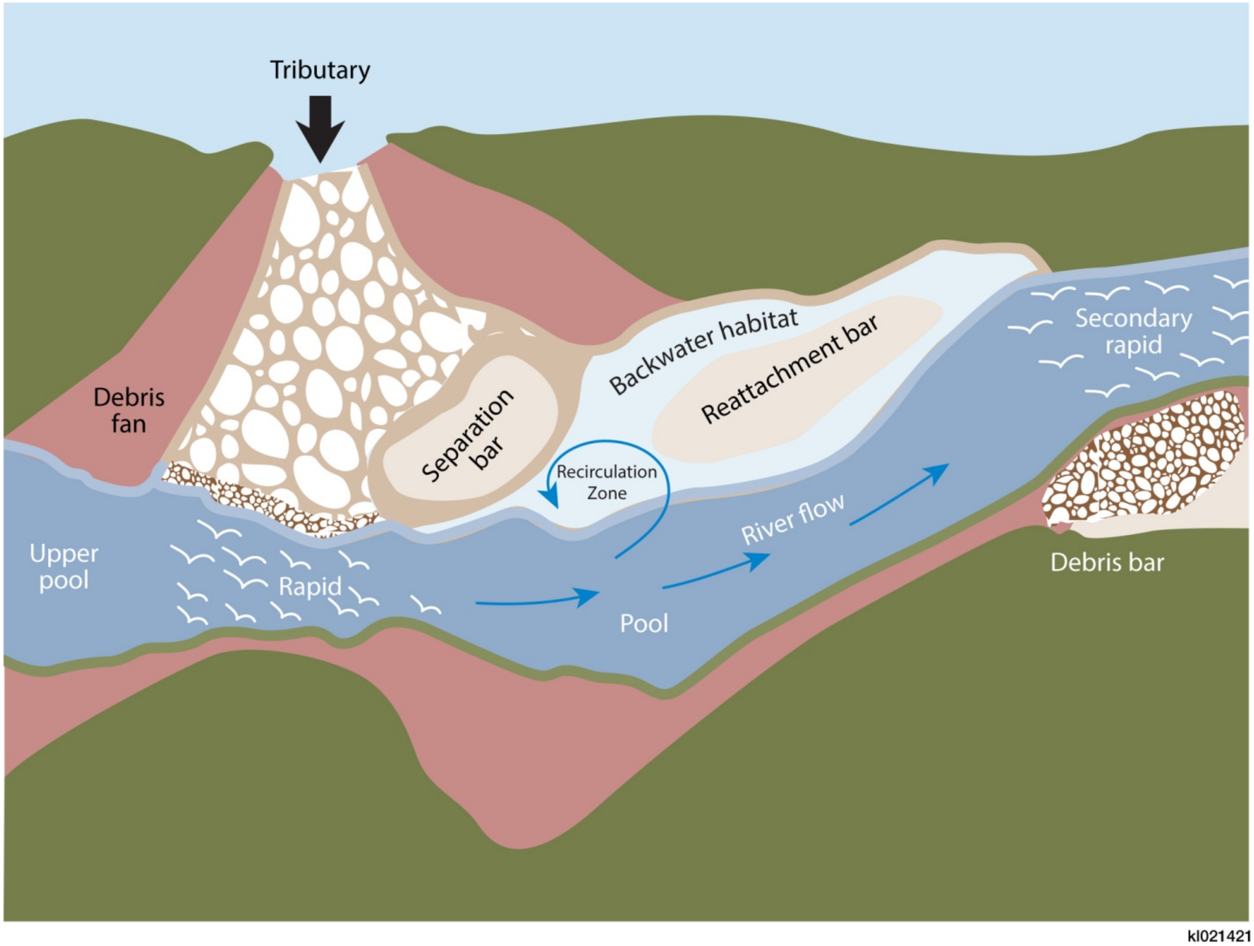

FIGURE 3.3-2 Schematic Diagram of the Fan-Eddy Complex on the Colorado River (Source: Webb and Griffins 2001)

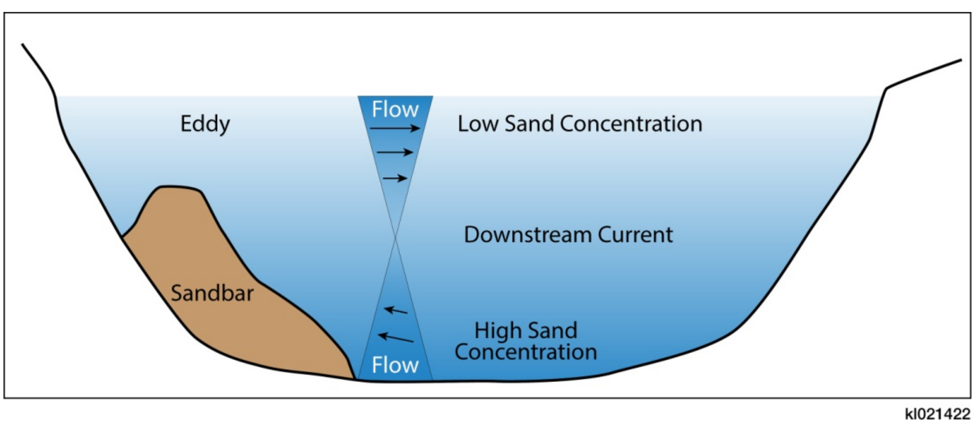

FIGURE 3.3-3 River Cross Section Depicting Sediment Entrapment and Sandbar Building (Source: Reclamation 1995)

limited riparian vegetation in the arid environment. Low-elevation sandbars create zones of low-velocity aquatic habitat (i.e., backwaters) that may be utilized by juvenile native fish. These low-elevation sandbars are also a source of sand for wind transport that may help protect archaeological resources. In addition, beaches provide recreational value for visitors (e.g., camping areas for river and backcountry users). For recreational use (e.g., camping and boating), visitors generally prefer separation bars over reattachment bars because they are composed of finer grained sand, experience less frequent inundation by rising river levels, and have lower velocity conditions for mooring boats (Reclamation 1995).

Fan-eddy complexes also produce important ecologic niches in the canyon. For example, stagnant return-current channels within eddies can support riparian vegetation, attract native fish (e.g., humpback chub), and provide stable substrate for other aquatic organisms (e.g., algae) (Schmidt et al. 2007; Webb and Griffiths 2001).

High Terraces

High-elevation terraces found in reaches of Glen and Grand Canyons support native vegetation and desert riparian communities and may contain buried or partly buried archeological remains. These terraces can be referred to as Holocene terraces because they were formed during the Holocene Epoch (i.e., the time since the last ice age). They were originally formed as sandbars as part of fan-eddy complexes during large natural pre-dam flood events (100,000 cfs and greater; for comparison, current operations have a maximum discharge of 45,000 cfs under normal operations). In general, larger flood flows resulted in higher terraces, and higher terraces are generally indicative of older deposits (Schmidt and Grams 2011a; Reclamation 1995); however, other factors, such as new large tributary debris flows, can also produce terraces under similar flow conditions.

Aeolian, or windblown, deposits can occur on high-elevation terraces and on sandbars near the river, as pictured in Figure 3.3-4. These deposits are generally supplied by sediment blown by wind from the active river channel and are termed “source-bordering” aeolian (dune) deposits (Draut 2012a; East et al. 2016). The supply of aeolian sediment from the active river channel can vary due to environmental factors and river regulation for source-bordering aeolian sediment deposits (Draut 2012a; East et al. 2016). As such, source-bordering aeolian deposits that are not currently significantly supplied by windblown sediment from the active river channel are classified as relic and are considered to be largely derived from older sediment emplaced in high terraces (East et al. 2016; Draut 2012a; Draut and Rubin 2008). Source-bordering aeolian deposits that are contemporarily supplied with sediment blown by wind from the active river channel and sandbars are classified as modern (East et al. 2016; Draut 2012a; Draut and Rubin 2008). Relic deposits are river sediment that is largely inactive with respect to aeolian transport because of a lack of replenishment of sediment from the active river channel and colonization by vegetation and biological soil crusts (Draut 2012a; East et al. 2016). For modern deposits, activity is largely controlled by prevailing wind direction and the amount of bare, dry sand surface area available on the deposit and the upwind sediment source area (Draut 2012a; East et al. 2016).

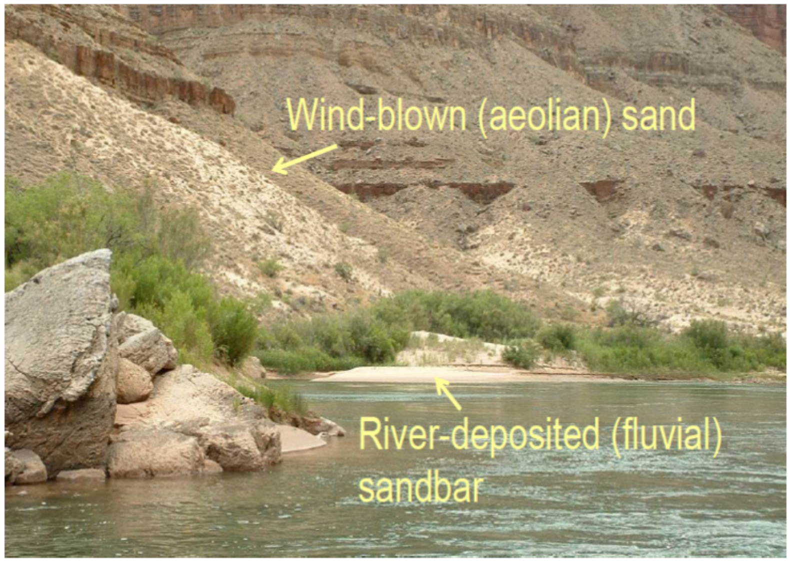

FIGURE 3.3-4 Aeolian and Fluvial Sand Deposits along the Colorado River (Source: Draut 2012b)

3.3.1.2 Glen Canyon Geomorphology

The river immediately downstream of Glen Canyon Dam was intentionally scoured in 1965 during a series of high-pulse flows, with the intent of raising the elevation of Lake Mead and scouring the reach immediately below the dam in order to increase the efficiency of the powerplant (Topping et al. 2003). During the initial pulse flows, approximately 5.0 million tons of fine sediment was scoured from Glen Canyon between the dam and Lees Ferry over a period of 3 months. In addition, approximately 17.62 million tons of material was scoured from the reach between Lees Ferry and Grand Canyon gaging stations near Phantom Ranch (Topping et al. 2003; Wright et al. 2005). These pulse flows, coupled with other dam operation activities, transformed the pre-dam Glen Canyon, which had plentiful sand, native species, and active natural processes, to a present-day Glen Canyon that is incised, narrowed, and armored (Grams et al. 2007).

Glen Canyon exhibits a low gradient and has few debris-fan deposits and small riffles. The Colorado River through Glen Canyon can be generally characterized as a stable gravel and cobble-bedded channel that is more similar in character to a cold Alpine headwater stream than a lowland desert river (Schmidt and Grams 2011b). For example, the average grain size of bed material has increased from 0.25-mm sand particles in 1956 to gravel particles larger than 20 mm in 1999 (Grams et al. 2007).

The flow and sediment supply conditions created by the closure and operation of the dam have resulted in bed incision, sediment evacuation, and abandonment to a large degree of any significant sandbar or terrace development in Glen Canyon. Despite this, several large sandbars exist at established recreational sites. The amount of material scoured is equivalent to a cumulative volume about 10.7 million m^3, or a 6- to 10-ft drop in channel elevation averaged over the entire reach, ending at the Paria riffle (Schmidt et al. 2004; Wright et al. 2005). This material is not being re-deposited because no major sediment source exists upstream of the Paria River, making sediment a non-renewable resource in modern-day Glen Canyon (Grams et al. 2007). Previously active sandbars, which have been transformed to gravel bars, are also no longer inundated. Based on repeated surveys in Glen Canyon, the channel appears to have adjusted and stabilized to the regulated flow regime, and the rate of erosion has declined since 1984 (Grams et al. 2007). Although the rate of erosion has declined, the remaining pre-dam high-terrace deposits in Glen Canyon are subject to ongoing erosion processes from the Colorado River and ephemeral tributaries (Anderson 2006; Pederson et al. 2011).

3.3.1.3 Marble and Grand Canyon Geomorphology

The longitudinal profile of the river consists of long, flat pool reaches with intermixed short, steep rapids. The water surface elevation of the Colorado River drops from 3,116 ft to 1,336 ft over the 226 mi from Lees Ferry to Diamond Creek. However, the majority of this elevation change (between 50 and 66%) occurs through the numerous rapids in less than 10% of the river’s length (Leopold 1969; Magirl et al. 2005). The rapids are typically associated with debris-fan deposits formed by tributary debris flows (i.e., fan-eddy complexes described in Section 3.3.1.1), which constrict the channel width, causing an upstream pool formation, steep rapids, and downstream scour hole and pool formation (Dolan et al. 1978; Howard and Dolan 1981; Melis et al. 1995) (Figure 3.3-2). For the Colorado River below Lees Ferry, the locations of debris-fan deposits and rapids, as well as the associated changes in channel width and surface water elevations, have also been quantified (Magirl et al. 2008). Figure 3.3-5 depicts the number of debris fans per RM and the variation in water-surface elevation and channel width for modeled river flows of the Colorado River below Glen Canyon Dam (Schmidt and Grams 2011a).

Sandbars throughout the Colorado River, particularly those below Lees Ferry, tend to be associated with fan-eddy complexes and located in pool regions immediately downstream of debris fans (Dolan et al. 1978; Howard and Dolan 1981). It has been estimated that fan-eddy complexes cover approximately 20% of the total water surface area of the river downstream of Lees Ferry (Schmidt et al. 2004). As described previously in Section 3.3.1.1, sandbars are dynamic because of the continual reworking of the sandbar by erosional and depositional processes, which are further described in Section 3.3.2. In general, sandbars are erosional features that can aggrade due to deposition during flood flows.

One of the main resource considerations for sandbars in Marble and Grand Canyons relates to available campsites and campable areas, which is based on considerations of the size, slope, sediment material, and vegetation abundance of a sandbar (see Section 3.11.2 for more details). A comparison of sandbars used as campsites, based on inventories conducted in 1973, 1983, and 1991 (Figure 3.3-6), indicated that the number of campsites increased in both narrow and wide river reaches as a result of a flood in 1983. However, by 1991, erosion reduced the number of campsites to levels closer to the 1973 inventory values. The same study also noted that vegetative overgrowth further reduced the number of campable sites (Kearsley and Warren 1993). According to a study compiled by USGS and cooperating scientists, the open

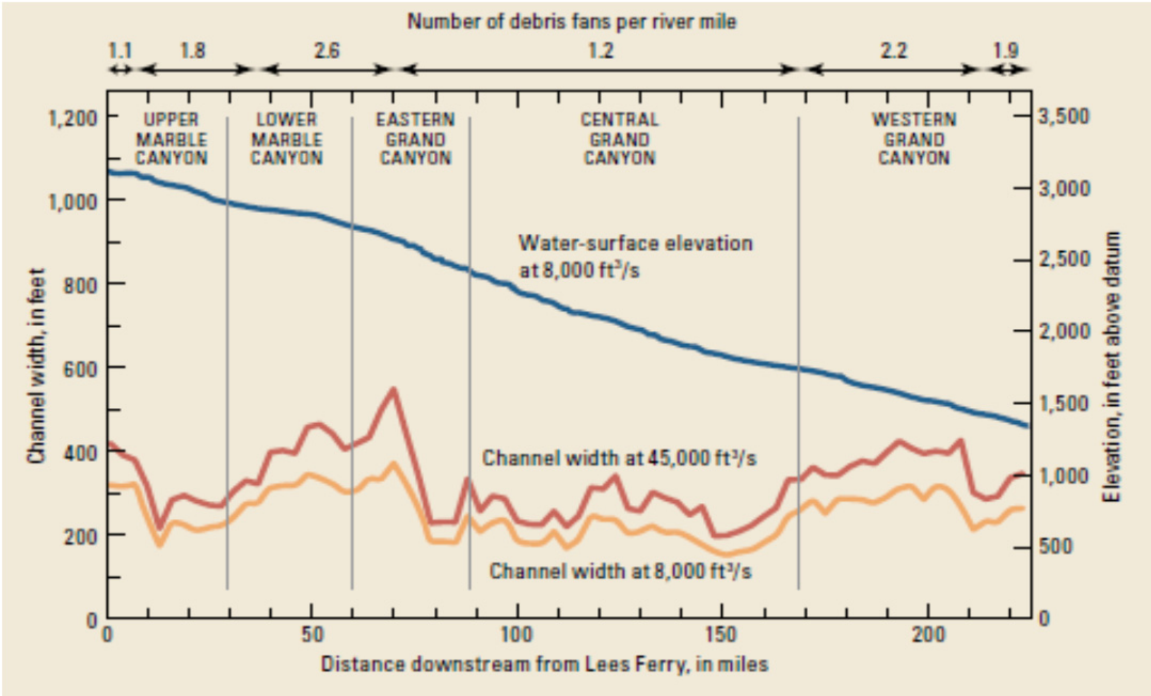

FIGURE 3.3-5 Debris Fans and Variation in Water-Surface Elevation and Channel Width for Colorado River Flows below Glen Canyon Dam (Source: Schmidt and Grams 2011a)

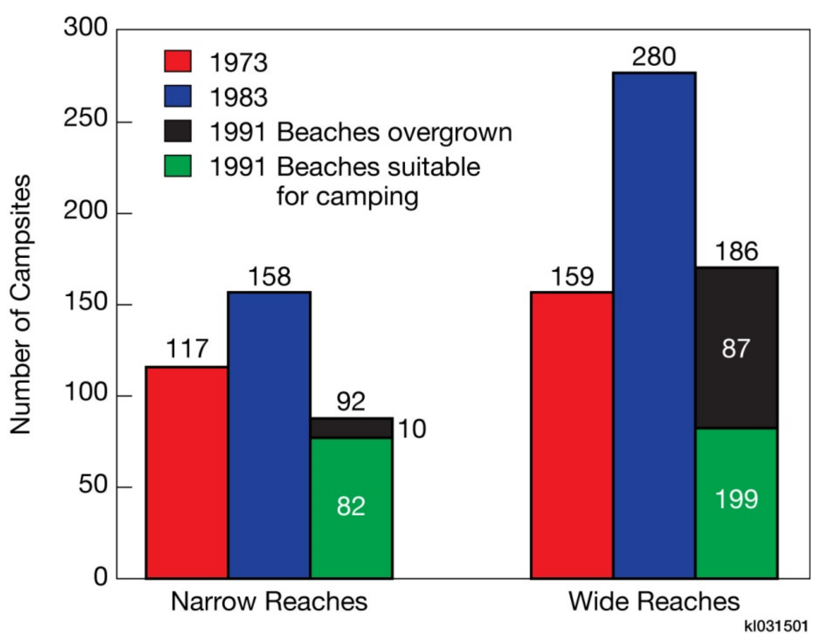

FIGURE 3.3-6 Comparison of Sandbars Used as Campsites, based on Inventories Conducted in 1973, 1983, and 1991 (Source: Kearsley and Warren 1993)

sand area preferred by recreational campers has decreased by 55% since 1998, with an average rate of decline of about 15% per year (Kaplinski et al. 2005).

Debris fans continue to be replenished and enlarged by debris flows from tributaries. Thus, the formation of new rapids and the steepening of existing ones will continue in Marble and Grand Canyons. However, it has also been noted that the presence of the Glen Canyon Dam has greatly reduced both the magnitude and frequency of flood flows and, thereby, the capability of the river to move boulders from the rapids (Reclamation 1995). As a result, many debris fans may experience a buildup of boulders and an accumulation of smaller sediment particles (Melis and Webb 1993). Dam releases above powerplant capacity flows (i.e., >31,500 cfs) can partially rework debris-fan deposits, but this reworking is at a rate that is slower than the aggradation from tributary debris-flow deposits (Yanites et al. 2006). Pre- and post-MLFF flows have the same maximum potential release value (31,500 cfs); however, because MLFF has a maximum normal release value of 25,000 cfs and pre-MLFF had a maximum normal release of 31,500 cfs, the effect on debris flows of post-MLFF operations may be slightly less.

3.3.2 Sediment Characteristics and Transport Mechanisms

Sediment, especially as it occurs in sandbars along the Colorado River below Glen Canyon Dam, is an important and dynamic resource. The GCMRC has been focused on gathering sediment-related data, and understanding of important aspects of sediment science has evolved since the 1995 EIS (Reclamation 1995).

Glen Canyon Dam, completed in 1963, affects stream flow, sand supply, and sand transport in the Colorado River in Glen, Marble, and Grand Canyons. Historically, the Colorado River conveyed high suspended sediment concentrations throughout most seasons and had much larger flood flows and lower base flows (Schmidt and Grams 2011a). Because sediment sources for the Colorado River are not uniformly distributed in the Colorado Plateau, the placement of Glen Canyon Dam effectively cut off approximately 94% of the historical sediment supply from the upper watershed (Andrews 1991; Topping et al. 2000a; Wright et al. 2005). The conditions for sediment replenishment downstream of the dam are now imposed by the tributaries (e.g., Paria River and Little Colorado River), which contribute to the Colorado River downstream of the dam and affect the mechanisms that control sandbars in Glen, Marble, and Grand Canyons. Because of the dam, the capacity of the Colorado River to transport sand and other sediment in the Colorado River Ecosystem is reduced. Sediment transport in the Colorado River was already in decline in the pre-dam era as a result of changes in seasonal rainfall patterns, increased upstream diversions and dam construction, and the slowing of stream entrenchment (Howard and Dolan 1981). Maximum releases from the dam are substantially less than the historic annual peak flows. The high-water zone has been lowered to the level corresponding to managed releases as a result of the dam. These changed conditions have reduced the height of annual deposition and increased the rate of erosion of sediment (Reclamation 1995), and contributed to the loss of beaches and sandbars for many years. Figure 3.3-7 illustrates some of the common changes that have occurred from 1955 to 2008.

FIGURE 3.3-7 Repeated Photography Illustrating Sediment Losses and Sandbar Changes along the Colorado River (These photographs show a portion of the bank of the river in Grand Canyon, 150 mi downstream from the dam. View is downstream from the right (north) bank of the Colorado River. The top image [Source: USGS 2002], taken in 1952, shows a large sandbar. The middle image [Source: USGS 2002], taken in 1995, shows little remaining sand. The bottom image [Source: J. Schmidt, GCMRC], taken in June 2013, shows that some sand was deposited by the November 2012 HFE.)

The sediment resource goal for the LTEMP EIS is to increase and retain fine sediment volume, area, and distribution in the Glen, Marble, and Grand Canyon reaches above the elevation of the current average base flow for ecological, cultural, and recreational purposes. As a resource, the primary considerations for sediment relate to the spatial and temporal dynamics of sediment storage throughout the Colorado River below Glen Canyon Dam. The focus of this section is the sediment characteristics and transport mechanisms that interact with flow regimes dictated by releases from Glen Canyon Dam to govern erosional and depositional processes affecting sandbars. The processes that generate sandbars are linked to several factors, including particle size, sediment supply, flow velocity, channel geomorphology (described previously), and river stage, so it is necessary to consider all these factors when assessing impacts on sediment resources.

3.3.2.1 Particle Size and Sediment Supply

Sediments are typically classified by particle size, and they include the following classes:

- Silt and clay (<0.06 mm);
- Sand (0.06 mm–2.0 mm);
- Gravel and cobbles (2.0 mm–200 mm); and
- Boulders (>200 mm).

In general, the term “fine sediment” refers to sediments that are sand-sized or smaller. This group makes up the most abundant sediment size class found along the river, especially in GCNP below the Paria River. GCNRA has little to no fine sediment input and contains mostly coarse sediment until the river reaches its first major tributary, the Paria River. The majority of the sediment delivered to and transported by the Colorado River is defined as silt and clay, which are carried in suspension by most dam releases. The quantity of silt and clay transported depends mainly on tributary supply. Sandbars contain some silt and clay, but their existence primarily depends on the transport of sand.

Sand is stored throughout Glen and Grand Canyons in bars (or patches) on the riverbed, in eddies, and on terrace sandbars. Sandbars and terraces are used as campsites by boaters and are substrate for vegetation and wildlife habitat. The next-largest sizes are gravel and cobbles, which, together with small boulders, armor the streambed in some places. Certain 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 also a 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 (Graf 1995).

3.3.2.2 Sediment Transport Capacity

The river's capacity to transport sediment increases non-linearly, as a power function of the volume of water flowing in the river. The turbulence of flowing water can increase the amount of sediment in suspension and available for transport. Once the weight of the sediment particles exceeds the suspension force from the water current, the sediment is deposited. The greater the river's flow, the greater its velocity; the greater the turbulence, the greater its sediment load-carrying capacity. Finer particles (i.e., clay and silt) are carried in suspension by nearly all dam releases. Flows in the river are often large enough to carry sand grains in suspension or roll them along the riverbed, temporarily depositing the grains in areas where water velocity is insufficient to move them. Higher flows and velocities are needed to move gravel and cobbles. The largest boulders remain in place for decades or more, awaiting a flood large enough to move them even short distances along the riverbed.

The amount of sand stored within the riverbed each year depends on the tributary sand supply (which is highly variable), the pattern of water released from the dam, and the amount of sand already deposited on the riverbed at the beginning of the year. Sand stored on the riverbed is the principal source for building sandbars during periods of high releases.[5]

3.3.2.3 River Stage

River stage defines the water level associated with a given discharge, which may be a result of both dam release and tributary inflow. Fluctuations in river stage are particularly important to cycles of deposition and erosion within sandbars. While fine sediments are readily transported by the Colorado River, the height of their deposition depends on river stage. Seepage-induced erosion is also affected by fluctuations in river stage because groundwater levels within exposed sandbars rise and fall with increases and decreases in river stage. When the river stage declines faster than groundwater can drain from the sandbar, the exposed bar-face becomes saturated, forming rills that move sand particles toward the river (Reclamation 1995; Alvarez and Schmeeckle 2013).

3.3.3 Sediment Sources

Sediments in the Colorado River are delivered by tributary streams and ephemeral washes. Although most of the water in the Colorado River originates in the Rocky Mountains, most of its sediment load originates from more arid regions in the interior of the river basin (Schmit and Schmidt 2011). In the post-dam era, the Colorado River is no longer the source of sediment to the river downstream of the dam. As a result of the closure of the Glen Canyon Dam,

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5 In an average pre-dam year, sand in Marble Canyon and the upper Grand Canyon would accumulate during 9 months of low flow (July through March); higher flows in April through June (from spring snowmelt) would then erode and transport the stored sand. Since the closure of Glen Canyon Dam, there is no discernible seasonal pattern of accumulation in the Canyons (Topping et al. 2000a; Hazel et al. 2006).

the annual sediment supply past Lees Ferry dropped from a pre-dam level of around 57 million metric tons per year (MT/yr) to about 0.24 million MT/yr during the post-dam period from 1966 to 1970, a reduction in sediment supply at Lees Ferry of more than 99% (Topping et al. 2000a).

The Paria River, Little Colorado River, and nearly 800 smaller gaged and ungaged tributaries now serve as the primary sources of sediment to this reach of the river (Webb et al. 2000; Schmidt and Grams 2011a). Taken together, the contributions of sand from various sources provide the Grand Canyon with approximately 16% of its pre-dam sand levels (Wright et al. 2005). Mass balance sand budgets in the Colorado River below the dam vary within and among years, depending on the amount of tributary sediment input and the monthly volume releases from the dam. Because of this dynamic nature, it is only possible to provide an estimate of the relative sediment budget that is representative of the river channel. In general, the lesser tributaries in the upper Marble Canyon upstream of RM 30 together contribute roughly 10% of the amount of sand annually supplied by the Paria River; downstream from RM 30, the lesser tributaries supply negligible amounts of sand (Griffiths and Topping 2015). However, the sediment inputs from these tributaries appear to be decreasing over time (see the following sections for further details related to gaged and ungaged tributary sediment inputs). Sediment supply is one of the important uncertainties related to managing this resource.

Debris flows have been documented in nearly 740 tributaries in the Marble and Grand Canyons between Lees Ferry and Diamond Creek; tributaries between the dam and Lees Ferry were found to produce only stream flow (Webb et al. 2000). Debris flows tend to be high-magnitude, short-duration events. Debris flows create and maintain the rapids (i.e., hydraulic controls), control the size and location of eddies, and serve as potential sources of sand to replenish sandbars of the Colorado River in the Marble and Grand Canyons.

The coarse sediments associated with debris-fan deposits can only be mobilized during flood flows and do not constitute a significant contribution to sediment loads transported by the river. However, their dynamics are important with respect to their retention of fine sediments and the development of geomorphic structures (e.g., fan-eddy complexes). While it has been predicted that the reduction in flood flows caused by Glen Canyon Dam could result in a greater accumulation of coarse sediment on debris fans, it has been shown that flood flows during the post-dam era also have the potential to transport coarse sediments from debris flows and eroding sandbars (Schmidt and Grams 2011a).

The occurrence and size of both debris flows and flash floods are influenced by geologic and geomorphic conditions within the watershed (see Section 3.3.1.1 for more detail on the geomorphic features of the Colorado River within the project area). They are also affected by the prior history of flows and the amount and intensity of precipitation. For example, Havasu Creek has not had a debris flow in recent geologic time, but it had an enormously destructive flash flood in September 1990. In general, slope failures in the steep tributary valleys commonly trigger debris flows; however, the geologic conditions favorable for debris flows from side canyons vary greatly throughout the area. Therefore, the potential for sand delivery from these tributaries to the mainstem Colorado River also varies throughout the canyon (Webb et al. 2000).

3.3.3.1 Gaged Tributaries

The two largest sediment-contributing tributaries to the Colorado River downstream of the Glen Canyon Dam are the Little Colorado River and Paria River. Sand contribution from the Paria and Little Colorado Rivers, estimated at USGS gaging stations, varies greatly from year to year (see Figure 3.3-8). Together, these two tributaries supplied about 10 to 15% of the total sand load in the pre-dam era (Topping et al. 2000a). Today, they are the two principal suppliers of sand to the Colorado River downstream of the dam through the project area.

The amount of sediment supplied by the Paria River is one of the highest among watersheds on the Colorado Plateau. From 1997 to 2014, the mean annual load has been estimated to be about 2.24 million MT/yr (GCMRC 2015a). Long-term records of sand inputs for the Paria River have suggested that approximately 75% of the average sand supply is delivered during the summer and fall when monsoonal storms are most likely to erode hill slopes in the upper basin and carry more fine sediments (Topping et al. 2010; Wright and Kennedy 2011). The historical median diameter of Paria River sand is approximately 0.13 mm; based on more recent data from 1994 to 2000, about 92% of the influx of sand from the Paria River is finer than 0.25 mm (Topping 1997; Hazel et al. 2006).

The annual average sediment load for the Little Colorado River, using data from 1994 and 2009, has been estimated to be about 4.34 million MT/year, of which approximately 30 to 40% was sand (GCMRC 2015a). Research from the mid-1980s through the early 2000s showed that the Little Colorado River contributed substantially less sand than the Paria River over a decadal time scale, despite the fact that the Little Colorado River basin is nearly 18 times larger than the Paria River basin (Wright et al. 2005; Rubin et al. 2002). These differences in sediment supply could be related to differences in watershed characteristics, including water loss (infiltration) in dryland channels in the increasingly arid climate within the Little Colorado River watershed (Block and Redsteer 2011) and the presence of multiple small dams or impoundments in the Little Colorado River drainage.

3.3.3.2 Ungaged Tributaries

Sediment supplied by the numerous small ungaged tributaries along the Colorado River is much more difficult to estimate because there are no stream gages. Studies have attempted to calculate sediment loads from ungaged tributaries using a number of methods, including mass-balance calculations assuming quasi-equilibrium, regional sediment-yield equations, sediment-rating curves, and peak discharge to total sediment-load relations (Griffiths and Topping 2015). However, there has been some scientific debate over these methods and over the resulting estimates from these various sources (Griffiths and Topping 2015; Schmidt and Grams 2011a). As a result, eight new gages were established in the late 2000s on previously ungaged lesser tributaries in Glen, Marble, and Grand Canyons to better estimate the supply of fine sediment (sand, silt, and clay) from these tributaries to the Colorado River (Griffiths and Topping 2015). Over the 13-year study period, the annual sediment load from the lesser tributaries to the Colorado River in upper Marble Canyon was found to vary two orders of magnitude, from approximately 1,800 to 340,000 metric tons of sand and around 2,900 to 370,000 metric tons of

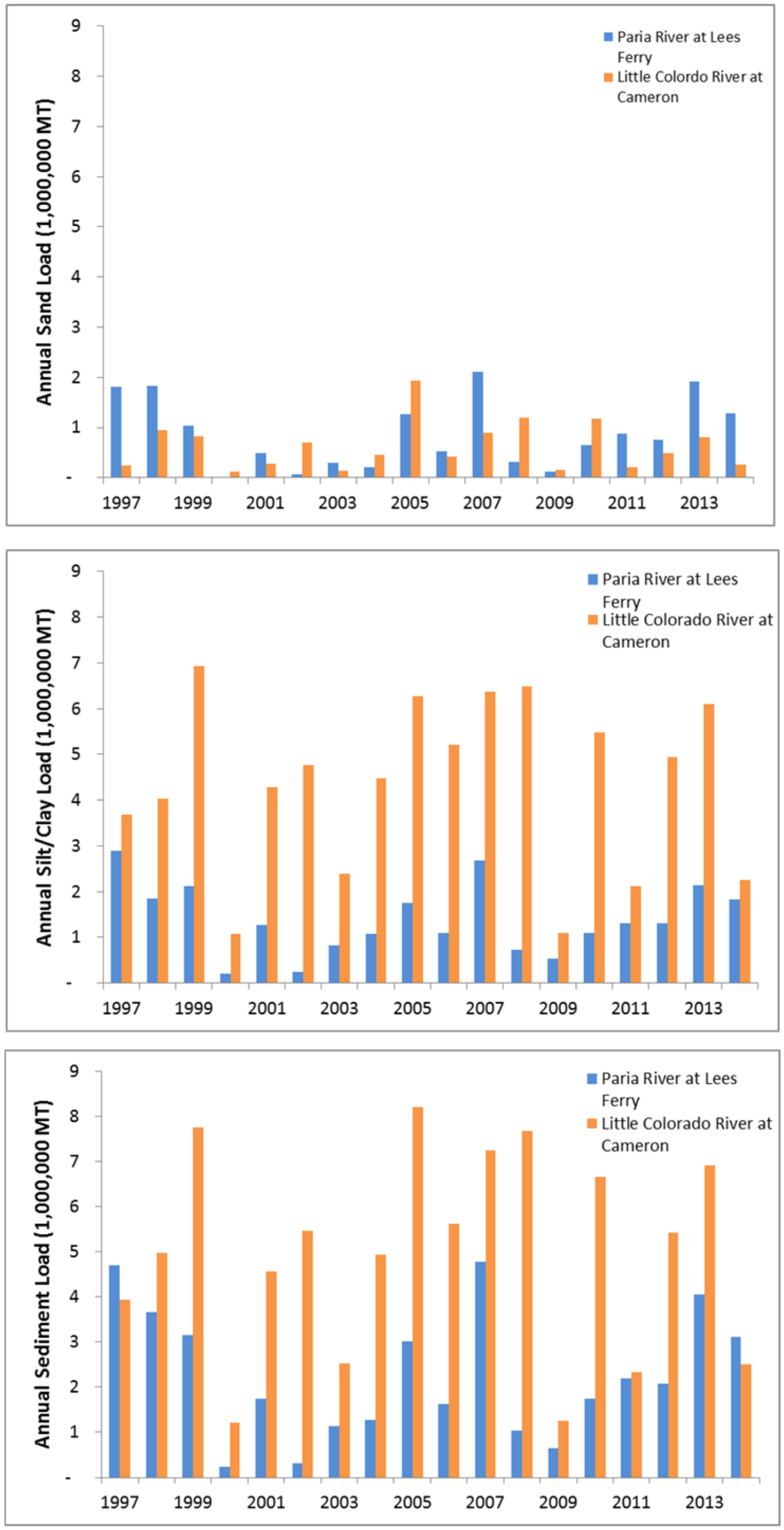

FIGURE 3.3-8 Annual Sediment Contributions from the Paria and Little Colorado Rivers (Source: GCMRC 2015a)

silt and clay. This is equivalent to about 10% of the measured mean annual sand load and about 8% of the measured mean annual silt and clay load in the Paria River. The annual sand load of the lesser tributaries ranged from1.6 to 49% of the annual sand load of the Paria River during individual years. The measured mean-annual silt-and-clay load translates to about 8% of that in the Paria River over the same period (Griffiths and Topping 2015).

Results from the more recent sediment-monitoring network also found that sediment loads do not necessarily correlate with drainage size, and cumulative sediment loads may vary by two orders of magnitude on an annual basis. Thus, previous indirect estimates of annual sediment load from the tributaries were generally too high; this translates to a sediment budget for the Colorado River below Glen Canyon Dam that is in greater deficit than previously concluded by most researchers (Griffiths and Topping 2015).

3.3.4 Sediment Transport and Storage

The operations of Glen Canyon Dam that affect sediment resources can be generally categorized as either operational flows (e.g., daily, monthly, and seasonal) or experimental releases (i.e., HFEs, described in more detail below). Using different flow regimens to manage sediment resources involves establishing a balance between erosional and depositional processes, which is controlled by many factors, including sediment sources and characteristics (described above), as well as physical aspects of sediment transport and storage (described below), that control the sediment balance. However, many uncertainties still remain regarding how these factors influence erosion and depositional processes, which generate the spatial and temporal variations in sandbar and channel-margin deposits throughout the Colorado River (Schmit and Schmidt 2011).

3.3.4.1 Sediment Transport

The term “sediment load” refers to sediment being transported by the river. Sediment load is further categorized as either bedload (i.e., particles moving along the river bottom) or suspended sediments (i.e., particles in the water column). More than 90% of the sand transported through the Colorado River system is considered suspended load (Schmidt and Grams 2011b). Sediment transport is controlled by a balance of forces (shear stress, drag, buoyancy, and gravity) acting on sediment particles, where the force balance is further controlled by properties of the flow, river geomorphology, and the surface area, concentration, density, size, and shape of the sediment particles available for transport.

A mass balance approach is commonly used to quantify sediment transport. Mass balance is calculated as the mass of sediment within a reach of the river relative to the amount of sand transported into and out of the reach. A positive mass balance indicates that more sediment is transported into the reach than out of the reach, and a negative balance indicates that more sediment is transported out of the reach than into the reach. Theoretical and empirical formulations that quantify sediment transport are described in more detail in Appendix E.

3.3.4.2 Sediment Storage

Sediment deposits at rest on the riverbed, within sandbars, and along channel margins represent the sediment storage of a river. Sediment storage is the result of coupled flow, sediment transport, and geomorphological conditions (e.g., low-energy recirculating flow within fan-eddy complexes) that result in deposition of sediments. It is important to note that sediment storage does not necessarily mean that there is no movement; instead, it refers to the net condition (i.e., mass balance) between sediment deposition and erosion at a point of interest over a specified period of time. Thus, sediment storage is a dynamic condition that varies based on the specific spatial and temporal scales considered; it can be increasing (net deposition), decreasing (net erosion), or at equilibrium. For example, the net sediment mass balance for a river reach may be in equilibrium over a year-long period. However, on a finer geographic scale, an individual bar may actually be aggrading or eroding as it exchanges sediment with another location within a reach. On a finer temporal scale, seasonal variation over the year-long period would also become apparent.

It has been estimated that more than 80% of the post-dam fine sediment in the Marble Canyon reach is stored in eddies below the 8,000-cfs stage (Hazel et al. 2006). However, deposition above this stage determines the amount of sand that can be seen and used by visitors to GCNP and how much sand is potentially available for campsites (Schmidt and Grams 2011b). Research has also shown that sand supplied from unregulated tributaries remains in storage for only a few months before most of it is transported downstream, unless flows are below approximately 9,000 cfs (Topping, Rubin, et al. 2000a; Rubin et al. 2002; Schmidt and Grams 2011b).

3.3.4.3 High-Flow Experiments

The Glen Canyon Dam Adaptive Management Program (GCDAMP) has conducted six HFEs (the first was called a Beach Habitat Building Flow), which occurred in 1996,[6] 2004, 2008, 2012, 2013, and 2014, to study the controlling factors that act together to build and maintain sandbars. The primary goal of an HFE is to rework sediments contributed by the Paria River, the Little Colorado River, and ungaged tributaries from the riverbed up to sandbar features that are at elevations above operational flow stages (Schmidt and Grams 2011b; Wright and Kennedy 2011; Reclamation 2011d). The first three HFEs conducted have been extensively studied and reported on (Melis 2011; Melis et al. 2011). Overall, these types of sediment-enriched flows were found to be effective at building sandbars (see Figure 3.3-9 as an example), although post-HFE erosion of sandbars did occur at varying rates depending on flow conditions (Wright and Kennedy 2011). More importantly, the research on these early HFEs highlighted the need to study the cumulative effects of more frequent HFEs and motivated Reclamation to

6 Although the purpose of the 1996 HFE was to control nearshore vegetation and remove nonnative fish downstream of Lees Ferry, the experiment also yielded important information on sediment deposition on sandbars (Schmidt and Grams 2011a). It differed in many significant ways from later HFEs including that it was not sediment-triggered and was much longer in duration.

develop an HFE protocol (Reclamation 2011d) that outlines conditions for implementing HFEs. The protocol also provides a methodology for determining the timing, magnitude, and duration of an experimental HFE (Russell and Huang 2010; Reclamation 2011d). The subsequent 2012, 2013, and 2014 HFEs were a direct result of this protocol.

In general, high flows with low suspended sediment concentrations have greater erosive potential, while high flows with high suspended sediment concentrations generate a greater potential for deposition (Topping et al. 2010). Thus, the primary mechanism for building sandbars seems to involve flood events that can mobilize and rework sediments from the tributary inputs and riverbed and deposit them at a high-flow stage in fan-eddy complexes and channel-margin areas. However, several factors affect both the efficiency with which a flood event can build sandbars and the spatial variability of the sandbar response.

Preliminary results indicate that sandbar building occurred in Marble and Grand Canyons during each of the fall HFEs conducted from 2012–2014. Sandbars were larger following each HFE at more than half of the 45 long-term monitoring sites (Grams et al. 2015). Immediately following the 2012, 2013, and 2014 HFEs, sandbars were larger at 52%, 52%, and 57% of the monitoring sites, respectively (Grams 2016). Sandbar size did not change substantially at 35% of the monitoring sites following each of the same HFEs. The most recent topographic surveys completed in fall 2015 indicate the total volume of sand with the long-term monitoring sandbars increased during the first 4 years of implementation of the HFE protocol (Grams 2016). Preliminary results also indicate that each of these later HFEs evacuated less sand from upper

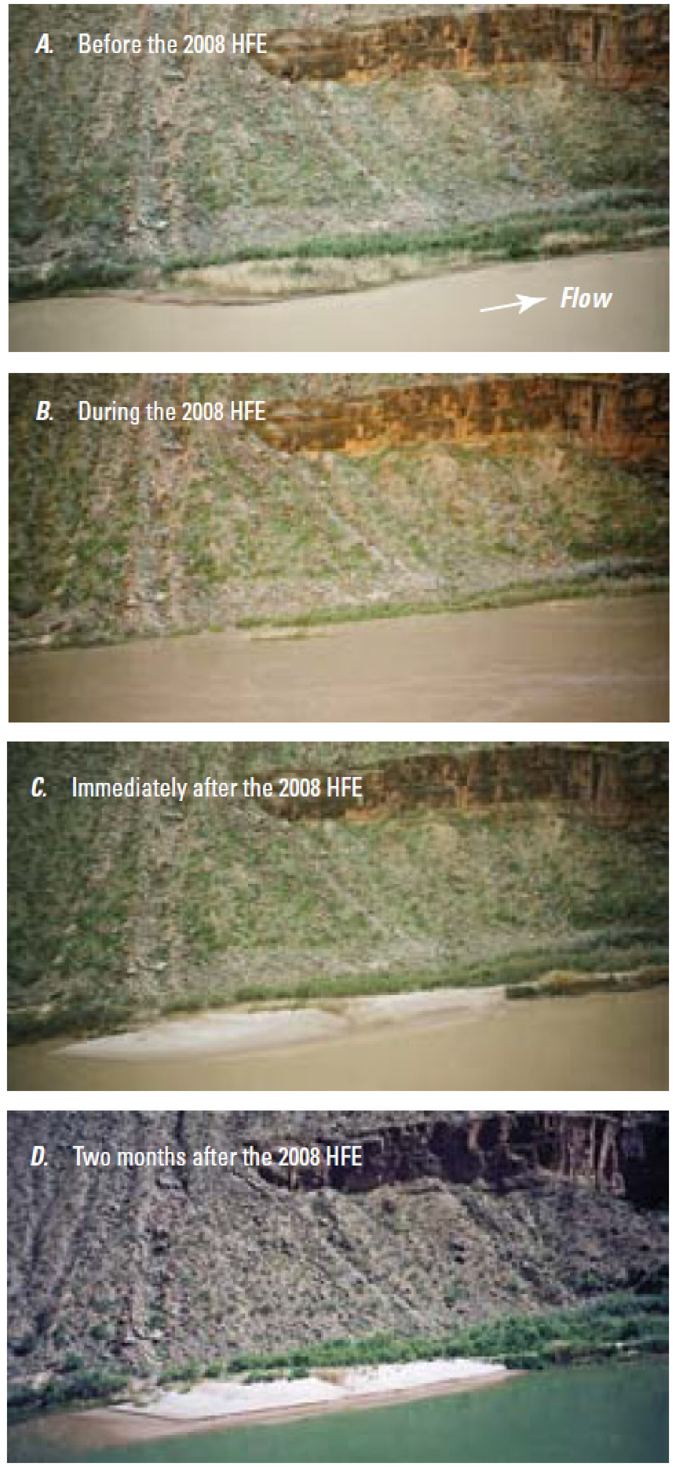

FIGURE 3.3-9 Matched Photographs of RM 172 Illustrating Positive Depositional Response to the 2008 HFE (Source: Schmidt and Grams 2011b)

Marble Canyon than had been delivered there in the immediately preceding fall accounting season (Schmidt 2015). The net effect of less sand being evacuated by each HFE in relation to each year's sand delivery from tributaries has led to progressive sand accumulation in upper and lower Marble Canyon (Schmidt 2015).

3.3.4.4 Sediment Supply Limitation

In general, flow hydraulics and sediment particle sizes, in addition to the presence of critical geomorphic features (e.g., fan-eddy complexes), appear to be the primary factors controlling sandbar deposition (Topping et al. 2010). Thus, an HFE needs to have high velocities and turbulence, coupled with ample fine sediment supplies in the main channel, to increase suspended sediment concentrations. However, it is difficult to predict the sediment transport and storage in the Colorado River in response to HFEs, primarily because the quantity and particle size distributions of sediment available for transport are not consistent throughout a flood hydrograph, between floods, or over the length of the river (Schmidt and Grams 2011a).

Sediment supply limitations can affect the physical processes that govern sediment deposition during HFEs. It is necessary to have a higher concentration of suspended sediments in the main channel to ensure deposition in the fan-eddy complex (Rubin et al. 1998). Conversely, when suspended sediment concentrations are higher in the fan-eddy complex than in the main channel, there exists the potential to erode sand from the fan-eddy complex. During the early stages of an HFE, the finer-grained components are preferentially entrained from the riverbed and transported; consequently, the early sandbar deposits during a high flow are dominated by finer-grained sand. Once the finer-grained sand is winnowed from the riverbed, the suspended sand concentration decreases and the sand in suspension becomes coarser-grained.

3.3.4.5 Sandbar Deposition and Retention

Sandbars experience cycles of deposition and erosion during normal dam operations. Generally, net erosion is a result of turbulent exchange, decreases with distance downstream of the dam, and increase with daily fluctuations in stage. Sandbar erosion can also result from nearshore currents, waves generated by rapids, seepage erosion caused by dewatering sandbars and groundwater flow, wind, tributary floods, and hillslope runoff (Alvarez and Schmeeckle 2013; Schmidt and Grams 2011a; Melis et al. 1995; Budhu and Gobin 1994; Bauer and Schmidt 1993). Sandbar deposition requires high flows and adequate sediment supply. Without occasional periods of sustained high releases (i.e., above powerplant capacity), sandbars, particularly those at high elevation, will eventually erode and not rebuild (Andrews 1991; Schmidt and Grams 2011a).

Long-term rehabilitation of eddy sandbars can occur only if the increases in sand volume caused by high flows exceed the erosion that occurs during the intervening periods. Alternatively, if there are only small amounts of deposition during high flows and large volumes of erosion during intervening periods, a long-term decrease in sandbar size will result. Figure 3.3-10 presents a conceptual diagram illustrating the dependency of net sandbar size on

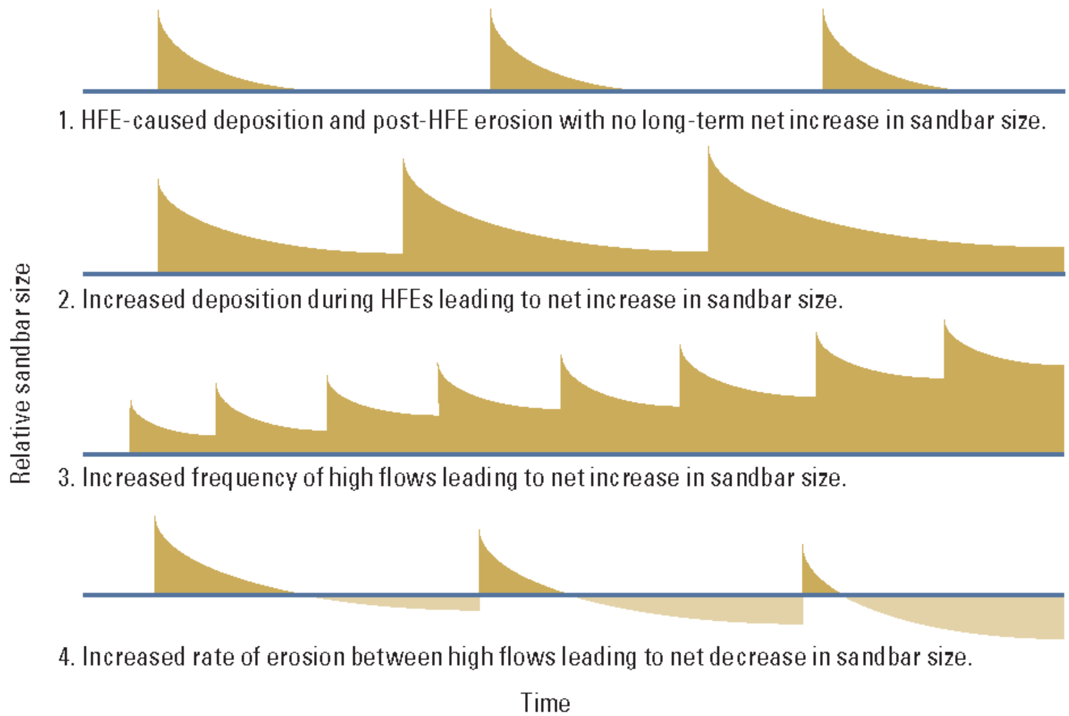

FIGURE 3.3-10 Conceptual Diagram of the Dependency between Net Sandbar Size, Duration and Frequency of HFEs, and Post-HFE Erosion Rates (Source: Schmidt and Grams 2011a)

potential variations during a series of hypothetical HFEs in the amount of deposition, frequency of HFEs, and rate of post-HFE erosion. The first graph shows HFE deposition followed by an equal amount of erosion. The second and third result in net increases in sandbar size by increasing the amount of deposition during HFEs and increasing the frequency of HFEs, respectively; this would require sufficiently great antecedent sand enrichment to support either larger or more frequent HFEs. The last graph depicts a higher rate of erosion following the HFEs, resulting in net decreases in sandbar size (Schmidt and Grams 2011b).

In each of the HFEs,[7] the majority of sandbars exhibited net deposition, as illustrated by the data presented in Figure 3.3-11. The highest level of eddy-sandbar deposition above the reference stage was observed in the parts of Marble and Grand Canyons where the suspended-sand concentration was greatest (Schmidt and Grams 2011b). It is also important to note that, conversely, between 14 and 18% of the monitored sandbars exhibited net erosion (Schmidt and Grams 2011b). Overall, the 1996 HFE (previously referred to as a Beach Habitat Building Flow) resulted in more sandbar erosion than was expected, and antecedent sediment conditions

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7 Summary sandbar results presented are for the 1996, 2004, and 2008 HFEs. The 2012, 2013, and 2014 HFEs post-date the referenced report. Findings from the later HFEs will be released by GCMRC once the research is complete (GCMRC 2014).

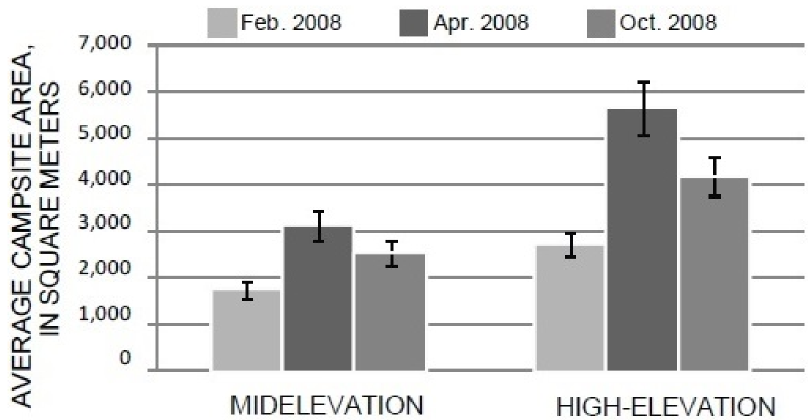

FIGURE 3.3-11 Average Campsite Area above the References Stage: before, after, and 6 Months following the 2008 HFE (Source: Hazel et al. 2010)

(pre-HFE tributary inputs and analyses of sediment storage) were determined to be limiting with respect to sediment storage in the system. As a result, subsequent HFEs were all performed under more enriched sediment conditions, because it was assumed that increased sand enrichment volumes would yield increased suspended sediment loads and higher volume deposits. However, analysis of data from the 2004 and 2008 HFEs suggested that this assumption was not necessarily true. Greater levels of sand enrichment will lead to greater reach-averaged bed-sand area, but will not always lead to finer reach-averaged bed-sand grain size. Thus, both grain size and magnitude of sand supply need to be considered in order to maximize sandbar deposition (Topping et al. 2010).

In the period after each of the HFEs, sandbars tended to erode. In general, sandbar erosion rates were especially high immediately following each of the HFEs, then continued at a slower rate (Schmidt and Grams 2011b). The pattern of net erosion after the HFEs mirrors the changes that occurred during flooding. That is, the pattern of high-elevation deposition and low-elevation erosion is dominant during high-flow, high-elevation erosion, and low-elevation deposition is the dominant pattern during intervening low flows (Hazel et al. 2006).

Overall, research suggests that the HFEs are effective at temporarily building the area and volume of sandbars in fan-eddy complexes. However, long-term rehabilitation of sandbars is only possible if the increases in sand volume caused by the HFEs exceed the erosion during intervening operational flow periods (Schmidt and Grams 2011b) (see Figure 3.3-10). Furthermore, net storage gains in the sandbars as a whole cannot occur if sand is simply being transferred from one bar to another during an HFE. The current state of knowledge suggests that modifying the base flow regime alone (flows below 31,500 cfs and without the use of HFEs) cannot increase the area and volume of sandbars over annual or multi-year timescales (Topping et al. 2010). High flows are needed to get the water surface high enough to deposit sand at higher elevations. Therefore, the research suggests that both the number of HFEs and the base flow regime are factors that affect the building and retention of sandbars.

3.3.5 Lake Deltas

Sedimentation rates among reservoirs are highly variable, due mainly to regional climatic and geomorphic differences that affect sediment delivery. In general, the coarser particles (i.e., mostly sand) carried into the reservoirs by tributaries are deposited as deltas in the tributaries arm. The majority of finer particles (i.e., silt and clay) are carried farther downstream 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 the delta may be transported downstream as a result of flood flow when the reservoir is low. The upper surfaces of deltas function as important substrate for vegetation and riparian habitat and can affect recreational navigation and the water quality of the reservoir (Reclamation 1995).

The characteristics of a delta depend on variables such as the quantity and size of inflowing sediment, dam operations, surface water elevation, 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 reservoir levels and the slope of the channel through the delta (Strand and Pemberton 1982; Reclamation 1995).

The live storage capacity of Lake Mead is 26.399 maf at an elevation of 1,221.4 ft. All sediment transported into Lake Mead by the Colorado River and its tributaries is trapped in deltas and lakebed deposits. Before closure of Glen Canyon Dam, the total upstream drainage area contributing sediment to Lake Mead was 171, 500 mi^2. Since the dam's closure in 1963, sediment contribution upstream of Lake Powell has been essentially cut off. As a result, the drainage area that could contribute sediment above Lake Mead has been reduced by an estimated 65%, or approximately 59,800 mi^2 (Ferrari 2008). Additional information on the hydrology and water quality of Lake Mead is presented in Sections 3.2.1.3 and 3.2.2.3, along with a map of the reservoir and vicinity (Figure 3.2-2).

Longitudinal profiles of the mainstem Colorado Riverbed elevation upstream of the Hoover Dam in 1935, 1948, 1963, and 2001 are illustrated in Figure 3.3-12. In general, the location along the river where the Colorado River intersects Lake Mead depends greatly on the reservoir's water level elevation, which is primarily controlled by the combination of releases from the Glen Canyon and Hoover Dams. The maximum recorded riverbed elevation was 1,220 ft, which roughly corresponds to the elevation of the riverbed downstream of Bridge Canyon (RM 235) in Lower Granite Gorge. Thus, RM 236 is the approximate upper end of the Colorado River delta, which extends past Pierce basin to about RM 290 (Reclamation 1995).

The shape of the Colorado River delta profile is also affected greatly by reservoir elevation. The delta surface in lower Granite Gorge and upper Lake Mead is relatively flat and composed mainly of sand, which begins to drop out of suspension at the point where the river meets the reservoir (as noted above). Beyond the delta, river and reservoir currents can carry large volumes of finer sediment farther into Lake Mead. Lakebed sediments consist of predominantly fine sediments: 60% clay, 28% silt, and 12% sand. Lakebed deposits extend all the way to Hoover Dam at RM 355, even though the longitudinal profile dips steeply at the delta

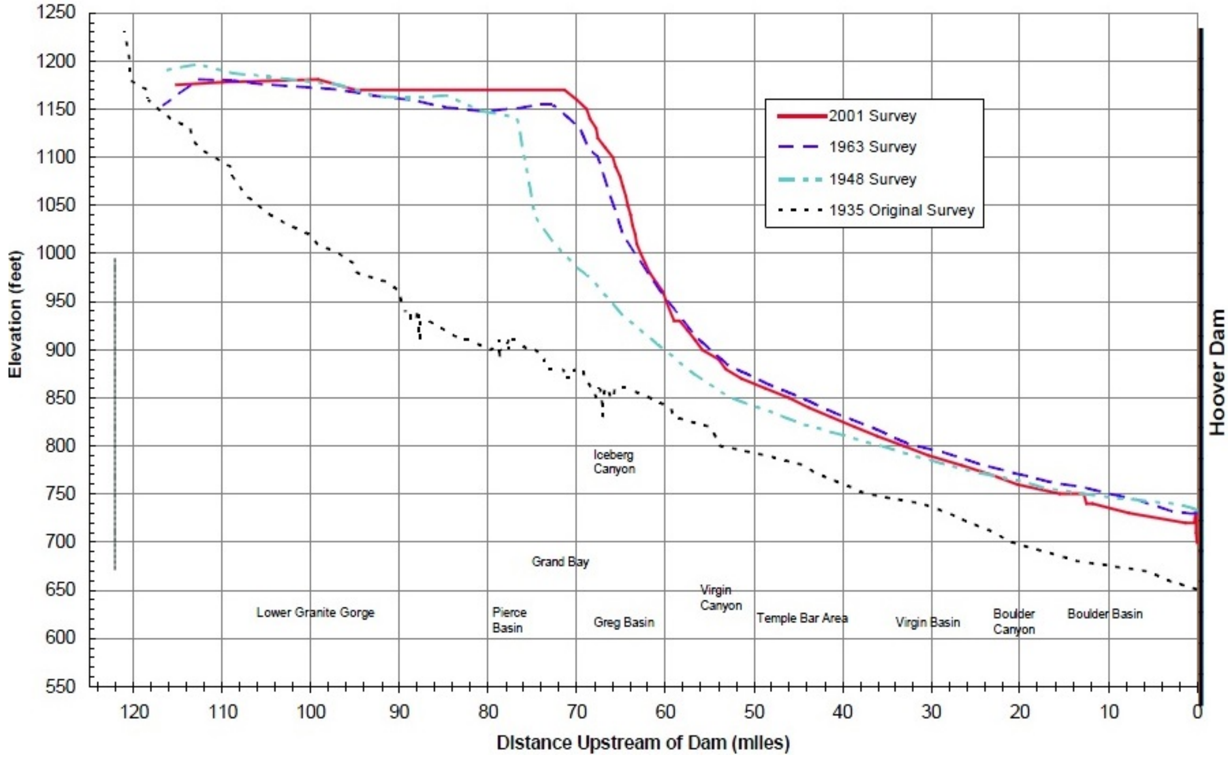

FIGURE 3.3-12 Longitudinal Profiles of the Mainstem Colorado Riverbed Upstream of the Hoover Dam in 1935, 1948, 1963, and 2001 (Source: Ferrari 2008)

crest. The elevation of the delta crest, where the slope changes from relatively flat to relatively steep, has migrated over time (see Figure 3.3-12). According to the 1948–1949 survey of the delta, the delta crest was at RM 278; by the time of the 1963–1964 survey, it had progressed to RM 286 (Reclamation 1995). As of 2001, the delta had progressed another 2 to 3 mi lakeward. The recreational impacts of sediment accumulation in the lower reaches of the western Grand Canyon are described in Sections 3.10.2 and 4.10.2.6.

3.4 NATURAL PROCESSES

The Colorado River Ecosystem is defined as the Colorado River mainstream corridor and interacting resources in associated riparian and terrace zones, located primarily from the forebay of Glen Canyon Dam to the western boundary of GCNP. It includes the area where dam operations impact physical, biological, recreational, cultural, and other resources. An important objective of management of the Colorado River Ecosystem is the ability to sustain healthy populations of native plants and animals and natural ecological processes. NPS management policies state that (1) "whenever possible, natural processes will be relied upon to maintain native plants and animals and influence natural fluctuations in populations of these species" and (2) "the Service … will try to maintain all components and processes of naturally evolving park ecosystems, including the natural abundance, diversity, and genetic and ecological integrity of the plant and animal species native to those ecosystems" (NPS 2006b). For the LTEMP, the natural processes resource goal is to "restore, to the extent practicable, ecological patterns and processes within their range of natural variability, including the natural abundance, diversity, and genetic and ecological integrity of the plant and animal species native to those ecosystems." It is not possible to operate Glen Canyon Dam in a manner that could fully restore natural processes and their drivers to those that occurred under unregulated conditions due to, among other things, the existence of the dam and laws governing conveyance of water between the Upper and Lower Colorado River Basins.

Major drivers of natural processes in river ecosystems, including regulated rivers below dams, are river flow, water temperature, sediment transport, and water quality (including nutrients and turbidity) (Poff et al. 1997; Olden and Naiman 2010; Jones 2013a). These drivers directly and/or indirectly determine the abundance, condition, and status of native and nonnative plants and animals and their habitats in the ecosystem below a dam. The primary effects of dam operations on native plant and animal species and their habitats below the dam are a direct function of (1) the physical conditions (e.g., sediment transport, water temperature) that occur below a dam under specific operations; (2) how those conditions affect habitat quality, quantity, and stability; and (3) how aquatic and terrestrial biota will respond to those changes.

The construction and operation of Glen Canyon Dam has altered the ecosystem both above and below the dam (e.g., Turner and Karpiscak 1980; Brown and Johnson 1988; Carothers and Brown 1991; Blinn et al. 1992; Gloss and Coggins 2005; Kennedy and Ralston 2011; Cross et al. 2013). Before the dam, the river was sediment rich, transporting large quantities of sediment during spring and early summer and during flood events. Prior to construction of the dam, there was considerable seasonal and annual variability in flow and water temperature. Annual peak discharge typically reached between 85,000 and 120,000 cfs with records of 300,000 cfs, while flows in late summer, fall, and winter could be less than 3,000 cfs (Wright et al. 2005; Webb et al. 2005; Vernieu et al. 2005). Water temperatures fluctuated seasonally between 0°C (32°F) and 30°C (86°F), with highest water temperatures occurring in summer.

The physical changes that have resulted from dam construction and operation include serving as a barrier to the movement of most aquatic organisms between the Upper and Lower Colorado River Basins, a decrease in mean main channel water temperatures, a reduction in sediment supply and transport, increased bed scouring and incision, a reduction in peak flows with coupled reductions in the height of annual sediment deposition and areas of sediment erosion, increased daily fluctuations in flow and stage, and increased water clarity (Reclamation 1995; Topping et al. 2000a, 2003; Grams et al. 2007). Following completion of the dam, operations resulted in lower maximum annual volumes, lower peak flows, higher base flows, and decreased annual flow variability (Topping et al. 2003). In addition, in order to increase the value of hydropower, daily fluctuations increased, at times varying from 5,000 to 30,000 cfs (Wright et al. 2005). The incoming sediment load is deposited in Lake Powell and water released from the dam is clear. As a consequence, there has been a significant reduction in sediment supply and transport in the main channel below the dam (Topping et al. 2000a; Vernieu et al. 2005; Wright et al. 2005). Because of the location of the penstocks, water released from the dam is cold, averaging between 9 and 12°C (48° and 54° F), with warmest river temperatures occurring in late fall (Vernieu et al. 2005). Downstream water temperatures are more naturalized and exhibit greater variation, ranging from about 9°C (48°F) to 18°C (64°F) in the western Grand Canyon near Diamond Creek.

The presence of the dam and dam operations has resulted in changes in flow, sediment transport, connectivity, and water temperature. These physical changes, in turn, have resulted in an increase in nonnative riparian vegetation, changes in the distribution and composition of riparian vegetation communities, changes in the aquatic food base, the loss or reduction of native fish, and increases in nonnative fishes (Valdez and Carothers 1998; Gloss and Coggins 2005; Ralston 2005). The physical changes have resulted in a downslope migration of riparian vegetation toward the river's edge (Reclamation 1995; Sankey et al. 2015), the establishment of marshes in the varial zone (Stevens et al. 1995), the development of a cold-water zone that supports rainbow trout (McKinney, Speas et al. 2001; Reclamation 2011e), changes in the composition and productivity of the aquatic food base (Kennedy and Gloss 2005), and a restriction in the distribution, reproduction, and growth of native fish in locations downstream of the dam and tributaries (Gloss and Coggins 2005).

The status of physical conditions in the river is described in Section 3.2 (Water Resources) and Section 3.3 (Sediment Resources). These sections describe the past and current conditions associated with hydrology and flow, water quality (including temperature), and sediment transport and storage. Descriptions of biological resources in the system may be found in Sections 3.5.1 (Aquatic Food Base), 3.5.2 (Native Fish), 3.5.3 (Nonnative Fish), 3.6 (Vegetation), and 3.7 (Wildlife).

3.5 AQUATIC ECOLOGY

This section presents information on the aquatic ecology of the Colorado River between Glen Canyon Dam and the inflow of Lake Mead. Included are discussions of the aquatic food base (i.e., invertebrates, algae, rooted plants, and organic matter that serve as the base of the food web for fish; Section 3.5.1), native fish (including endangered and other special status species; Section 3.5.2), and nonnative fish (including coldwater and warmwater species; Section 3.5.3). For all of these topics, the effects of dam operations and other factors on these resources are discussed.

3.5.1 Aquatic Food Base

Invertebrates (animals without backbones), algae, rooted plants, and organic matter serve as the aquatic food base for fishes in the Colorado River Ecosystem (Gloss et al. 2005). Although most of this food base is produced within the aquatic system, terrestrial inputs to the Colorado River Ecosystem of organic matter (e.g., leaf litter) and invertebrates also contribute. In turn, instream production of both algae and invertebrates helps support terrestrial consumers such as grasshoppers and spiders, insectivorous birds and bats, reptiles, and waterfowl; indirect links include peregrine falcons, belted kingfishers, osprey, great blue herons, and bald eagles, which feed on fishes or waterfowl that consume aquatic food base organisms (Bastow et al. 2002; Baxter et al. 2005; Sabo and Power 2002; Shannon, Kloeppel et al. 2003; Shannon et al. 2004;

Stevens and Waring 1986a; Yard et al. 2004). See Section 3.7 of this EIS for a discussion of riparian and terrestrial wildlife. Flow patterns and temperature (all of which were and continue to be influenced by the presence and changing operations of Glen Canyon Dam) have a major influence on the food base of the Colorado River Ecosystem within the Grand Canyon.

This section presents an overview of the aquatic food base prior to and following the construction and operation of Glen Canyon Dam. Included in the discussion are invasive aquatic species that have affected or may affect food base organisms of the Colorado River downstream of Glen Canyon Dam. The major groups of aquatic food base organisms include (1) periphyton (e.g., algae and cyanobacteria that live attached to rocks and other surfaces) and rooted aquatic plants, (2) plankton (very small plants [phytoplankton] and animals [zooplankton] that occur in the water column), and (3) macroinvertebrates (i.e., invertebrates that are visible to the naked eye).

As summarized by Cross et al. (2013), large dams alter the physical template of rivers by changing flow, temperature, and sediment regimes. Nutrients and sediments are trapped in reservoirs such as Lake Powell rather than being carried downstream (Johnson and Carothers 1987). These changes alter riverine food webs, reduce biodiversity, and often lead to extirpation of native species and facilitation of invasion by nonnative species.

Prior to the construction of Glen Canyon Dam, the productivity of the Colorado River was low due to scouring by annual floods and high turbidity, although there were productive areas in rapids, riffles, whirlpools, and backwaters (Woodbury 1959; Haden et al. 2003). Collections made along the banks of the Colorado River in Glen Canyon and in tributaries or side canyons included 28 species of green algae, 5 species of cyanobacteria, 20 species of diatoms, and 91 species of aquatic insects (e.g., mayflies, dragonflies, true bugs, dobsonflies, caddisflies, aquatic moths, beetles, and true flies). Only 16 insect species were collected from sites along the river in Glen Canyon (including 4 species of mayflies and 3 species of caddisflies), while 77 species were collected from tributaries. Examination of fish stomach contents indicated that organisms derived from tributaries and terrestrial habitats played an important part in the diet of river fishes in Glen Canyon (Woodbury 1959).

The combination of altered flows, reduced organic inputs from areas upstream of the dam, decreased turbidity, and an altered thermal regime has led to a shift in the aquatic food base in the Colorado River below Glen Canyon Dam (Benenati et al. 2002; Blinn et al. 1995; Kennedy and Gloss 2005). In general, aquatic invertebrate diversity has declined, while density and biomass have increased (Kennedy and Gloss 2005). The influence of Glen Canyon Dam, coupled with sediment inputs from tributary streams, has resulted in a stair-step decrease in the food base biomass in the Colorado River. In the post-dam period, the 16-mi reach of Glen Canyon accounted for 69% of the algal and 50% of the macroinvertebrate mass collected throughout the 224-mi section of the Colorado River. Sites within Marble and Grand Canyons contributed 18 and 41% and 13 and 9%, respectively, of algal and macroinvertebrate biomass. Food base reductions in reaches downstream of the Paria River result from elevated sediment inputs from tributary streams. The suspended sediments increase turbidity and the deposited sediments alter substrate characteristics (Shannon et al. 1994, 2001). Thus, the aquatic food base of the tailwater section (between the dam and the Paria River) and the rest of the mainstem (e.g., between the Paria River and Diamond Creek) are often discussed separately. The Colorado River below the Paria River is seasonally influenced by tributary sediment and organic matter inputs, making them more similar to the pre-dam condition, particularly as distance from the dam increases (Rosi-Marshall et al. 2010).

Glen Canyon Dam operations have played a significant role in the formation of the varial zone (i.e., the portion of the river bottom that is alternately flooded and dewatered during operations, often on a daily basis). Benthic communities subject to periodic stranding, desiccation, ultraviolet radiation, and winter freezing often have depleted species diversity, density, and/or biomass in the varial zone (Fisher and LaVoy 1972; Hardwick et al. 1992; Blinn et al. 1995; Stevens, Shannon, et al. 1997).Recent studies have demonstrated that this varial zone actually constrains the abundance and diversity of aquatic insects in the Colorado River downstream of Glen Canyon Dam (Kennedy et al. 2016), thereby limiting the amount of invertebrate prey that is available to support native and desired nonnative fish populations. Most aquatic insects have complex life cycles with a winged adult stage that is terrestrial, while egg, larval, and pupal stages are aquatic. The majority of adult aquatic insects (~80%; Kennedy et al. 2016) use river edge habitats for egg laying, whereby eggs are cemented onto rocks or vegetation along the river edge and just under the water surface. Brief desiccation of insect eggs (e.g., 1 hour), as is typical of eggs laid in the varial zone, leads to their complete mortality (Kennedy et al. 2016). Evidence for this egg mortality effect can be seen throughout Grand Canyon, with aquatic insects being more abundant in locations where the timing of daily low flows coincides with peak egg laying activity (i.e., late afternoon), because insect eggs laid in these locations are never subjected to desiccation induced mortality. Additional evidence for this egg mortality effect is seen by comparing insect diversity downstream of dams throughout the Western United States, with insect diversity being strongly and negatively related to the degree of hydropower production (Kennedy et al. 2016). Thus, the varial zone downstream of hydropower dams, such as Glen Canyon, greatly reduces the quality and availability of river edge habitats that are used by aquatic insects for their egg laying; this constrains both the diversity and abundance of aquatic insects that are present in these ecosystems.

More detailed information on the effects of dam operations on the aquatic food base is provided in Section 4.5.

3.5.1.1 Periphyton and Rooted Aquatic Plants

Physical factors associated with dam releases that have the greatest influence on tailwater algal communities include (1) daily and seasonal constancy of water temperatures, (2) modifications in nutrient regimes, (3) reduced sediment and increased water clarity, (4) formation of stable armored substrates, (5) fluctuations in water levels that produce daily drying and wetting cycles, and (6) reductions in seasonal flow variability and alterations in the timing or occurrence of extreme flows (Blinn et al. 1998). These conditions allowed ubiquitous *Cladophora glomerata* (a filamentous green algae) to become the dominant algal species below Glen Canyon Dam within 6 years of dam closure in 1963 (Czarnecki et al. 1976; Carothers and Minckley 1981; Blinn et al. 1989, 1998; Stanford and Ward 1991). This species remained dominant until 1995 (Blinn and Cole 1991; Blinn et al. 1995; Benenati et al. 1998). Changes in flow regimes (e.g., repeated episodes of exposure and desiccation of the varial zone) and diluted nutrient concentrations associated with higher reservoir volumes caused the decrease in dominance of *Cladophora* (Benenati et al. 1998, 2000, 2002). Prior to June 1995, *Cladophora* comprised 92% of the phytobenthic community, but it decreased to <50% after that time (Benenati et al. 2000). The aquatic flora is now dominated by miscellaneous algae, macrophytes, and bryophytes (MAMB) including filamentous green algae (mainly *Ulothrix zonata* and *Spirogyra* spp.), the stonewort *Chara contraria*, the aquatic moss *Fontinalis* spp., and the macrophyte *Potamogeton pectinatus*. *Cladophora* is still present, but in much reduced levels, probably due to changes in reservoir and river chemistry and discharge regimes (Benenati et al. 2000; NPS 2005a; Yard and Blinn 2001).

Cladophora occurs along the entire course of the river; however, its abundance decreases downstream (Blinn and Cole 1991; Shannon et al. 1994; Shaver et al. 1997; Stevens, Shannon et al. 1997). This decrease results from high suspended sediment loads contributed from the major perennial tributaries, particularly the Paria River and Little Colorado River (Blinn et al. 1995). Suspended sediments reduce photosynthetic efficiency and scours *Cladophora* from substrates (Blinn et al. 1995; Hall et al. 2015).

Cladophora is colonized by a wide variety of diatoms (a group of unicellular or colonial algae) and macroinvertebrates because it can offer protection from predators, food, or a substrate that is anchored against flow disturbance (Dodds and Gudder 1992). Diatoms are the dominant food in the tailwaters of Glen Canyon Dam, but become less important downstream, where bacteria play a more important role in the food web (Blinn et al. 1992). *Cladophora* that becomes detached from the substrate in Glen Canyon is exported downstream where it enters the detrital pathways (Angradi and Kubly 1993, 1994).

The cyanobacteria *Oscillatoria* is co-dominant with *Cladophora* in Marble Canyon and dominates farther downstream in the Grand Canyon due to its tolerance of exposure to air and lower light levels compared to *Cladophora* (Blinn et al. 1992; Stevens, Shannon et al. 1997). Fewer diatoms occur on *Oscillatoria* compared to *Cladophora* (Shannon et al. 1994). Closely attached (adnate) diatoms dominate those that do occur on *Oscillatoria*, while upright or stalked diatoms dominate those that occur on *Cladophora*. Macroinvertebrates and fishes more easily consume the upright diatoms. While *Oscillatoria* provides cover for burrowing midges and aquatic worms, it has little food value for macroinvertebrates (Blinn et al. 1992). Energy from macroinvertebrate biomass associated with tufts of *Cladophora* is 10 times higher than for *Oscillatoria*. Therefore, replacement of *Cladophora* by *Oscillatoria* indirectly reduces potential energy flow in the Colorado River food web (Shaver et al. 1997).

Submerged macrophytes collected in the mainstem included horned pondweed (*Zannichellia palustris*), Canadian waterweed (*Elodea canadensis*), Brazilian elodea (*Egeria densa*), pondweed (*Potamogeton* spp.), aquatic moss (*Fontinalis* spp.), and muskgrass (*Chara* spp. [green alga]) (Carothers and Minckley 1981; Valdez and Speas 2007).

The distribution, ecological importance, and favorable temperature range for select primary producer taxa that occur downstream of Glen Canyon Dam are summarized in Table F-5 (Appendix F).

3.5.1.2 Plankton

Plankton occurring in the Colorado River downstream from Glen Canyon Dam includes both phytoplankton and zooplankton. The phytoplankton population in the Colorado River downstream of the dam is diverse, but sparse (numbers never exceeded 3 million organisms/m^3 [3,000 organisms/L]), and decreased with distance downstream of Lees Ferry. A total of 122 species were identified, with diatoms being dominant. In general, the phytoplankton of the Colorado River is considered relatively unproductive due to a combination of high flow rates, low temperatures, elevated turbidity (with increasing distance from the dam), and scouring action by rapids and suspended solids, which limit reproduction and survival (Sommerfeld et al. 1976).

The factors that regulate zooplankton in the Colorado River below Glen Canyon Dam are the distribution and abundance of zooplankton in Lake Powell and operations of the dam (AZGFD 1996; Speas 2000). Low levels of Lake Powell may result in increases in the composition and density of zooplankton downstream as waters are withdrawn from layers closer to the surface (Reclamation 1995). Cole and Kubly (1976) concluded that most zooplankton in the Colorado River originated from Lake Powell or tributaries (primarily Elves Chasm and Tapeats and Diamond Creeks). Mean zooplankton density in the 352 km of the Colorado River downstream of Glen Canyon Dam was 614 organisms/m^3 (0.614 organisms/L) (Benenati et al. 2001).

It has been reported that backwater areas are localities where zooplankton populations can persist (Haury 1986), and that zooplankton densities in backwaters are significantly higher than those from the main channel (AZGFD 1996). Backwaters were thought to support more zooplankton because they are more stable habitats and may retain nutrients that benefit both phytoplankton and zooplankton (AZGFD 1996). Some production of zooplankton occurs in eddies, backwaters, and other low-velocity areas (AZGFD 1996; Stanford and Ward 1986; Blinn and Cole 1991). However, given that even under stable flows waters in backwaters are recycled 1.5 to 3.4 times per day, it seems unlikely that water-column resources such as zooplankton could ever become substantially higher in backwaters than in the mainstem river (Behn et al. 2010).

The temperature requirements for select zooplankton taxa are summarized in Table F-6 (Appendix F).

3.5.1.3 Macroinvertebrates

Temperature and suspended sediment alterations associated with Glen Canyon Dam, and operations of Glen Canyon Dam itself, resulted in a food base with low species diversity. Although productivity of the food base is high in the Glen Canyon reach, food base production in the Grand Canyon is extremely low, falling in the bottom 10% of production values for streams and rivers throughout the world (Cross et al. 2013). Owing to these changes in the physical template of the river, coupled with intentional and accidental introductions of nonnative invertebrates, the food base consists of both native and nonnative species. The abundant aquatic macroinvertebrates within Lees Ferry include *Gammarus lacustris* (an introduced nonnative amphipod), midges (order Diptera, family Chironomidae), snails (*Physella* sp. and *Fossaria obrussa*), and segmented worms (especially Lumbricidae and Lumbriculidae), which are associated with *Cladophora* beds, as well as ooze- and gravel-dwelling worms (Naididae and Tubificidae), fingernail clams in the family Sphaeriidae (*Pisidium variable* and *P. walkeri*), and the planarian *Dugesia* spp. (Blinn et al. 1992; Stevens, Shannon et al. 1997). Prior to 1995, gastropods (snails) were infrequent but have since increased in abundance due to invasion by the nonnative New Zealand mudsnail (*Potamopyrgus antipodarum*) (Valdez and Speas 2007; Cross et al. 2010). This species is discussed later in this section.

Glen Canyon Dam limits the downstream transport of terrestrial materials such as insects, leaf litter, and woody debris. This reduction of organic input, coupled with low temperature variability and highly variable discharges, can contribute to decreased biodiversity and density of macroinvertebrates (Kennedy et al. 2016), particularly within the Glen Canyon reach. Seasonal turbidity increases, particularly from the confluence of the Paria River to Lake Mead, and reduces overall invertebrate biomass. The decrease in light penetration lowers primary production and favors the growth of the less nutritious cyanobacteria *Oscillatoria* in the lower reaches of the Colorado River (Blinn et al. 1999; Hall et al. 2012).). Macroinvertebrates are not generally associated with *Oscillatoria* because it is very compact, has little surface area for colonization, and largely lacks epiphytic diatoms (Blinn et al. 1995).

In contrast to insects, *Gammarus* and other non-insect aquatic macroinvertebrates can complete their development over a relatively wide temperature range (Vinson 2001), and non-insect aquatic macroinvertebrates lack a terrestrial life stage so their entire life cycle occurs in the river. *Gammarus* is largely replaced by midges and blackflies below the Paria River (Blinn et al. 1992; Seegert 2010; Donner 2011). The decrease in standing stock of *Gammarus* with distance from Glen Canyon Dam (Blinn and Cole 1991; Blinn et al. 1992) corresponds to a decrease in *Cladophora* biomass and associated epiphytic diatoms downriver (Hardwick et al. 1992). Although blackflies and midges are relatively less prevalent in Glen Canyon, they support more than half of the rainbow trout (*Oncorhynchus mykiss*) production in that reach (Cross et al. 2011). The 2008 HFE caused a 60% decline in overall invertebrate production that was driven by a large reduction in the production of nonnative New Zealand mudsnails (Cross et al. 2011). However, the production of midges and blackflies increased by 30 and 200%, respectively, in the year following the HFE, and these insects supported a 200% increase in rainbow trout production (Cross et al. 2011).

The relatively high densities of blackfly larvae in the downstream reaches of the Colorado River suggest the presence of smaller food particles (e.g., bacteria) in these reaches (Blinn et al. 1992; Wellard Kelly et al. 2013). Being filter feeders, blackflies are more common in high-velocity areas with little algal cover, including hard, smooth substrates and driftwood lodged among rocks. Limited data suggest that the blackfly assemblage in the river has changed from at least a five-species assemblage to a near monoculture of *Simulium arcticum* (Blinn et al. 1992).

The Colorado River in Glen and Grand Canyons supports very few mayflies, stoneflies, or caddisflies because of a combination of stressors, including altered temperature regimes and a large varial zone (Stevens, Shannon, et al. 1997; Kennedy et al. 2016). Cold water released from

Glen Canyon Dam can prevent aquatic insect eggs from hatching and may limit successful recruitment of these orders from warmer tributaries (Oberlin et al. 1999), while a large varial zone associated with hydropower production leads to desiccation-induced mortality of insect eggs laid along river edge habitats (Kennedy et al. 2016). The caddisfly *Ceratopsyche oslari* occurs throughout the Colorado River but at a low abundance (Blinn and Ruiter 2009). Haden et al. (1999) believe that interspecific interactions between *Gammarus* and the net-building *C. oslari* may contribute to the caddisfly's limited occurrence in the Colorado River below Glen Canyon Dam. Since 1994, recent colonizers (possibly as a result of reduced discharge variability from Glen Canyon Dam) throughout the river include caddisflies (*Hydroptila arctica*, *Rhyacophila* spp., *C. oslari*, and others), true flies (*Bibiocephala grandis* and *Wiedemannia* spp.), mayflies (*Baetis* spp.), beetles (*Microcylloepus* spp.), planarians, and water mites (Shannon et al. 2001). However, caddisflies and mayflies remain relatively sparse in the Colorado River, especially upstream of the Paria River. Tables F-2 through F-4 (Appendix F) present the biomass, production, and abundance of invertebrates, respectively, over the course of 3 years at various locations in the Colorado River.

Flow fluctuations and repeated inundation and exposure can have a significant impact on food base organisms in the varial zone. Warm air temperatures in summer or subfreezing air temperatures in winter can cause mortality of macroinvertebrates stranded in the varial zone (Gislason 1985). The varial zone probably provides poor habitat for species with multiple life history stages (Jones 2013b). Dewatering within the varial zone may adversely impact areas where adult aquatic insects either emerge or deposit eggs (Vinson 2001; Kennedy et al. 2016).

Drifting macroinvertebrates, particularly blackflies and midges, are an important food resource for rainbow trout (McKinney and Persons 1999) and other fishes. Flow regime, discharge, and distance from the dam influence drift of macroinvertebrates in the Colorado River (Shannon et al. 1996; Stevens et al. 1998; Sublette et al. 1998; Kennedy et al. 2014). In general, a positive correlation exists between invertebrate drift concentrations and flow magnitude; however, reduced flow can increase stream drift through behavioral factors such as crowding and avoidance of desiccation (Blinn et al. 1995; Kennedy et al. 2014). The density of invertebrates on the river bottom is also an important control of invertebrate drift concentrations (Kennedy et al. 2014). Tributary and terrestrial insects compose a small portion of the stream drift in the Colorado River corridor (Shannon et al. 1996). It is possible that terrestrial invertebrate drift is high during and immediately after rainstorms and is therefore a rare but locally important resource for mainstem Colorado River fishes (Shannon et al. 1996).

Table F-7 (Appendix F) summarizes information on the distribution, importance to higher trophic levels, and temperature range for common macroinvertebrates that occur downstream of Glen Canyon Dam.

Tribal Perspectives on Aquatic Food Base

The Zuni believe that macroinvertebrates are underwater species that are not yet ready for this world, and any disturbance to them could have negative consequences. The river's life begins at the headwaters. The river is the umbilical cord to the earth, and through the Zuni religion, prayers, and songs there is also an invisible cord to the Zuni. This statement about underwater species relates to the Zuni history, as Zunis believe that their most ancient ancestors emerged onto this world only when they were ready for emergence. To force an aquatic species to change is to impede the species' natural development and future progress, a violation of Zuni beliefs about the world's natural order.

3.5.1.4 Nonnative Invasive Species

Some nonnative species have been introduced to supplement the aquatic food base. Because of the low benthic food base noted in the late 1960s, Arizona Game and Fish Department (AZGFD) biologists introduced macroinvertebrates into the Glen Canyon reach, including crayfish, snails, damselflies, caddisflies, crane flies, midges, true bugs, beetles, and leeches (McKinney and Persons 1999). These introductions were not monitored for a sufficient length of time to determine their success; however, most of these taxa did not persist in the river (Carothers and Minckley 1981; Blinn et al. 1992). *Gammarus lacustris* was also introduced into the Glen Canyon reach in 1968 to provide food for native and nonnative fishes (Ayers et al. 1998). *Gammarus* and midges have become important components of the aquatic food base.

Other nonnative invasive species that have potentially detrimental effects on both the food base and fish communities have become established in the Colorado River below Glen Canyon Dam. New Zealand mudsnail was first detected in Glen Canyon in 1995. By 1997, densities on cobble/gravel substrates reached about 3,390/ft^2. Densities averaged 5,567/ft^2 between 1997 and 2006, except for 2000, when densities averaged 20,540/ft^2. High densities that year coincided with experimental steady flows. Although the New Zealand mudsnail can withstand short periods of desiccation, its density is generally higher in systems with constant flows (see Section F.2.1.3 of Appendix F). The New Zealand mudsnail has dispersed downstream through Grand Canyon and was documented in Lake Mead in 2009 (Sorensen 2010). The mudsnail accounted for 20 to 100% of the macroinvertebrate biomass at six cobble bars studied in the Colorado River. The snails probably consume the majority of the available epiphytic diatom assemblage. The New Zealand mudsnail is a trophic dead-end and may adversely affect the food base in the Colorado River (Shannon, Benenati, et al. 2003). Epiphytic diatom biomass estimates at Lees Ferry were an order of magnitude lower in 2002 compared to 1992 (before New Zealand mudsnails were present) (Benenati et al. 1998; Shannon, Benenati et al. 2003). However, the biomass of other dominant aquatic food base taxa has been variable and not apparently influenced by the presence of the snails (Cross et al. 2010). However, at high population levels (e.g., ≥9,300 individuals/ft^2), New Zealand mudsnails can substantially modify lower trophic levels (Hall et al. 2006).

The New Zealand mudsnail can directly affect native species by consuming a large proportion of the primary production (especially periphyton), competing with native snails and other grazing invertebrates, and negatively impacting both invertebrates and vertebrates at higher trophic levels in aquatic food webs that depend on the aquatic invertebrate food base (Riley et al. 2008; Hall et al. 2003, 2006; Vinson and Baker 2008). At high densities, the New Zealand mudsnail may compete with other macroinvertebrates for food (e.g., diatoms) or space (Kerans et al. 2005). Hall et al. (2006) suggest that the New Zealand mudsnail is sequestering a large fraction of the carbon available for invertebrate production and altering food web function.

The New Zealand mudsnail has a good chance of being transported by either biological or physical vectors because of its small size and locally high population density (Haynes and Taylor 1984). Recreational fishing and fish stocking have been implicated in the spread and introduction of the New Zealand mudsnail (Moffitt and James 2012). The New Zealand mudsnail can also be carried by waterfowl from one system to another and by fish within a system (Haynes et al. 1985).

Vinson and Baker (2008) evaluated the ability of rainbow trout to assimilate New Zealand mudsnails. They found that juvenile rainbow trout will readily ingest the snails but receive little nutritional value because the snails have an operculum that protects them from digestive agents. Also, trout lack pharyngeal teeth that would assist in grinding snail shells. Trout-fed mudsnails lost 0.14 to 0.48%/d of their initial body weight, while those fed amphipods gained 0.64 to 1.34%/d of their initial body weight. Only 15% of New Zealand mudsnails were assumed to have been digested, 32% were dead but present in their shells and assumed to be undigested, and 53% were alive. The results confirm that North American trout fisheries face potential negative impacts from the New Zealand mudsnail invasion (Vinson and Baker 2008). Although the New Zealand mudsnail occurs throughout the river from the Glen Canyon Dam to Lake Mead, its densities tend to be much higher in the upper reaches of the river (Cross et al. 2013). For example, in the Glen Canyon reach, densities of mudsnails were an order of magnitude higher than downstream in Grand Canyon (Cross et al. 2013).

A few nonnative invasive invertebrates are fish parasites that use food base organisms as an intermediate host. For example, the internal parasite *Myxobolus cerebralis*, which causes whirling disease in salmonids, uses the oligochaete worm *Tubifex tubifex* as an intermediate host (see Section 3.5.3.1 for additional information on whirling disease). The parasitic trout nematode (*Truttaedacnitis truttae*) is present in rainbow trout in the Glen Canyon reach. The ecological impact of the infestation is poorly known, but may influence food consumption, impair growth, and reduce reproductive potential and survival of rainbow trout. The nematode may require an intermediate host such as a copepod or other zooplankton taxa (McKinney, Robinson, et al. 2001).

The Asian tapeworm (*Bothriocephalus acheilognathi*) was first introduced into the United States with imported grass carp (*Ctenopharyngodon idella*) and was discovered in the Little Colorado River by 1990. It now parasitizes the humpback chub population from the Colorado and Little Colorado Rivers. The tapeworm could infect all species of native and nonnative fish species in the Little Colorado River (USGS 2004). Cyclopoid copepods are intermediate hosts for the tapeworm; however, fish that prey upon small infected fish can acquire tapeworm infections as well. Thus, large humpback chub that normally consume little zooplankton can become infected by preying upon smaller infected fish (USGS 2004).

Asian tapeworms were recovered in all fish species sampled from the Little Colorado River but were rare in suckers, rainbow trout, and catfish (mean ≤0.08/fish). Their highest abundance and prevalence were in humpback chub (mean 18.36/fish with 84% of fish infected). The abundance and prevalence of the tapeworm in nonnative cyprinids, such as the fathead minnow (*Pimephales promelas*—mean 0.84/fish, with 23% of fish infected), red shiner (*Notropis lutrensis*—mean 1.2/fish, with 63% of fish infected), and common carp (*Cyprinus carpio*—mean 3.5/fish, with 52% of fish infected), as well as the plains killifish (*Fundulus zebrinus*—mean 1.26/fish, with 15% of fish infected), implicates any of these species as being potential hosts that introduced the tapeworm into the Little Colorado River. It is also possible that bait bucket transfers into the upper reaches of the Little Colorado River or into the Colorado River may have been responsible for the introductions (Choudhury et al. 2004).

Increased body loads of the parasitic copepod known as anchor worm (*Lernaea cyprinacea*) and the Asian tapeworm cause poorer body condition in humpback chub from the Little Colorado River. For fishes collected from 1996 to 1999, prevalence of the anchor worm was found to be 23.9%, and the mean intensity was 1.73/fish in the Little Colorado River compared to 3.2% and 1.0/fish in the Colorado River. The prevalence of Asian tapeworm was 51.0% and 252/fish in the Little Colorado River, but only 15.8% and 12/fish in the Colorado River. Differences in parasite density and abundance between the Little Colorado River and Colorado River are caused by temperature differences. Temperatures in the Colorado River near the Little Colorado River do not reach those necessary for either parasite to complete its life cycle; thus, these parasites were probably contracted while the humpback chub was in the Little Colorado River (Hoffnagle et al. 2006). Table F-8 (Appendix F) presents the temperature requirements for the Asian tapeworm, anchor worm, and the trout nematode.

Table F-8 (Appendix F) summarizes information on the temperature requirements for the Asian tapeworm, anchor worm, and trout nematode. While not included in the table, whirling disease infection prevalence and severity in salmonids is greatest at 10 to 15°C (Steinbach Elwell et al. 2009).

There are concerns about the potential for other nonnative invasive species to become established in the future and further impact the condition of the aquatic food base. The quagga mussel (*Dreissena bugensis*) is one species of particular concern. It can alter food webs by filtering phytoplankton and suspended particulates (Benson et al. 2013). Although there was conflicting information as to the presence of quagga mussels in Lake Powell for a few years prior to 2012, a noticeable population had not yet developed in that year (NPS 2012c). However, as of 2014, thousands of adult quagga mussels have been observed within the reservoir on canyon walls, the Glen Canyon Dam, boats, and other underwater structures (Repanshek 2014). Quagga mussels established in Lake Powell may cause changes in dissolved nutrients, phytoplankton, and zooplankton within the reservoir, which would likely impact food web structure or trophic linkages below Glen Canyon Dam (Nalepa 2010). The quagga mussel was first detected in the Colorado River below Glen Canyon Dam in 2014 after it began to establish in Lake Powell.

As the population of quagga mussels develops in Lake Powell, the potential for mussel larvae to travel though Glen Canyon Dam increases. Those that survive could attach in low flow areas of the Colorado River, but it is not known if they could reach high numbers (NPS 2012c). The risk of the quagga becoming established within the Colorado River Ecosystem is low, except in the Glen Canyon reach, where lower suspended sediment and higher nutrient levels (compared to downstream reaches) favor its establishment (Kennedy 2007). It is unlikely to establish at high densities within the river or its tributaries because of high suspended sediment, high ratios of suspended inorganic/organic material, and high water velocities, all of which interfere with the ability of the quagga mussel to effectively filter food. High concentrations of sand may cause abrasion and physically damage its feeding structures (Kennedy 2007). In addition, it only takes 5 days for water to travel from Glen Canyon Dam to Diamond Creek (Kennedy 2007), so few quagga mussel larvae exported from Lake Powell will be large enough (i.e., >0.2 mm) to colonize the mainstem before they reach Lake Mead, where there is already an established quagga population. Larval mortality in the rapids of Grand Canyon also is likely to be high (Kennedy 2007). Quagga mussels are being found in the river below the dam in relatively low numbers; one mussel has been reported from as far downstream as River Mile 209.

If the quagga mussel obtained moderate densities in Lees Ferry, estimates of filtration capacity indicate they are unlikely to substantially alter the quality (e.g., nutrient concentrations, suspended organic matter concentrations) of water within or exported from Lees Ferry (Kennedy 2007).

3.5.1.5 Food Web Dynamics

Primary production, specifically diatoms, forms the base of the aquatic food web in Glen Canyon. In contrast, a combination of primary production and terrestrial and tributary inputs of organic matter is the basis of the aquatic food web in Marble and Grand Canyons, but high-quality algal matter supports the food web to an extent that is disproportionate to its availability. Midges and blackflies principally fuel the production of native and nonnative fishes, and fish production throughout the river appears to be limited by the availability of high-quality prey, particularly midges and blackflies, and fish may exert top-down control on their prey (Carlisle et al. 2012).

The food web within Glen Canyon is rather simple. Complexity increases with distance from the dam (Figures G-2 and G-3 in Appendix G) (Cross et al. 2013). The New Zealand mudsnail and nonnative rainbow trout dominate the food web in the Glen Canyon reach of the Colorado River. The simple structure of this food web has a few dominant energy pathways (diatoms to a few invertebrate taxa to rainbow trout) and large energy inefficiencies (i.e., <20% of invertebrate production consumed by fishes). Epiphytic diatoms, *Gammarus*, midges, and blackflies provide the primary food base for rainbow trout (Cross et al. 2013).

Below large tributaries, invertebrate production declines about 18 fold, while fish production remains similar to upstream sites. However, sites below large tributaries have increasingly diverse and detritus-based food webs. Midges and blackflies are the dominant invertebrates consumed in downstream reaches (Cross et al. 2013). Fish populations are food-limited throughout most of the mainstem, and tend to consume all of the available invertebrate production in downstream reaches (Cross et al. 2013).

3.5.2 Native Fish

Human activities have greatly affected the fish fauna of the Colorado River between Glen Canyon Dam and Lake Mead. Warmwater nonnative fish were introduced as early as the late 1880s (Carothers and Brown 1991). Overall, the Colorado River Basin once contained a unique assemblage of 35 native fish species, 74% of which were endemic (Minckley 1991). Relatively little information is available regarding the fish community prior to the construction of Glen Canyon Dam. Limited sampling in Glen Canyon before dam construction (conducted from 1957 to 1959) reported only two species from the mainstem proper: the nonnative channel catfish (*Ictalurus punctatus*; about 90% of the captures) and the native flannelmouth sucker (*Catostomus latipinnis*; about 10% of the catch) (Woodbury et al. 1959; McDonald and Dotson 1960). In contrast, mainstem backwaters and tributaries of the Colorado River within the Glen Canyon reach had a more diverse fish community, with 14 nonnative and 6 native species, dominated by the native flannelmouth sucker and speckled dace (*Rhinichthys osculus*).

Prior to Glen Canyon Dam closure in 1963, the river carried high sediment loads and, depending on season, flows and water temperatures varied widely (see Section 3.3.3). Construction and closure of Glen Canyon Dam permanently altered the river downstream, creating a relatively clear river with nearly constant year-round cold temperatures (<12°C [54°F]) and daily fluctuating but seasonally modulated flows based on tributary inflows and water storage and electrical generation needs (Reclamation 1995; NPS 2013e). As a consequence, the cold water temperatures in many miles of the main channel are below those needed for spawning, egg incubation, and growth of most native fish (Figure 3.5-1), and successful reproduction has been largely supported in tributaries (Reclamation 1995). In recent years, however, there has been some newly documented reproduction of native fish in portions of the lower Grand Canyon; adult and larval razorback suckers have been captured there (Bunch, Makinster, et al. 2012; Bunch, Osterhoudt et al. 2012; Albrecht et al. 2014; Rogowski and Wolters 2014; Rogowski, Wolters, et al. 2015). Razorback suckers have also been recently observed in the San Juan River arm of Lake Powell (Francis et al. 2015). Colorado River tributaries continue to exhibit natural flow and temperature regimes conducive to native fish spawning and rearing. Most native fish in the mainstem from the dam to the Little Colorado River are large juveniles and adults, while earlier life stages rely extensively on more protected and warmer near-shore habitats, primarily backwaters (Johnstone and Lauretta 2007; Ackerman 2008). The habitats and reproduction of native species in the system are discussed in more detail in later sections.

In addition to the effects of the altered mainstem physical environment on the reproduction, growth, survival, and distribution of native fishes in the Colorado River below Glen Canyon Dam, past introductions of nonnative fish species, both intentional and accidental, have affected native fish in the Colorado River and its tributaries downstream of Glen Canyon Dam. Coldwater and/or warmwater nonnative fish exist in all fish-bearing waters in GCNP and GCNRA below Glen Canyon Dam (see Section 3.4.4). These species can dominate the fish community in some areas and may threaten native species survival. Nevertheless, habitats in the Colorado River and its tributaries in GCNP support the largest remaining endangered humpback chub population, and this population has been growing since the late 1990s (Coggins and Walters 2009) and is now estimated at approximately 11,000 adults (Yackulic et al. 2014). Over

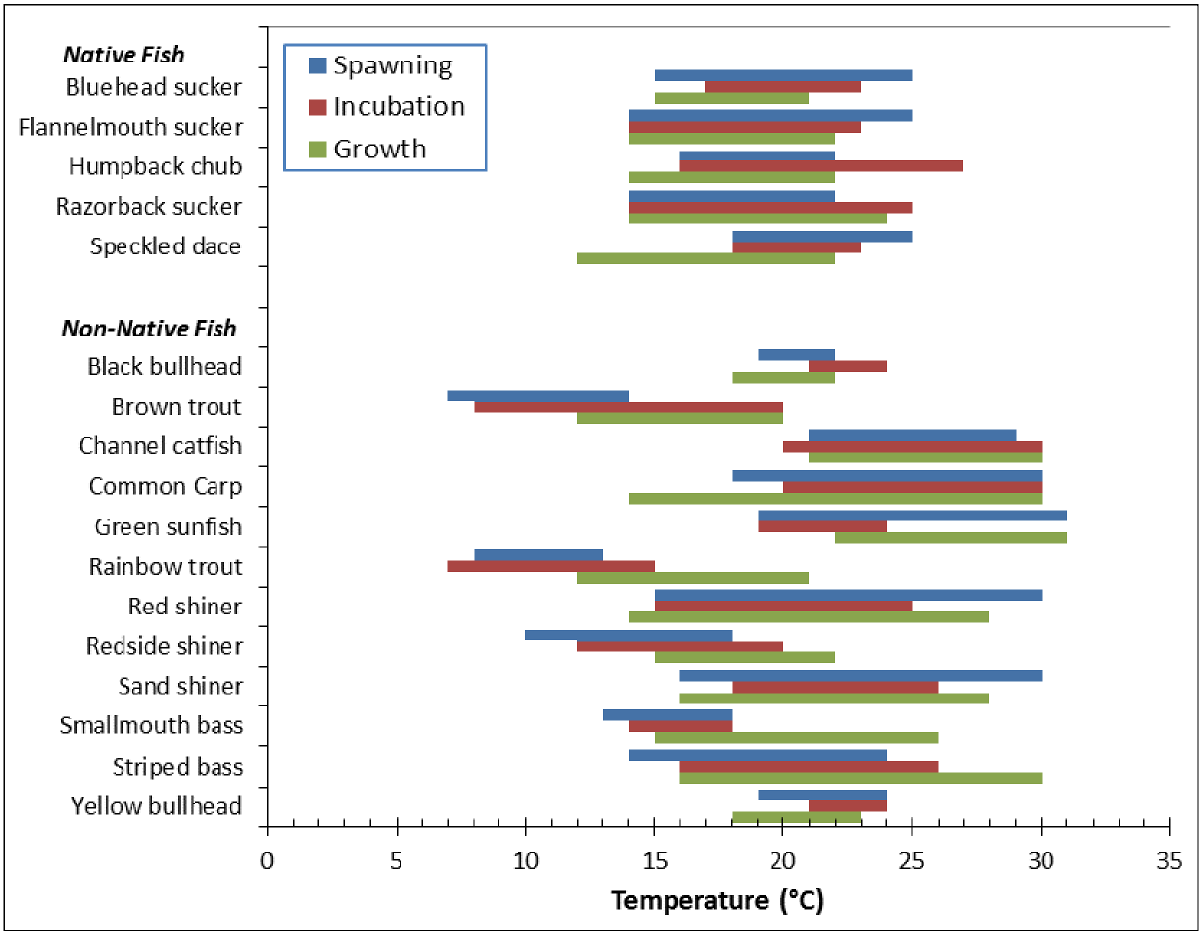

FIGURE 3.5-1 Temperature Ranges for Spawning, Egg Incubation, and Growth by Native and Nonnative Fishes of the Colorado River System below Glen Canyon Dam (Source: Valdez and Speas 2007)

this same time period, the Grand Canyon fish community has also shifted toward a more dominant native species component (Lauretta and Serrato 2006; Johnstone and Lauretta 2007; Ackerman 2008; Makinster et al. 2010). It is hypothesized that the recent shift from nonnative to native fish is due in part to warmer than average water temperatures and the decline of coldwater salmonids (Ackerman 2008; Andersen 2009; Reclamation 2011c; Yackulic et al. 2014).

There are 11 species of native fishes that occur, may occur, or historically have occurred within the study area (Table 3.5-1). Among these native species, five species—the humpback chub, razorback sucker (*Xyrauchen texanus*), bluehead sucker (*Catostomus discobolus*), flannelmouth sucker, and speckled dace—occur within the mainstem and its tributaries. Three other species—the Zuni bluehead sucker (*Catostomus discobolus yarrowi*), Little Colorado sucker (*Catostomus latipinnis* sp. 3), and Little Colorado spinedace (*Lepidomeda vittata*)—are endemic to the upper reaches of the Little Colorado River. The remaining three species—the bonytail chub (*G. elegans*), roundtail chub (*G. robusta*), and Colorado pikeminnow (*Ptychocheilus lucius*)—have been extirpated from the mainstem between Glen Canyon Dam

TABLE 3.5-1 Native Fish of the Colorado River through Glen and Grand Canyons

Species	Listing Status[a]	Presence in Project Area[b]
Humpback chub (*Gila cypha*)	ESA-E, CH; AZ-SGCN	Lake Powell, Paria River confluence to Separation Canyon, Little Colorado River, Havasu Creek
Bonytail chub (*Gila elegans*)	ESA-E, CH; AZ-SGCN	Lake Powell; extirpated from the Grand Canyon
Razorback sucker (*Xyrauchen texanus*)	ESA-E, CH; AZ-SGCN	Lake Powell; Lake Mead upstream to Lava Falls
Colorado pikeminnow (*Ptychocheilus lucius)*	ESA-E; AZ-SGCN	Lake Powell; extirpated from the Grand Canyon.
Bluehead sucker (*Catostomus discobolus*)	AZ-SGCN	Paria River to Lake Mead, including tributaries
Flannelmouth sucker (*Catostomus latipinnis*)	NL	Lake Powell to Lake Mead
Speckled dace (*Rhinichthys osculus*)	NL	Glen Canyon Dam to Lake Mead, including tributaries

[a] ESA = Endangered Species Act; E = listed as endangered; CH = federally designated critical habitat in project area; AZ-SGCN = Arizona Species of Greatest Conservation Need; NL = not listed.

[b] Habitat and life history information is presented in species-specific discussions in this section.

Sources: 56 FR 54957; AZGFD (2001a,b; 2002a,b; 2003a); Andersen (2009); Bezzerides and Bestgen (2002); Coggins and Walters (2009); Francis et al. (2015); Makinster et al. (2010); Ptacek et al. (2005); Rees et al. (2005); Rinne and Magana (2002); FWS (2002a); Ward and Persons (2006); Woodbury et al. (1959); Gloss and Coggins (2005); GCMRC (2014); Albrecht et al. (2014).

and Hoover Dam. The extirpated species and those found only in the upper reaches of the Little Colorado River are considered outside the affected area considered in this EIS. Currently, five species of native fish are known to exist in the Colorado River between Glen Canyon Dam and Lake Mead; these are discussed in detail in the following sections.

3.5.2.1 Special Status Fish Species

Two species of native fish that are listed under the Endangered Species Act of 1973 (ESA) (16 USC 1531, as amended)—the humpback chub and the razorback sucker—occur in the potentially affected portions of the Colorado River and its tributaries between Glen Canyon Dam and the inflow to Lake Mead. These two species are also designated as Arizona Species of Greatest Conservation Need (AZ-SGCN). In addition, two other native fish, the flannelmouth sucker and bluehead sucker, are included in the Arizona statewide conservation agreement for six native fish species (AZGFD 2006a).

Humpback Chub

The humpback chub is a large, long-lived species endemic to the Colorado River system. This member of the minnow family may attain a length of 20 in., weigh 2 lb or more, and live as long as 40 years (Andersen 2009).

Distribution and Abundance. The humpback chub was federally listed as endangered in 1967. Historically, this species occurred throughout much of the Colorado River and its larger tributaries from below Hoover Dam upstream into Arizona, Utah, Colorado, and Wyoming (AZGFD 2001a). Currently, the humpback chub is restricted to six population centers, five in the upper Colorado River basin and one in the lower basin (FWS 2011a). The upper basin populations occur in (1) the Colorado River in Cataract Canyon, Utah; (2) the Colorado River in Black Rocks, Colorado; (3) the Colorado River in Westwater Canyon, Utah; (4) the Green River in Desolation and Gray Canyons, Utah; and (5) the Yampa River in Yampa Canyon, Colorado. The only population in the lower basin occurs in the Colorado River in Marble Canyon, the Grand Canyon, and Little Colorado River (FWS 2011a).

The Colorado River/Little Colorado River population is the largest of the six population centers of the humpback chub. Within the Grand Canyon, this species is most abundant in the vicinity of the confluence of the Colorado River and Little Colorado River (Paukert et al. 2006). In addition, eight other areas (aggregation areas) where humpback chub are, or have been, regularly collected have been identified; these aggregation areas are located at 30-Mile, Lava Chuar-Hance, Bright Angel Creek inflow, Shinumo Creek inflow, Stephen Aisle, Middle Granite Gorge, Havasu Creek inflow, and Pumpkin Spring (Figure 3.5-2; Valdez and Ryel 1995). In addition, since 2009, translocations of humpback chub have been made by the U.S. Fish and Wildlife Service (FWS) to introduce juvenile fish upstream of Chute Falls in the Little Colorado River, and by NPS to introduce juvenile fish into Shinumo and Havasu Creeks, with the goal of establishing additional spawning populations within the Grand Canyon (NPS 2012b, 2013g). Survey data collected in 2013, 2014, and 2015 suggest that translocated humpback chub have successfuly spawned in Havasu Creek (NPS 2013g). Sampling conducted between October 2013 and September 2014 in the western Grand Canyon between Lava Falls (RM 180) and Pearce Ferry (RM 280) collected 144 juvenile humpback chub during sampling of the small-bodied fish community, and 209 larval and juvenile humpback chub during sampling of the larval fish community (Albrecht et al. 2014). These results suggest that young humpback chub are using nursery and rearing habitats between RM 180 and RM 280 in the western Grand Canyon that are not clearly associated with any of the aggregation areas identified above.

Monitoring data show that from 1989 through 2001, there was a steady decline of adult humpback chub within the Little Colorado River aggregation in the Grand Canyon; estimated numbers declined from approximately 11,000 adults (age 4+) in 1989 to about 5,000 adults in 2001 (Coggins et al. 2006; Coggins and Walters 2009) (Figure 3.5-3). However, since about 2001, the downward population trend reversed, with the estimated number of adult fish

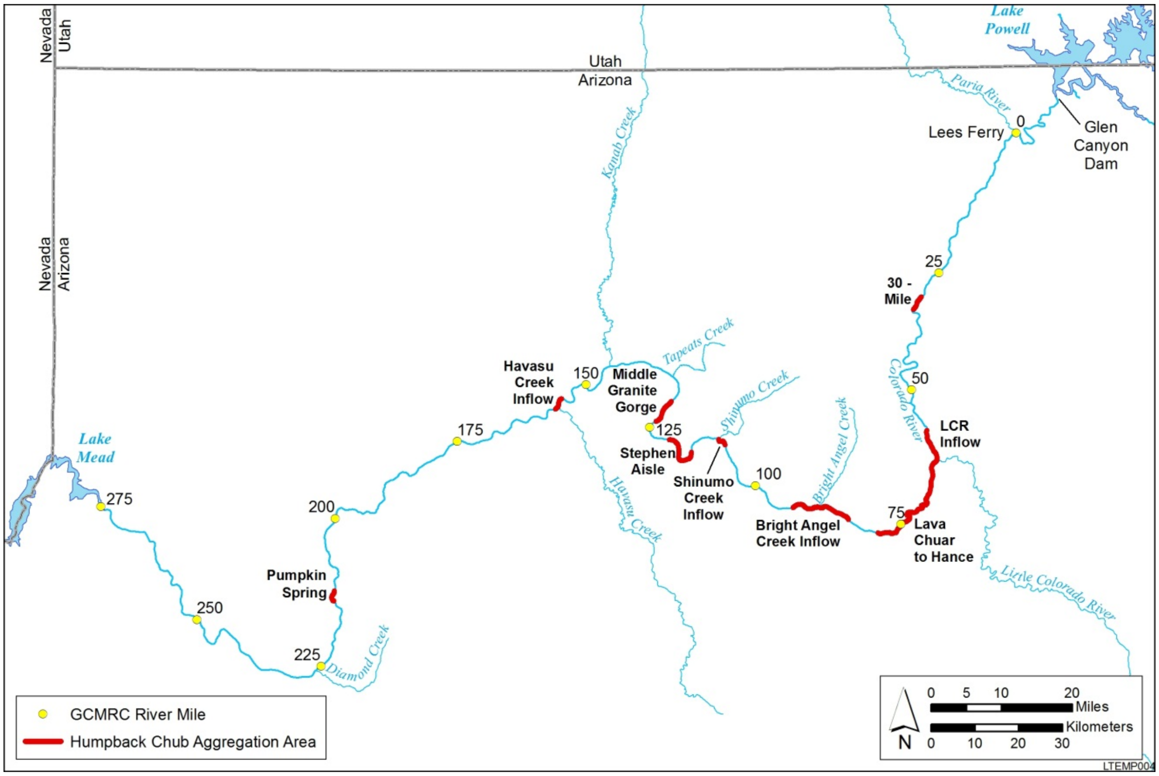

FIGURE 3.5-2 Humpback Chub Aggregation Areas along the Colorado River between Glen Canyon Dam and Lake Mead (Sources: VanderKooi 2011; NPS 2013b)

increasing to approximately 8,000 fish by 2008 (Figure 3.5-3) (Coggins and Walters 2009). More recently, abundance estimates for 2009 to 2012 suggest the population has continued to increase to approximately 11,000 adults (Figure 3.5-4) (Yackulic et al. 2014). Factors suggested as being responsible for this estimated increase are discussed later in this section. In addition, recent preliminary population estimates for humpback chub aggregations suggest that humpback chub in several aggregations may have increased as a result of (1) translocations to Shinumo and Havasu Creeks; (2) good production in the Little Colorado River; (3) water temperatures that were about 1°C (1.8°F) warmer since the early 2000s (including significantly warmer than normal water temperatures in 2004, 2005, and 2011); and (4) declines in trout abundance at the Little Colorado River inflow due to implementation of trout control measures, a system-wide decline in trout abundance, or both (NPS 2013e; Yackulic et al. 2014).

Habitat. Throughout the humpback chub's current range, adults are found in turbulent, high-gradient canyon-bound reaches of large rivers (AZGFD 2001a) as well as in deep pools separated by turbulent rapids. Within the Grand Canyon, the humpback chub occurs primarily in the vicinity of the Little Colorado River (RM 30-110; Figure 3.5-2), with adults being associated with large eddy complexes. Converse et al. (1998) found that densities of subadult humpback chub in the mainstem Colorado River downstream of the Little Colorado River were greater along shoreline areas with vegetation, talus, and debris fans than in areas with bedrock, cobble,

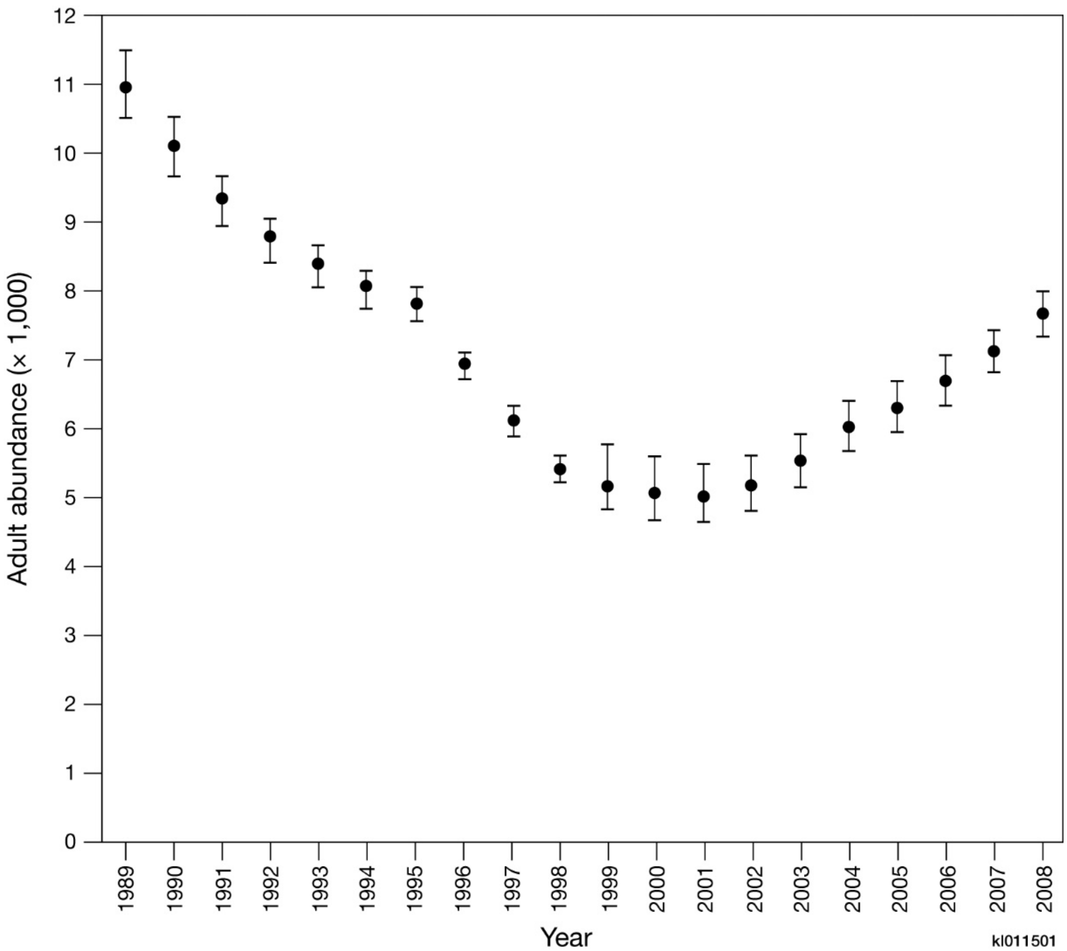

FIGURE 3.5-3 Estimated Adult Humpback Chub Abundance (Age 4+) from Age-Structured Mark-Recapture Model Incorporating Uncertainty in Assignment of Age (Error bars represent minimum 95% confidence intervals and do not consider uncertainty in growth or mortality.) (Source: Coggins and Walters 2009)

and sand substrates. One recent mark-recapture study reported that approximately 87% of recaptured fish were collected in the same mainstem river reach or tributary where they were originally tagged, with 99% of all recaptures occurring in and around the Little Colorado River (Paukert et al. 2006). However, some of the marked fish were determined to have moved as much as 96 mi throughout the Grand Canyon. In the Little Colorado River, adults inhabit a variety of habitats, including pools and areas below travertine dams (AZGFD 2001a). More recently, a study conducted in 2010 examined the movement of 30 radio-tagged adult humpback chub in the Colorado River during 2 months of fluctuating flow followed by 2 months of steady flow (Gerig et al. 2014). The radio-tagged fish were found to use eddies extensively while avoiding runs. During both flow treatments, the tagged fish exhibited only small daily movements of about 33 ft/day, and no effect of flow was observed on either habitat selection or movement.

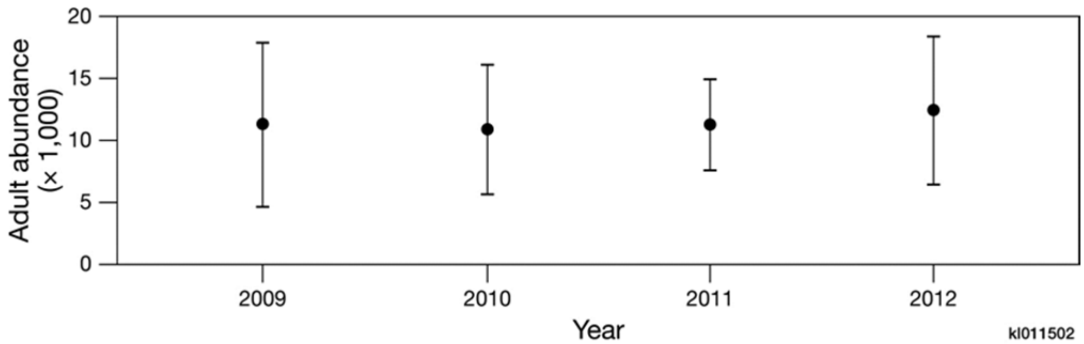

FIGURE 3.5-4 Estimated Total Adult Abundance of Humpback Chub in the Lower 8 mi of the Little Colorado River and a 2-mi Portion of the Colorado River Just Downriver of the Confluence of the Little Colorado and Colorado Rivers, for September, 2009 through 2012 (Error bars represent the 95% confidence intervals.) (Source: Yackulic et al. 2014)

The main spawning area for the humpback chub within the Grand Canyon is the Little Colorado River, which provides warm temperatures suitable for spawning and shallow low-velocity pools for larvae (Gorman 1994). Many of the larval fish remain in the Little Colorado River for one or more years, and growth rates and survival are relatively high compared to estimates for the colder waters of the mainstem Colorado River (Dzul et al. 2014). Spring abundance estimates for age-1 humpback chub within the Little Colorado River from 2009 to 2012 ranged from approximately 1,000 to more than 9,000 individuals (Dzul et al. 2014). Within the Little Colorado River, young humpback chub prefer shallow, low-velocity near-shore pools and backwaters; they move to deeper and faster areas with increasing size and age (AZGFD 2001a). In the mainstem of the Colorado River, young-of-the-year (YOY) fish may be found in backwater and other near-shore, slow-velocity areas that serve as nursery habitats (Valdez and Ryel 1995; Robinson et al. 1998; AZGFD 2001a; Stone and Gorman 2006). Juvenile humpback chub (<3 years old) have been collected in all types of near-shore habitats by the Humpback Chub Near-shore Ecology Study, with the highest numbers collected from talus slopes (Dodrill et al. 2015).

These near-shore habitats may be beneficial to the humpback chub (and other native fishes) as they provide shallow, productive, warm refugia for juvenile and adult fish (Reclamation 1995; Hoffnagle 1996). Temperature differences between main channel and near-shore habitats can be pronounced in backwaters and other low-velocity areas. The extent of warming is variable and depends on the timing of the daily minimum and maximum flows, the difference between air and water temperatures, and the topography and orientation of the backwater relative to solar insolation (Korman et al. 2006). For example, summertime water temperatures in backwaters have been reported to be as high as 25°C (77°F) while main channel temperatures are near 10°C (50°F) (Maddux et al. 1987). The amount of warming that occurs in backwaters is affected by daily fluctuations, which drain and fill backwater habitats with cold main channel waters (Valdez 1991; Angradi et al. 1992; AZGFD 1996; Behn et al. 2010). During the low steady summer flow experiment conducted in 2000, temperatures in one backwater were as much as 13°C (23°F) warmer than in the adjacent main channel during some portions of the day; temperature differences were much less at night (Vernieu and Anderson 2013). Backwater temperatures in summer have been reported to be as much as 2 to 4°C (3.6 to 7.2°F) warmer under steady flows than under fluctuating flows (Hoffnagle 1996; Trammell et al. 2002; Korman et al. 2006; Anderson and Wright 2007). In general, the levels of warming observed in nearshore areas and backwaters during the low summer steady flows in 2000 persisted only for short periods of time and were smaller than seasonal changes in water temperatures (Vernieu and Anderson 2013). Consequently, temperature effects on native fishes were probably small.

Although the use of thermal refugia such as backwaters has been documented in a variety of systems (e.g., Tyus and Haines 1991; Bodensteiner and Lewis 1992; Torgersen et al. 1999; Ebersole et al. 2001; Westhoff et al. 2014), the overall importance of backwater habitats in the Colorado River relative to humpback chub survival and recruitment is uncertain (Reclamation 2011c). While juvenile humpback chub have been reported to show positive selection for backwater habitats, the spatial extent of such habitats in the Colorado River is small compared to other nearshore habitats such as talus slopes (Dodrill et al. 2015). Dodrill et al. (2015) reported that the total abundance of juvenile humpback chub was much higher in talus than in backwater habitats, and that when relative densities were extrapolated using estimates of backwater prevalence after an HFE, the majority of juvenile humpback chub were still found outside of backwaters. This suggests that the role of HFEs in influencing native fish population trends in the Colorado River may be limited.

Life History. The humpback chub is primarily an insectivore, with larvae, juveniles, and adults all feeding on a variety of aquatic insect larvae and adults, including dipterans (primarily chironomids and simulids), Thysanoptera (thrips), Hymenoptera (ants, wasps, bees), and amphipods (such as *Gammarus lacustris*) (Kaeding and Zimmerman 1983; AZGFD 2001a; Cross et al. 2013). Feeding by all life stages may occur throughout the water column as well as at the water surface and on the river bottom.

The Grand Canyon humpback chub population reproduces primarily in the lower 8 mi of the Little Colorado River, although occasional spawning is suspected in other areas of the Colorado River as well (Valdez and Masslich 1999; Anderson et al. 2010; AZGFD 2001a). Adults move into the Little Colorado River from the Colorado River to spawn from March to May (Kaeding and Zimmerman 1983; Gorman and Stone 1999; FWS 2008). Relatively little spawning and juvenile rearing occur in the mainstem of the Colorado River, primarily because of the cold mainstem water temperatures (Andersen 2009). Mainstem spawning is suspected near 30-mile spring, or in other areas in the western Grand Canyon following the detection of larval humpback chub in recent years (Albrecht et al. 2014, Kegerries et al. 2015), although studies have not been completed to identify spawning areas or habitat in the Colorado River in the Grand Canyon. This species requires a minimum temperature of 16°C (61°F) to reproduce, but mainstem water temperatures typically have ranged from 7 to 12°C (45 to 54°F) because of water releases from Glen Canyon Dam (Andersen 2009). Drought-induced warming has resulted in mainstem water temperatures since 2003 consistently exceeding 12°C (54°F) in the summer and fall months. Although some increases in spawning may have played a role in the estimated increase in the humpback chub population in the system since that time, it is likely that the increased temperatures resulted in higher survival of juveniles in the mainstem (Andersen 2009; Coggins and Walters 2009; Yackulic et al. 2014).

Following spawning, larvae have been reported to drift in the Little Colorado River from April through June, and many drift out into near-shore habitats of the Colorado River (FWS 2008). Robinson et al. (1998) estimated about 38,000 larval humpback chub drifted from the Little Colorado River into the mainstem in May and June 1993. Juveniles generally have lower monthly rates of movement than adults, with the exception of a high probability of juveniles being transported from the Little Colorado River to the Colorado River during high flows of the monsoon season, when numbers of juvenile humpback chub in the mainstem have been documented to increase by as much as 4,000 fish (Yackulic et al. 2014).

Although survival of larval and juvenile fish in the mainstem was once thought to be very rare because of seasonally constant, low water temperatures (Clarkson and Childs 2000), more recent information suggests that juveniles can successfully rear to adulthood in the Colorado River mainstem, at least under recent environmental conditions that include warmer water (Yackulic et al. 2014). Increasing water temperatures have been shown in the laboratory to increase hatching success, larval survival, larval and juvenile growth, and improve swimming ability and reduce predation vulnerability (Hamman 1982; Ward 2011; Ward and Morton-Starner 2015). Yackulic et al. (2014) postulated that, with warmer water, growth and survival of juveniles in the mainstem will be greater and result in increased mainstem recruitment, and thus contribute to the overall adult population. Increased water temperatures may also affect predation of YOY humpback chub by rainbow and brown trout (*Salmo trutta*) (Ward 2011; Ward and Morton-Starner 2015; Yard et al. 2011). Ward and Morton-Starner (2015) conducted laboratory studies that indicated predation success of rainbow trout on YOY humpback chub decreased from approximately 95 to 79% as water temperature increased from 10°C to 20°C (50°F to 68°F); predation success by brown trout was about 98% and did not change significantly over the same temperature range. Yard et al. (2011) examined the effects of temperature on trout piscivory in the Colorado River and reported no relationship between water temperature and the incidence of piscivory by rainbow trout, but a significant positive correlation was found between water temperature and the incidence of piscivory for the brown trout.

Factors Affecting Distribution and Abundance in the Grand Canyon. These factors include habitat alterations associated with dams and reservoirs and the introduction of nonnative fishes, which act as competitors and/or predators of the humpback chub (see Section 3.5.3.3) (AZGFD 2001a; Andersen 2009; Yard et al. 2011; Kennedy et al. 2013). The abundance and distribution of nonnative fishes are discussed in Section 3.5.3. In addition, the Colorado River now includes nonnative fish parasites, such as the Asian tapeworm and anchor worm, which may infect some humpback chub and affect survival (Clarkson et al. 1997; Andersen 2009). While coldwater releases from Glen Canyon Dam have limited reproduction and recruitment of humpback chub (and other native fishes) in the mainstem Colorado River, warmer water temperatures in the mainstem over the last decade have been sufficiently high to allow for modest growth, survival, and recruitment of humpback chub, contributing to the improving status of this species in the Grand Canyon (Reclamation 2011a; Yackulic et al. 2014).

Population estimates indicate that the number of adult humpback chub in the Grand Canyon increased from about 2001 to 2008 (Figures 3.5-3) and has been stable in recent years (Figure 3.5-4). A number of factors have been suggested as being responsible for the observed increases, including experimental water releases, trout removal, declines in trout abundance due to low DO levels during 2006, and drought-induced warming (Andersen 2009; Coggins and Walters 2009). Some experimental releases, such as the November HFE in 2004, may have adversely affected rainbow trout and improved humpback chub habitat along the main channel (Korman et al. 2010). However, the March 2008 HFE may have improved rainbow trout spawning habitat quality and age-0 survival rates (Korman et al. 2011) in the Glen Canyon reach. Following this, the abundance of rainbow trout (using catch-per-unit-effort as a surrogate for abundance) in this reach was reported to be about 300% larger in 2009 than in 2007 (about 3.9 fish per minute vs. 1.3 fish per minute, respectively) (Makinster et al. 2011), and a similar increase in rainbow trout abundance between 2007 and 2009 was observed at the Little Colorado River confluence (RM 56–69) (Kennedy and Ralston 2011). The effects of HFEs on trout abundance are discussed in more detail in Section 3.5.3.4.

Predation by rainbow and brown trout at the Little Colorado River confluence has been identified as an additional mortality source affecting humpback chub survival, reproduction, and recruitment (Valdez and Ryel 1995; Marsh and Douglas 1997; Yard et al. 2011). Predation by channel catfish and black bullhead (*Ictalurus melas*) are also thought to threaten humpback chub in the Grand Canyon, particularly if warmer water conditions occur (NPS 2013e). Because of their size, adult humpback chub are less likely to be preyed on by trout; however, emergent fry, YOY, and juvenile humpback chub are susceptible to predation in the mainstem Colorado River in the vicinity of the Little Colorado River (Yard et al. 2011).

Experimental removal of nonnative brown and rainbow trout was conducted in the Colorado River in the Grand Canyon between 2003 and 2006 (see Section 3.5.3.4). Twenty-three trips to remove trout from the vicinity of the confluence of the Little Colorado River (RM 56–RM 66) resulted in the removal of more than 23,000 nonnative fish (mostly rainbow trout). During this time, the rainbow trout population in the Colorado River in the vicinity of the Little Colorado River was decreased by more than 80% (Andersen 2009). Although the estimated humpback chub abundance increased during this time (Figure 3.5-3), the relationship between trout removal at the Little Colorado River, decreases in trout abundance, and increases in humpback chub abundance are not clear; trout abundance declined throughout the mainstem Colorado River downstream of Glen Canyon Dam during the same general time frame (Coggins et al. 2011). Increased numbers of humpback chub may also be attributable to a variety of other factors, including warmer water temperatures that occurred during this time, the HFE experimental flows, or a general decrease in rainbow trout abundance throughout the Grand Canyon ecosystem (Andersen 2009; Coggins et al. 2011; also see Section 3.5.3.4).

To aid in the mechanical trout removal effort, an experimental nonnative fish suppression flow regime from Glen Canyon Dam was implemented between January and March in 2003, 2004, and 2005 (Reclamation 2011c). These flows were intended to reduce rainbow trout abundance in the Glen Canyon reach by increasing mortality of incubating life stages. While the experimental flows were successful in reducing hatching and survival of young trout, density-dependent factors compensated with higher survival and growth of the remaining fish

(Korman et al. 2005), and thus the flows were not effective in limiting trout recruitment. However, those flows differ from the trout management flows being proposed under many alternatives in this EIS. See Section 3.5.3.4 for more detailed discussions on both the nonnative fish suppression flows and mechanical trout removal.

As previously discussed, the cold water temperatures in the main channel are below the temperature needed for spawning, egg incubation, and growth of the humpback chub (as well as for most native fish) (Figure 3.5-1). Survival of humpback chub young in the mainstem is thought to be low because of cold mainstem water temperatures (Clarkson and Childs 2000; Robinson and Childs 2001), which may limit hatching success, reduce larval survival and larval and juvenile growth (Coggins and Pine 2010), reduce swimming ability, and increase predation vulnerability (Ward and Bonar 2003; Ward 2011). Water temperatures in the mainstem Colorado River have generally been elevated over the last decade (Figure 3.5-5). These temperatures are not optimal for humpback chub spawning and growth. However, juveniles can now successfully rear to adulthood in the Colorado River mainstem, and mainstem recruitment is likely contributing to the overall adult population that now appears to be stable or increasing (Yackulic et al. 2014; Figure 3.5-4).

Water temperatures below Glen Canyon Dam began increasing in 2003 as a result of drought conditions that lowered the level of Lake Powell and resulted in the release of warmer water from the dam (Andersen 2009; Andersen et al. 2010); temperatures have remained elevated relative to operations during the 1980s and 1990s due to continued drought-induced lower Lake Powell reservoir levels and somewhat due to relatively high inflow in 2008, 2009, and 2011. In 2005, maximum mainstem water temperature exceeded 15°C (59°F) at Lees Ferry and approached 18°C (64°F) in the vicinity of the Little Colorado River (RM 61), the warmest temperature at those locations since the reservoir was filled in 1980 (Figure 3.5-5). Maximum water temperature in the mainstem at Lees Ferry reached about 14°C (57°F) in 2008 (USGS 2014b), similar to temperatures in 2003 when drought effects from low Lake Powell levels began to raise Glen Canyon Dam release temperatures. In 2011, maximum mainstem water temperatures at Lees Ferry and the Little Colorado River confluence (RM 61) reached about 15°C (59°F) and 16°C (61°F), respectively (Figure 3.5-5). This warmer water appears to have benefitted the humpback chub and other native fish, but they may also have benefitted nonnative warmwater species (e.g., channel catfish, striped bass) that are more abundant farther downstream in the Grand Canyon (Andersen 2009; Coggins and Walters 2009; Kennedy and Ralston 2011).

Tribal Perspectives on Humpback Chub. The Navajo people revere all creatures within the Grand Canyon and its tributaries as sacred and unique in maintaining the balance of the natural order and natural laws. But here it is important to note that the humpback chub is one of the utmost sacred beings that dwell within the Grand Canyon (more specifically the Little Colorado River). It is mentioned extensively within oral history when the Navajo Na adin Tahi of the waterway ceremony (voyager) took his journey through the canyon on a hallowed log with the turkey that ran alongside him. It is said that the voyager encountered many dangers and monsters that attempted to stop him in his journey. The humpback chub is a product of the one Teehooltsodii (Water Monster), as they are her children, and she negotiated with Haashch cheii

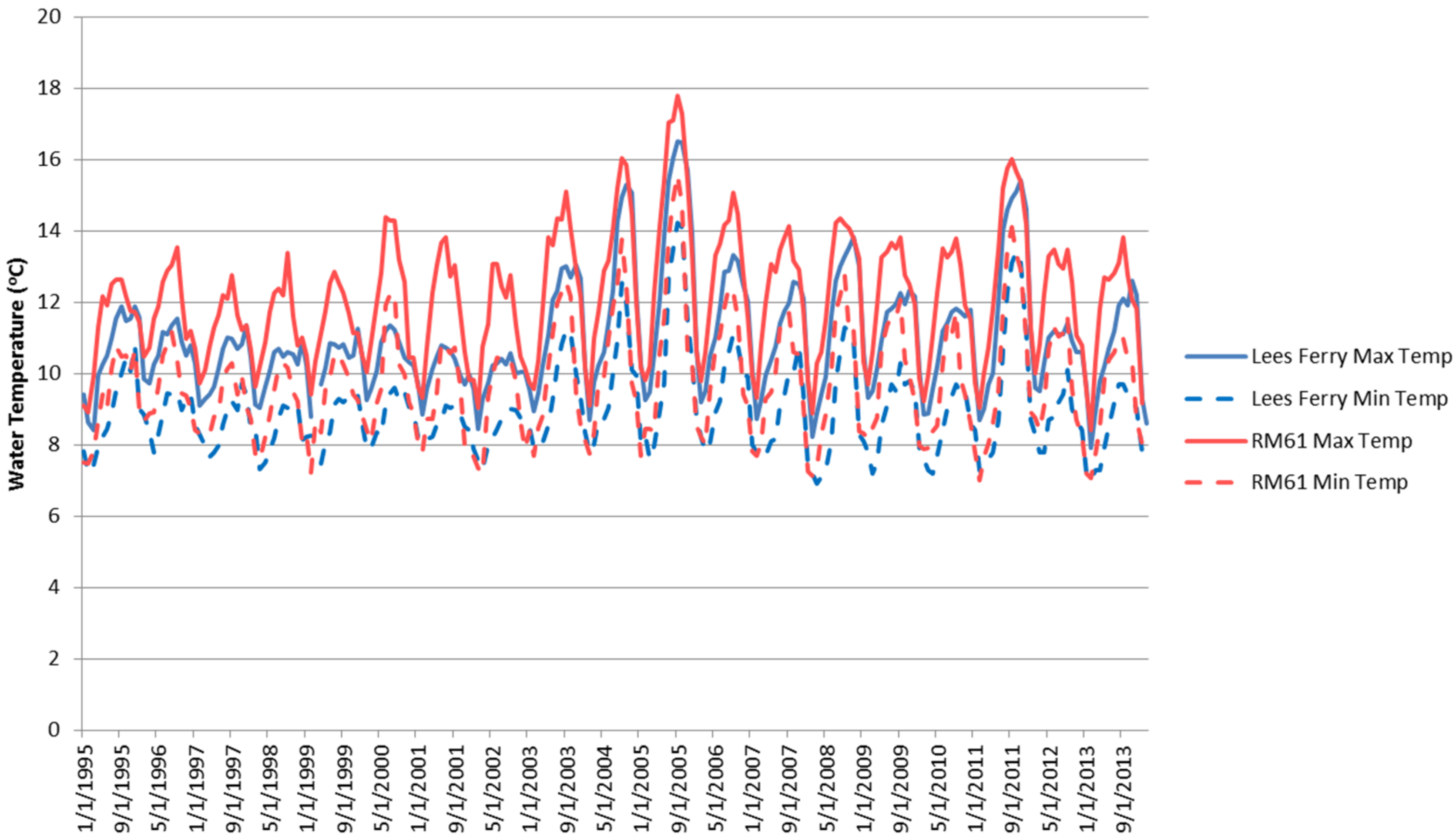

FIGURE 3.5-5 Water Temperatures at Lees Ferry and the Little Colorado River Confluence (RM 61), 1995 to Present (Source: USGS 2014b)

yaal tii (Talking God) that they would be able to stay within the Little Colorado River or Little Colorado River Confluence after she was cast out for stealing Talking God's grandchild.

Razorback Sucker

The razorback sucker is a large river sucker (Catostomidae) endemic to the Colorado River system. It is a large fish, with adults reaching lengths up to 3 ft and weighing as much as 13 lb (FWS 2002a), and may live 40 years or more (AZGFD 2002a).

Distribution and Abundance. The razorback sucker was listed as endangered in 1991 (56 FR 54957). The species is endemic to large rivers of the Colorado River Basin from Wyoming to Mexico. Currently, it occurs in the Green River, upper Colorado River, and San Juan River subbasins; the lower Colorado River between Lake Havasu and Davis Dam; Lake Mead and Lake Mohave; and tributaries of the Gila River subbasin (FWS 2002a), and Lake Powell (Francis et al. 2015). The largest remaining wild-spawned population was in Lake Mohave (Marsh et al. 2003); however, the wild fish have died from old age and the population is being supported by rearing of wild-spawned larvae in hatcheries and release of those fish to the reservoir. Within the Grand Canyon, this species historically occurred in the Colorado River from Lake Mead into Maxson Canyon (RM 252.5), with several documented captures at the Little Colorado River inflow in 1989 and 1990, and from the Paria River mouth (in 1963 and 1978, as reported in NPS 2013e). The population in Lake Mead is believed to be self-sustaining, and in 2002 was estimated to consist of about 400 adults (FWS 2002a). More recently (2009–2011), the lakewide population in Lake Mead was estimated to range from 733 to 982 fish (Shattuck et al. 2011).

Until recently, the last razorback sucker collected from the Grand Canyon (RM 39.3) was caught in 1993, and the species was considered extirpated from the Grand Canyon. However, razorback suckers and flannelmouth-razorback sucker hybrids have recently been captured from the western Grand Canyon (Bunch, Makinster et al. 2012; Bunch, Osterhoudt et al. 2012; Rogowski and Wolters 2014; Rogowski, Wolters, et al. 2015). Four fish that were sonic-tagged in Lake Mead in 2010 and 2011 were detected in the spring and summer of 2012 in GCNP up to Quartermaster Canyon (RM 260) (Kegerries and Albrecht 2012, as cited in NPS 2013e). An additional untagged adult razorback sucker was captured in GCNP near Spencer Creek (RM 246) in October 2012 (Bunch, Osterhoudt, et al. 2012), and another adult was collected in late 2013 (GCMRC 2014). Recent sampling of channel margin habitats has also documented razorback sucker larvae as far upstream as RM 179 (just upstream of Lava Falls), indicating that spawning is occurring in the mainstem river in the western Grand Canyon (Albrecht et al. 2014 [462 larvae]; Kegerries et al. 2015 [81 larvae]). Adult razorback suckers have also recently been located as far upstream as RM 184.4 near Lava Falls, and numerous adults have been documented in the western Grand Canyon, indicating that the species utilizes the Colorado River above the Lake Mead inflow area more than previously thought (Albrecht et al. 2014).

Habitat. The razorback sucker uses a variety of habitats, ranging from mainstream channels to slow backwaters of medium and large streams and rivers (AZGFD 2002a). In rivers, habitat requirements of adults in spring include deep runs, eddies, backwaters, and flooded off-channel areas; in summer, runs and pools, often in shallow water associated with submerged sandbars; and in winter, low-velocity runs, pools, and eddies (FWS 2002a). In reservoirs, adults prefer areas with water depths of 3 ft or more over sand, mud, or gravel substrates. Young require nursery areas with quiet, warm, shallow water such as tributary mouths, backwaters, and inundated floodplains along rivers, and coves or shorelines in reservoirs (FWS 2002a). Recent captures of larval razorback sucker in the western Grand Canyon found the highest density of larvae in isolated pools, which composed less than 2% of all habitat sampled (Albrecht et al. 2014). Similar results were found in 2015, when the highest catch of larval razorback sucker was found in isolated pools, followed by backwaters, which composed 2.1% and 9.1% of habitats sampled, respectively (Kegerries et al. 2015). Critical habitat was designated for this species in 1994, and includes the Colorado River and its 100-year floodplain from the confluence of the Paria River downstream to Hoover Dam (a distance of about 500 mi), including Lake Mead to full pool elevation (59 FR 13374).

Life History. Both adults and immature fish are omnivorous, feeding on algae, zooplankton, and aquatic insect larvae. In Lake Mohave, their diet has been reported to be dominated by zooplankton, diatoms, filamentous algae, and detritus (Marsh 1987).

Razorback suckers exhibit relatively fast growth the first 5 to 7 years of life, after which growth slows and possibly stops (AZGFD 2002a). Both sexes are sexually mature by age 4. Spawning in rivers occurs over bars of cobble, gravel, and sand substrates during spring runoff at widely ranging flows and at water temperatures typically greater than 14°C (57°F) (FWS 2002a). In reservoirs, spawning occurs over rocky shoals and shorelines. Temperatures for spawning, egg incubation, and growth of this species range from 14 to 25°C (57 to 77°F) (Figure 3.5-1). Hatching success is temperature dependent, with complete mortality occurring at temperatures less than 10°C (50°F); optimum temperatures for adults are around 22–25°C (72–77°F) (AZGFD 2002a). Based on back-calculation from the dates of larval collection, Kegerries et al. (2015) estimated that the onset of spawning in the Grand Canyon was in mid-February when average daily water temperatures were between 10 and 12°C (50 and 54°F). Spawning appeared to peak toward the end of March when water temperatures ranged from 12–14°C (54–57°F), although the entire spawning period was estimated to range from mid-February to July (Kegerries et al. 2015).

Historically, this species exhibited upstream migrations in spring for spawning, although current populations include groups that are sedentary and others that move extensively (Minckley et al. 1991). Adults in the Green River subbasin have been reported to move as much as 62 mi to specific areas to spawn (Tyus and Karp 1990). In Lake Mohave, individuals have been reported to move 12 to 19 mi between spring spawning and summer use areas (Mueller et al. 2000). Kegerries et al. (2015) reported that sonic-tagged razorback sucker either stayed near spawning areas or moved up to 361 km (224 mi) within the western Grand Canyon, the Colorado River inflow to Lake Mead, and throughout Lake Mead.

Factors Affecting Distribution and Abundance in the Grand Canyon. The decline of the razorback sucker throughout its range has been attributed primarily to habitat loss due to dam construction, loss of spawning and nursery habitats as a result of diking and dam operations, and alteration of flow hydrology (AZGFD 2002a). For example, the 80% reduction in the historical distribution of this species has been attributed to the construction of Hoover, Parker, Davis, and Glen Canyon Dams on the Colorado River and Flaming Gorge Dam on the Green River (Valdez et al. 2012). In addition, competition with and predation by nonnative fishes have also been identified as important factors in the decline of this species (Minckley et al. 1991; FWS 2002a). In the Grand Canyon, the decline of native fish, including razorback sucker, has been attributed in large part to an increased diversity and abundance of nonnative fishes along with the effects of Glen Canyon Dam on water temperatures, flow, and sediment (Gloss and Coggins 2005).

As described above, recent efforts to better understand the use of the western Grand Canyon by razorback sucker has revealed that the species is more widespread there than previously thought, occupies and spawns in the river from at least Lava Falls to throughout Lake Mead, and maintains a reproducing population in the project area (Albrecht et al. 2014; Kegerries et al. 2015). Currently, there is little information on the habitat use and life history needs for the species in the Grand Canyon and Lake Mead. Additional research and monitoring are needed to better understand the management implications for recovery of razorback sucker in this reach of its range (Albrecht et al. 2014).

Bluehead Sucker

The bluehead sucker is a member of the Catostomidae family. Adults may reach 12 to 18 in. in total length in large rivers but may be smaller in smaller tributaries; they may live from 6 to 8 years to as many as 20 years (Sigler and Sigler 1987; Bezzerides and Bestgen 2002; AZGFD 2003a). This species has been reported to be as large as 20 in. long in the mainstem Colorado River in Grand Canyon, with tributary fish being smaller (AZGFD 2003a). A related subspecies, the Zuni bluehead sucker, occurs in the headwaters of the Little Colorado River along with bluehead suckers that are the same subspecies as those that occur in the mainstem Colorado River (AZGFD 2002b).

Distribution and Abundance. Bluehead sucker populations are declining throughout the species' historic range, and the species has been identified as an AZ-SGCN (AZGFD 2012). The bluehead sucker is included in the Arizona statewide conservation agreement for six native fish species (AZGFD 2006a). In the Colorado River Basin, this species is found in the Colorado River and its tributaries from Lake Mead upstream into Arizona, Colorado, New Mexico, Utah, and Wyoming. This species is also found in the Snake River (Idaho and Wyoming), the Bear River (Idaho and Utah), and Weber River (Utah and Wyoming) drainages (Bezzerides and Bestgen 2002; AZGFD 2003a).

Within the Grand Canyon, the bluehead sucker occurs in the Colorado River mainstem and its tributaries, including the Little Colorado River, Clear Creek, Bright Angel Creek, Kanab

Creek, and Havasu Creek (Rinne and Magana 2002; AZGFD 2003a; Ptacek et al. 2005; NPS 2013e), and prior to 2014, in Shinumo Creek (Healy et al. 2014). Annual fish monitoring conducted between 2000 and 2009 in the Colorado River between Glen Canyon Dam and the inflow to Lake Mead show the bluehead sucker to be present in all reaches of the river (Makinster et al. 2010). This species is very rare in the upper sections of GCNP and increases in number near the Little Colorado River inflow and downstream (Bunch, Makinster et al. 2012; Bunch, Osterhoudt et al. 2012).

Abundance estimates using monitoring data and Age-Structured Mark-Recapture (ASMR) models show the abundance of age-1 (juvenile) bluehead suckers in the Grand Canyon declined from 1990 to 1995, increased from 1995 to 2003, and then declined through 2009 (Walters et al. 2012). Similar estimates for age-4 (adult) fish show abundance began increasing from the late 1990s until 2005 or 2006, after which abundance also declined. The estimated abundance of age-1 bluehead sucker has ranged from 1,000 or less to as many as 60,000 fish between 2000 and 2009 (Walters et al. 2012). Estimated abundance of age-4+ adults during this same period ranged from about 5,000 to as many as 75,000 fish. Although the bluehead sucker was likely extirpated from Shinumo Creek following fires and flooding in 2014 (Healy et al. 2014), relatively high numbers of individuals remain in the lower Colorado River between Lava Falls Rapid (RM 179) and Lake Mead (Bunch, Makinster, et al. 2012; Bunch, Osterhoudt et al. 2012). Recent sampling of the larval fish community in the western Grand Canyon between Lava Falls and Pearce Ferry collected bluehead sucker larvae throughout the study area (Albrecht et al. 2014). In this study area, the bluehead sucker was the most abundant species in the larval fish community, composing almost 40% of the total catch.

Habitat. The bluehead sucker typically inhabits large streams and may also occur in smaller streams and creeks (Sigler and Sigler 1987; AZGFD 2003a). Riverine habitats may range from cold (12°C [54°F]), clear streams to warm (28°C [82°F]), very turbid rivers. Large adults live in deep water (6 to 10 ft), while juveniles use shallower, lower velocity habitats (Bezzerides and Bestgen 2002). In clear streams, the bluehead sucker stays in deep pools and eddies during the day and moves to shallower habitats (e.g., riffles, tributary mouths) to feed at night, while in turbid waters they may use shallow areas throughout the day (Beyers et al. 2001; AZGFD 2003a). In the Grand Canyon, larval and young bluehead suckers inhabit backwater areas and other near-shore low-velocity habitats such as eddies, embayments, and isolated pools (Childs et al. 1998; AZGFD 2003a; Albrecht et al. 2014).

Life History. The bluehead sucker is an omnivorous benthic forager. It feeds by scraping algae, invertebrates, and other organic and inorganic materials off rocks and other hard surfaces (Ptacek et al. 2005). Larvae drift to backwaters and other areas of low current where they feed on diatoms, zooplankton, and dipteran larvae.

In the lower Colorado River, this species spawns in spring and summer after water temperatures exceed 16°C (61°F). Spawning in Grand Canyon tributaries occurs mid-March through June in water depths ranging from a few inches to more than 3 ft and at temperatures of 16 to 20°C (61 to 68°F) over gravel-sand and gravel-cobble substrates (AZGFD 2003a;

NPS 2013e). In Kanab Creek, spawning has been reported to occur at temperatures of 18.2–24.6°C (64.8–76.3°F) (Maddux and Kepner 1988). Smaller tributaries may provide nursery grounds for populations of large adjacent rivers (Rinne and Magana 2002).

Factors Affecting Distribution and Abundance in the Grand Canyon. As with the humpback chub, decreases in distribution and abundance of the bluehead sucker throughout its range, as well as in portions of the Colorado River and its tributaries below Glen Canyon Dam, have been attributed to two main factors: (1) habitat degradation through loss, modification, and/or fragmentation and (2) interactions with nonnative species (Gloss and Coggins 2005; Ptacek et al. 2005). Disturbance related to fire and flooding may also influence bluehead sucker distribution in tributaries. The construction and operation of Glen Canyon Dam has altered downstream temperature and flow regimes. Cold tailwaters below dams are below temperatures needed for spawning and recruitment (Rinne and Magana 2002; Walters et al. 2012). Past recruitment in the Colorado River below Glen Canyon Dam was low in the 1990s and then increased after 2000; the largest recruitment estimates coincided with brood years 2003 and 2004, when there was a sudden increase in mainstem water temperatures because of warmer releases from Glen Canyon Dam (Walters et al. 2012).

The introduction of nonnative fish has increased competition with and predation on bluehead sucker (AZGFD 2003a; Ptacek et al. 2005). Large nonnative predators such as channel catfish and trout, mid-sized fish like sunfishes, and even smaller nonnative minnows may all prey on one or more life stages of the bluehead sucker (Rinne and Magana 2002; Ptacek et al. 2005; Yard et al. 2011).

3.5.2.2 Other Native Species

Two other native fish species occur in the affected area of the Colorado River and its tributaries between Glen Canyon Dam and the inflow to Lake Mead—flannelmouth sucker and speckled dace (Table 3.5-1). Both speckled dace and flannelmouth sucker are identified as AZ-SGCN (AZGFD 2012). In addition, the flannelmouth sucker is included in the Arizona statewide conservation agreement for six native fish species (AZGFD 2006a). The flannelmouth sucker and speckled dace are discussed below.

Flannelmouth Sucker

The flannelmouth sucker is member of the sucker family (Catostomidae). It is a relatively large fish, with a maximum total length of greater than 2 ft and a maximum weight exceeding 3 lb (AZGFD 2001b; Rees et al. 2005). It is a long-lived species, living as long as 30 years (AZGFD 2001b).

Distribution and Abundance. Historically, the flannelmouth sucker ranged throughout the Colorado River Basin, in moderate to large rivers in Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming (Bezzerides and Bestgen 2002; Rees et al. 2005). Within the Grand Canyon, this species may be found in the mainstem Colorado River and its tributaries including the Little Colorado and Paria Rivers and Shinumo, Bright Angel, Kanab, and Havasu Creeks (Douglas and Marsh 1998; Weiss 1993; AZGFD 2001b; Bezzerides and Bestgen 2002). In contrast to bluehead sucker, flannelmouth sucker are only found below the barrier falls in Shinumo and Havasu Creeks. Annual monitoring conducted between 2000 and 2009 found the flannelmouth sucker to be present in all reaches of the river between Lees Ferry and the inflow to Lake Mead (Makinster et al. 2010). Abundance, across all reaches and measured as catch-per-unit-effort, has been increasing since 2000, especially since about 2004 (Makinster et al. 2010). However, abundance has been decreasing within individual reaches between RM 0 and RM 179 since about 2005, but increasing downstream of RM 179. Recent surveys of the small-bodied and larval fish communities in the western Grand Canyon (Lava Falls to Pearce Ferry) found flannelmouth sucker to be present throughout the reach, accounting for over 38% of the total larval catch in this area (Albrecht et al. 2014).

Abundance estimates using monitoring data and ASMR models show an increase in the abundance of age-1 (juvenile) and age-4 (adult) flannelmouth suckers in the Grand Canyon between 2000 and 2008 (Walters et al. 2012). Abundance of age-1 flannelmouth sucker increased from about 2,500 in 2000 to about 10,000 in 2008, while abundance of age 4+ adults increased from about 10,000 to about 25,000 for this same period (Walters et al. 2012). Other abundance estimates based on electrofishing catch-per-unit-effort for this same time period showed an increase in abundance from less than 1,000 in 2000 to about 12,000 in 2009, while the estimated abundance of age-4+ adults increased from about 2,500 in 2001 to about 31,000 in 2009 (Walters et al. 2012).

Habitat. This species prefers large to moderately large rivers. Adults may prefer deep water when not feeding (Rinne and Minckley 1991), while larvae and young are often associated with shallow, slow-moving near-shore areas such as backwaters and shoreline areas of slow runs or pools (AZGFD 2001b; Rees et al. 2005). Although it is a riverine species, in the upper Colorado River Basin the flannelmouth sucker has been collected from Flaming Gorge and Fontenelle Reservoirs. In the Colorado River in the Grand Canyon, subadults are found in eddies and runs over sand bottoms. In the Little Colorado River, adult and juvenile flannelmouth suckers use low-velocity, near-shore habitats with large amounts of cover during the daylight, and their use of faster, more exposed mid-channel habitats increases at night (Gorman 1994). Juveniles and adults may be considered habitat generalists and can be found using pool, run, and eddy habitats. Recent surveys of larval flannelmouth sucker in the western Grand Canyon (Lava Falls to Pearce Ferry) found the highest abundance of larvae in embayments, isolated pools, backwaters, and other low-velocity habitats (Albrecht et al. 2014).

Life History. The flannelmouth sucker is an omnivorous benthic feeder, foraging on invertebrates, algae, plant seeds, and organic and inorganic debris (Bezzerides and Bestgen 2002; Rees et al. 2005; Seegert et al. 2014). Larvae feed primarily on aquatic invertebrates, crustaceans, and organic debris (Childs et al. 1998). As they become juveniles and adults, their diet shifts and becomes primarily composed of benthic matter including organic debris, algae, and aquatic invertebrates (Rees et al. 2005; Seegert et al. 2014).

This species has been reported to prefer water temperatures ranging from 10 to 27°C (50 to 81°F), and is most common at about 26°C (79°F) (Sublette et al. 1990). Water temperatures reported during spawning activity range from 6 to 18.5°C (43 to 65°F), but are usually above 14°C (57.2°F) (Bezzerides and Bestgen 2002). In the lower Colorado River Basin, flannelmouth sucker spawning typically occurs in March and April (Bezzerides and Bestgen 2002). Water temperature has been suggested as a primary cue for spawning in other parts of this species range, but it does not appear to provide a spawning cue in the Grand Canyon where relatively synchronized spawning has been reported among sucker stocks from creeks with different temperature and flow regimes (Weiss 1993; Weiss et al. 1998). In the Paria River, the timing of spawning has been correlated with the receding limb of the hydrograph (Weiss 1993).

In the Grand Canyon, flannelmouth suckers apparently spawn at only a limited number of tributaries, and fish may move considerable distances to reach spawning sites (Douglas and Marsh 1998; Weiss et al. 1998; Douglas and Douglas 2000). Tributary spawning in the Grand Canyon may be timed to take advantage of warm, ponded conditions at tributary mouths that occur during high flows in the mainstem Colorado River (Bezzerides and Bestgen 2002).

Body condition of flannelmouth sucker is variable throughout the Grand Canyon, but is greatest at intermediate distances from Glen Canyon Dam, possibly because of the increased number of warmwater tributaries in this reach (Paukert and Rogers 2004). Mean condition peaks during the prespawn and spawning periods and is lowest in summer and fall (McKinney et al. 1999; Paukert and Rogers 2004). Sucker condition in September was positively correlated with Glen Canyon discharge during summer (June–August), possibly due to an increased euphotic zone and greater macroinvertebrate abundance observed during higher water flows (Paukert and Rogers 2004).

Factors Affecting Distribution and Abundance in the Grand Canyon. Flannelmouth sucker populations have declined throughout the species' historic range; in the lower Colorado River, this decline has been attributed primarily to flow manipulation and water development projects (Rees et al. 2005). Coldwater releases from Glen Canyon Dam have altered the thermal regime of the main channel of the Colorado River, which for larvae may result in slow growth, delayed transition to the juvenile stage, and possibly higher mortality (Rees et al. 2005).

In the cold tailwaters below Glen Canyon Dam, water temperatures (8 to 12°C [46 to 54°F]) are at the lower end of or below those needed for spawning and recruitment of flannelmouth suckers; even though water temperatures do warm downstream, the cold summer water temperatures have been suggested as a major factor limiting survival of YOY, recruitment, and condition of this species in the main channel (Thieme et al. 2001; Walters et al. 2012). Past recruitment in the Colorado River below Glen Canyon Dam was low in the 1990s and then increased after 2000; the largest recruitment estimates were for 2003 and 2004, when there was a sudden increase in mainstem water temperatures because of warmer releases from Glen Canyon Dam (Walters et al. 2012). Paukert and Rogers (2004) reported post-spawn condition of flannelmouth sucker below Glen Canyon Dam to be variable, but were typically greatest in the vicinity of warmwater tributaries such as the Paria River, the Little Colorado River, and Bright Angel Creek.

The flannelmouth sucker in the Grand Canyon may also be experiencing competition with and predation by nonnative species that are in the system (Rees et al. 2005). Potential competitors include species such as the channel catfish and the common carp. Potential predators include rainbow and brown trout and red shiner. Rainbow and brown trout diet sampling found enough juvenile flannelmouth suckers in trout stomachs to account for as much as 50% of the estimated annual mortality rates of juveniles (Yard et al. 2011; Walters et al. 2012). The ability of flannelmouth sucker to escape trout predation is also inhibited by colder water temperatures (Ward and Bonar 2003).

Speckled Dace

The speckled dace is native to the western United States and is one of eight species in the genus *Rhinichthys*. It is a small fish, typically less than 76 mm in length, and has a relatively short lifespan of about 3 years (Sigler and Sigler 1987).

Distribution and Abundance. This species is native to all major western drainages from the Columbia and Colorado Rivers south to Mexico (AZGFD 2002c). Within the Grand Canyon, this species occurs within the mainstem Colorado River and its tributaries, including the Little Colorado River (Robinson et al. 1995; Ward and Persons 2006; Makinster et al. 2010). Long-term fish monitoring of the Colorado River below Glen Canyon Dam since 2000 shows the speckled dace to be the third most common fish species (and most common native species) in the river between Glen Canyon Dam and the Lake Mead inflow, and it was captured most commonly in the western Grand Canyon and the inflow to Lake Mead (Makinster et al. 2010).

Habitat. The speckled dace may be found in a variety of habitats, ranging from cold, fast-flowing mountain streams to warm, intermittent desert streams and springs. Where found, it occurs in rocky runs, riffles, and pools of headwater streams, creeks, and small to medium rivers, typically in waters with depths less than 1.6 ft (AZGFD 2002c); it rarely occurs in lakes (Page and Burr 1991).

Life History. The speckled dace is an omnivorous bottom feeder, feeding primarily on insect larvae and other invertebrates, as well as algae and fish eggs (Seegert et al. 2014). Its young are mid-water plankton feeders (Sigler and Sigler 1987). This dace spawns twice, once in spring and again in late summer (AZGFD 2002c). Spawning occurs over gravel in areas prepared by the male.

Factors Affecting Distribution and Abundance in the Grand Canyon. The speckled dace is a widespread and abundant species in western North America (AZGFD 2002c). Although this species is the most widely distributed and abundant native fish species in the Grand Canyon ecosystem, its abundance and distribution could be affected by many of the same factors that affect the abundance and distribution of the other native fish in the ecosystem, namely altered temperature, flow, and sediment regimes and predation by nonnative fish (AZGFD 2002c; Gloss and Coggins 2005).

3.5.3 Nonnative Fish

As many as 25 nonnative species of fish have been reported with some regularity from Lakes Powell and Mead and the Colorado River and its tributaries between these reservoirs (Valdez and Speas 2007; Coggins et al. 2011; Reclamation 2011e; Table 3.5-2). Most of these introduced species are native to other basins in North America but not the Colorado River Basin, and a few are species from outside North America. These fish occur in the Grand Canyon as a result of intentional and unintentional introductions, especially into Lakes Powell and Mead. A number of species were stocked as game fish and others as forage fish for the stocked game fish. Among these nonnative species, three are largely restricted to Lake Powell and/or Lake Mead, and occur in the Colorado River and its tributaries below Glen Canyon Dam only occasionally; these species are black crappie (*Pomoxis nigromaculatus*), bluegill (*Lepomis macrochirus*), and gizzard shad (*Dorosoma cepedianum*) (Table 3.5-2). Another four species—northern pike (*Esox lucius*), threadfin shad (*Dorosoma petenense*), rock bass (*Ambloplites rupestris*), and yellow perch (*Perca flavescens*)—are largely restricted to the upper Little Colorado River watershed (Ward and Persons 2006; Valdez and Speas 2007). The remaining 18 species have been reported from the mainstem Colorado River and/or its tributaries between Glen Canyon Dam and the inflow to Lake Mead. New introductions of nonnative fish species continue to be documented throughout the Colorado River Basin, and new introductions are likely to occur (Martinez et al. 2014).

Common nonnative fish species in Lake Powell include striped bass, smallmouth and largemouth bass, walleye (*Sander vitreus*), bluegill, green sunfish (*Lepomis cyanellus*), common carp, and channel catfish. Species that occur in the reservoir, but that are mainly associated with tributaries and inflow areas, include fathead minnow, mosquitofish (*Gambusia affinis*), red shiner, and plains killifish (NPS 1996; Reclamation 2007a). Largemouth bass (*Micropterus salmoides*) and black crappie populations were stocked initially and, following successful establishment, these were the principal target species in the sport fisheries for many years. Both species have declined in recent years due to a lack of habitat structure for young fish. Filling and fluctuation of the reservoir resulted in changing habitat that eliminated most of the vegetation favored by many species (Reclamation 2007a). Smallmouth bass (*Micropterus dolomieu*) and striped bass (*Morone saxatilis*) were introduced following these changes in habitat structure and are presently the dominant predators in the reservoir (Reclamation 2007a). Threadfin shad were introduced to provide an additional forage base and quickly became the predominant prey species (NPS 1996). Gizzard shad were accidentally introduced into Morgan Reservoir in the San Juan River drainage in 1996 and subsequently proliferated in Lake Powell (Mueller and Brooks 2004; Vatland and Budy 2007).

TABLE 3.5-2 Nonnative Fish Found in the Colorado River through Glen and Grand Canyons

Species	Native Origin	Occurrence in Project Area
Coldwater Species		
Rainbow trout (*Oncorhynchus mykiss*)	North America	Colorado River from Glen Canyon Dam to Havasu Creek; abundant from Glen Canyon Dam to Lees Ferry; abundance decreases through Marble Canyon to the confluence with the Little Colorado River, although substantial numbers may still be present in some locations in some years; locally abundant at the Little Colorado River confluence and some locations through Grand Canyon in some years.
Brown trout (*Salmo trutta*)	Europe	Colorado River from Glen Canyon Dam to Kanab Creek; locally abundant near confluence with Bright Angel Creek, the Little Colorado River, and some other tributaries.
Warmwater Species		
Black bullhead (*Ictalurus melas*)	North America	Lake Powell, Lake Mead; Colorado River at the Little Colorado River; Colorado River downstream of Diamond Creek; generally absent from Glen Canyon, rare in Marble Canyon, and locally common in some areas of the Grand Canyon.
Yellow bullhead (*Ameiurus natalis*)	North America	Colorado River downstream of the Little Colorado River to Lake Mead; Little Colorado River, abundance presumed similar to that of black bullhead.
Channel catfish (*Ictalurus punctatus*)	North America	Lake Powell, Lake Mead, Colorado River from Marble Canyon to Lake Mead; generally absent from Glen Canyon, rare in Marble Canyon, and numerous in the Grand Canyon.
Green sunfish (*Lepomis cyanellus*)	North America	Lake Powell; Lake Mead; Kanab Creek; discovered in abundance in a slough located just downstream of Glen Canyon Dam in 2015 (eradication efforts conducted); generally absent from Glen Canyon and Marble Canyon; rare in the Grand Canyon.
Bluegill (*Lepomis macrochirus*)	North America	Lake Powell, Lake Mead; abundance presumed similar to that identified for green sunfish.
Largemouth bass (*Micropterus salmoides*)	North America	Lake Powell; Kanab Creek; Lake Mead to Maxson Canyon; generally absent from Glen Canyon and Marble Canyon; rare in the Grand Canyon.
Smallmouth bass (*Micropterus dolomieu*)	North America	Lake Powell; Colorado River at the Little Colorado River, below Glen Canyon Dam; rare from Glen Canyon through the Grand Canyon.

TABLE 3.5-2 (Cont.)

Species	Native Origin	Occurrence in Project Area
Warmwater Species (Cont.)		
Rock bass (*Ambloplites rupestris*)	North America	Lake Powell; Lake Mead; upper Little Colorado River watershed.
Black crappie (*Pomoxis nigromaculatus*)	North America	Lake Powell; Lake Mead; generally absent from Glen Canyon, Marble Canyon, and Grand Canyon.
Fathead minnow (*Pimephales promelas*)	North America	Colorado River from the Paria River confluence to Lake Mead; generally absent from Glen Canyon and Marble Canyon; locally common in some areas of the Grand Canyon.
Golden shiner (*Notemigonus crysoleucus*)	North America	Colorado River from Glen Canyon to Separation Canyon; Kanab Creek; generally rare throughout Glen Canyon, Marble Canyon, and the Grand Canyon.
Redside shiner (*Richardsonius balteatus*)	North America	Lake Powell; Colorado River at the Little Colorado River; generally rare throughout Glen Canyon, Marble Canyon, and Grand Canyon.
Red shiner (*Cyprinella lutrensis*)	North America	Colorado River at the Little Colorado River; Colorado River from Bridge Canyon to Lake Mead.
Common carp (*Cyprinus carpio*)	Eurasia	Lake Powell, Lake Mead, Colorado River from Glen Canyon Dam to Lake Mead.
Goldfish (*Carassius auratus*)	Eurasia	Lake Powell; Lake Mead; upper Little Colorado River watershed.
Plains killifish (*Fundulus zebrinus*)	North America	Little Colorado River; Colorado River from Little Colorado River confluence to Lake Mead; generally absent from Glen Canyon and Marble Canyon; locally common in some areas of the Grand Canyon.
Mosquitofish (*Gambusia affinis*)	North America	Lake Powell; Colorado River from Separation Canyon to Lake Mead; generally absent from Glen Canyon and Marble Canyon; locally common in some areas of the Grand Canyon.
Walleye (*Stizostedion vitreum*)	North America	Lake Powell; Colorado River from Lava Falls to Lake Mead; generally rare throughout Glen Canyon (but consistently observed during electrofishing surveys), Marble Canyon, and the Grand Canyon.
Yellow perch (*Perca flavesens*)	North America	Lake Powell; Lake Mead; upper Little Colorado River watershed.

TABLE 3.5-2 (Cont.)

Species	Native Origin	Occurrence in Project Area
Warmwater Species (Cont.)		
Striped bass (*Morone saxatilis*)	North America	Lake Powell; Colorado River from Havasu Creek to Lake Mead; generally rare throughout Glen Canyon, Marble Canyon, and the Grand Canyon.
Northern pike (*Esox lucius*)	North America	Lake Powell; Lake Mead; upper Little Colorado River watershed.
Gizzard shad (*Dorosoma cepedianum*)	North America	Lake Powell; generally absent from Glen Canyon, Marble Canyon, and the Grand Canyon.
Threadfin shad (*Dorosoma petenense*)	North America	Lake Powell; Lake Mead; Colorado River from Glen Canyon to Separation Canyon; Upper Little Colorado River watershed; generally rare in Glen Canyon, Marble Canyon, and the Grand Canyon.

Sources: Holden and Stalnaker (1975); Gloss and Coggins (2005); Valdez and Speas (2007); Coggins et al. (2011); Reclamation (2011e).

Common nonnative fish species present in Lake Mead include striped bass, largemouth bass, red shiner, common carp, threadfin shad, and mosquitofish. The sport fishery in Lake Mead is primarily for striped bass and largemouth bass, although catfish species and hatchery-reared rainbow trout are also targeted by some anglers (Reclamation 2007a). As with Lake Powell, nonnative fish species present in Lake Mead were established through intentional and unintentional introductions.

The coldwater releases from Glen Canyon Dam result in river temperatures that are substantially cooler in summer and fall than those that occurred prior to construction of the dam. During periods of the year with warmer air temperatures, water temperatures gradually warm with downstream distance from the dam. These low water temperatures generally do not support native fish reproduction in the mainstem, and largely restrict native fish spawning to warmwater tributaries (Vernieu et al. 2005; Kennedy and Ralston 2011). Cold water similarly limits growth rates and reproduction for many of the warmwater nonnative fishes present in the mainstem (Clarkson and Childs 2000). However, low reservoir elevations since 2003 have resulted in release temperatures as high as 16°C (61°F) in some years. Table 3.5-3 presents average recorded water temperatures for various locations downstream of Glen Canyon Dam from 2006 to 2009.

The nonnative fish community changes in response to temperature and turbidity gradients in the mainstem (Makinster et al. 2010). In general, the reaches of the river just downstream of Glen Canyon Dam are dominated by coldwater nonnative species while downstream reaches through the Grand Canyon are currently dominated by native species, although substantial

TABLE 3.5-3 Mean Water Temperature and Turbidity for Selected Sites in the Colorado River Mainstem from 2006 to 2009

Mainstem River Location	Mean Water Temperature (°C±SD [°F±SD])	Turbidity (NTU)[a]
Lees Ferry, RM 0	10.4 ±1.5 (50.7 ±2.7)	2 ±10.5
Fence Fault, RM 30	10.7 ±1.5 (51.3 ±2.7)	50 ±347
Upstream Little Colorado River Confluence, RM 61	11.3 ±1.7 (52.3 ±3.0)	71 ±478
Phantom Ranch, RM 88	12.0 ±2 (53.5 ±3.6)	225 ±672
Diamond Creek Vicinity, RM 225	13.8 ±3.1 (56.9 ±5.5)	347 ±1,070

[a] NTU = nephelometric turbidity units. As NTU increases, water clarity decreases.

Source: Kennedy and Ralston (2011).

numbers of warmwater nonnative species are also present (Makinster et al. 2010). The water temperatures in the Glen Canyon reach are suitable (although colder than optimal) for rainbow trout spawning and growth (McKinney, Speas, et al. 2001). In the reach of cool, clear water between the dam and the Little Colorado River, the productivity of the aquatic food web (Section 3.5.1) is driven by microscopic algae (Angradi 1994; Shannon et al. 1994), invertebrate biomass is higher than in reaches farther downstream (Stevens, Shannon, et al. 1997), and rainbow trout (a visual sight feeder) is the dominant fish species (Makinster et al. 2010). As water temperature and turbidity increase downstream of the Little Colorado River confluence, nonnative warmwater fish species such as the common carp, red shiner, and several species of catfish increase in number (Makinster et al. 2010). The warmer water temperatures provide suitable conditions for spawning and growth for many of the warmwater nonnative species, many of which are benthic feeders adapted to foraging in turbid conditions (Gloss and Coggins 2005).

In addition, the annual distribution of nonnative fishes in the lower portions of the Grand Canyon may also be influenced by the elevation of Lake Mead. As the elevation of Lake Mead rises, lake-like conditions suitable for many of the warmwater nonnative fishes will temporarily extend farther upstream into the lower portion of the Grand Canyon.

More detailed information on coldwater and warmwater nonnative fish species is provided in the next two sections.

3.5.3.1 Coldwater Nonnative Species

Brown and rainbow trout make up the coldwater nonnative fish community of the Colorado River between Glen Canyon Dam and the inflow to Lake Mead (Figure 3.5-1). The rainbow trout is common in the Glen Canyon reach and in the mainstem Colorado River between the confluence with the Paria River and the confluence with the Little Colorado River

(Makinster et al. 2010; Reclamation 2011e). Smaller numbers are found associated with tributaries, including Bright Angel Creek, Shinumo Creek, Deer Creek, Tapeats Creek, Kanab Creek, and Havasu Creek (Reclamation 2011e). Brown trout are found primarily in and near Bright Angel Creek, which supports a spawning population (Reclamation 2011e), but they are also found throughout the upper reaches of the river corridor, including in Glen Canyon.

Rainbow Trout

The rainbow trout is very common in the reach of the mainstem Colorado from Glen Canyon Dam to the Paria River, and this population serves as the principal basis for the trout fishery. This species is also found in relatively high abundance in Marble Canyon between the Paria River and the confluence of the Colorado River with the Little Colorado River (Makinster et al. 2010; Reclamation 2011e). Downstream of the Little Colorado River confluence, smaller numbers of rainbow trout are found in localized aggregations associated with some tributaries.

Rainbow trout were initially introduced in the Grand Canyon region through stocking of tributaries such as Bright Angel Creek during the 1920s. Additional introductions of rainbow trout were made downstream of Glen Canyon Dam in 1964 following completion of dam construction. Prior to 1991, the population was maintained through annual stocking, and stocking continued through 1998 (Makinster et al. 2011). Since that time, the Glen Canyon rainbow trout fishery has been maintained through natural reproduction of rainbow trout rather than through stocking, and, with the exception of localized spawning in some downstream tributaries, most of the rainbow trout production in the Colorado River downstream of Glen Canyon Dam occurs within the Glen Canyon reach. Collections of YOY rainbow trout during recent surveys in the vicinity of the Little Colorado River suggest that some successful spawning may be occurring in or near the Little Colorado River. Standardized annual monitoring of the population of rainbow trout in the 15-mi reach of the Colorado River between Glen Canyon Dam and Lees Ferry began in 1991. Based on catches of rainbow trout during annual monitoring surveys, the abundance of rainbow trout in Glen Canyon generally increased over the period from 1991 to 1997, remained at high levels until approximately 2001, and then declined to low levels by 2007 (Figure 3.5-6). From 2008 through 2010, the relative abundance of rainbow trout in the Glen Canyon reach again increased to near historic high levels. Relative abundance reached all-time high levels in water years 2011 and 2012, followed by a decline in water year 2013 consistent with previous high abundance estimates (AZGFD data as reported in GCMRC 2014; Figure 3.5-6).

Rainbow trout recruitment and population size within the Glen Canyon reach appear to be largely driven by dam operations (AZGFD 1996; McKinney et al. 1999; McKinney, Speas, et al. 2001; Makinster et al. 2011; Wright and Kennedy 2011; Korman, Kaplinski et al. 2011; Kormon et al. 2012). McKinney et al. (1999) attributed the increase in abundance from 1991 to 1997 to increased minimum flows and reduced fluctuations in daily discharges resulting from implementation of interim flows between 1991 and 1996 and adoption of the current modified low fluctuating flow regime in 1996. The decline in abundance from 2001 to 2007 has been attributed to the combined influence of increased trout metabolic demands

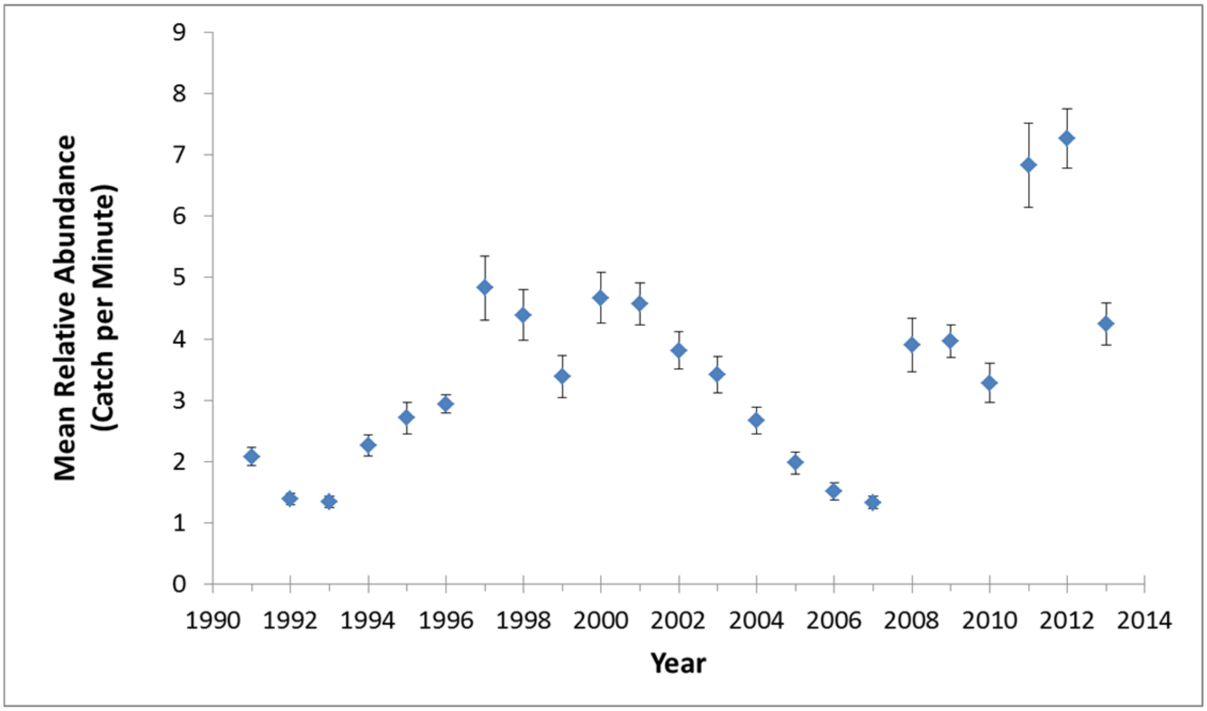

FIGURE 3.5-6 Mean (±2 SE) Electrofishing Catch Rates of Rainbow Trout in the Glen Canyon Reach, 1991–2013 (Source: Persons 2014)

due to warmer water releases from Glen Canyon Dam during that period, together with a static or declining food base, periodic DO deficiencies, and high numbers of the invasive New Zealand mudsnail, which serves as a poor food source (Cross et al. 2011). A similar decline in rainbow trout abundance below the Paria River was observed during the 2001 to 2007 time period (Makinster et al. 2010). Increases in recruitment levels and the levels of trout abundance in the Glen Canyon reach during 2008 and 2009 are believed to be due to improved habitat conditions and survival rates for YOY rainbow trout resulting from the HFE that occurred in March of 2008 (Makinster et al. 2011). Korman et al. (2012) also found that recruitment of rainbow trout in Glen Canyon was positively and strongly correlated with annual flow volume and reduced hourly flow variation, and also that recruitment increased after two of three high-flow releases related to the implementation of equalization flows. The abundance of rainbow trout within the Glen Canyon reach affects the condition (a measure of the weight-length relationship, or "plumpness") of rainbow trout in the population, with the condition generally being inversely related to the relative abundance of rainbow trout within the reach (Makinster et al. 2011). Thus, it has generally been observed that as the relative abundance of trout within the reach increases, the condition of trout within the reach declines; as condition falls lower, it is anticipated that survival and recruitment to the population would be affected.

Rainbow trout in Glen, Marble, and Grand Canyons are considered exposed to whirling disease. Whirling disease infects only salmon and trout species, and is caused by *Myxobolus cerebralis*, a myxozoan parasite introduced to North America from Europe in the 1950s. Whirling disease was initially detected in Glen Canyon in 2007 (Makinster 2007). Twenty-two percent of rainbow trout samples collected from Glen Canyon in 2011 were found to be infected with whirling disease. The presence of whirling disease has raised concerns regarding the potential to spread whirling disease to unaffected waters and watersheds through live removal and relocation of rainbow trout associated with the Nonnative Fish Control Environmental Assessment (EA) (Reclamation 2011e). It is anticipated that there is a low risk of spreading whirling disease as a consequence of conducting experimental floods as part of the High-Flow Experiment EA (Reclamation 2011d; VanderKooi 2012). The parasite is already present downstream from Glen Canyon Dam, and no barriers exist to prevent infected rainbow trout from moving into Marble and Grand Canyons. It is likely that HFEs will result in a decrease in the prevalence and severity of infections through reductions in the abundance of the intermediate host, the oligochaete worm *Tubifex tubifex*, and its preferred habitat of fine sediment and organic matter (VanderKooi 2012).

Because of the potential for trout to compete with and prey on native fish (Gloss and Coggins 2005; Yard et al. 2011; Whiting et al. 2014), the numbers of trout that leave the Glen Canyon reach and move to downstream locations is of potential concern. In particular, there is interest in limiting the numbers of trout that would enter the reach of the Colorado River in the vicinity of the confluence with the Little Colorado River because of the potential for negative effects on the endangered humpback chub population (Gloss and Coggins 2005; Yard et al. 2011). Data suggest that the numbers of trout that emigrate downstream from the Glen Canyon reach may largely be driven by the abundance of trout within the Glen Canyon reach. An increase in rainbow trout in the Little Colorado River reach after 2006 has been attributed to the increased survival and growth of young trout in the Glen Canyon reach following the March 2008 HFE (Wright and Kennedy 2011). The largest increases in trout abundance in both the Glen Canyon reach and the vicinity of the confluence with the Little Colorado River were seen after the 2011 equalization flows (Figure 3.5-6). It has been suggested that the 2008 HFE may have improved conditions for spawning and egg incubation of rainbow trout in the Glen Canyon reach by flushing fine sediment from spawning gravels and may have improved the survival of young trout by increasing the production and availability of invertebrates that serve as food for trout (Korman et al. 2010; Rosi-Marshall et al. 2010; see Section 3.5.1 for background information on the aquatic food base). Modeling conducted by Korman et al. (2012) suggests that 70% or more of the variation in the rates of rainbow trout emigration from the Glen Canyon reach could be explained by variation in recruitment levels in the Glen Canyon reach. Regardless, higher recruitment does not necessarily result in greater levels of emigration and there are years in which recruitment levels in the Glen Canyon reach were relatively high but emigration into Marble Canyon was not (e.g., following the HFE in 2012; Korman et al. 2012). In addition to emigration of trout to the Little Colorado River reach, recent captures of YOY trout upstream of the Little Colorado River confluence suggest that there may be some limited amount of spawning in lower Marble Canyon. Efforts to control nonnative fish in the Little Colorado River reach using flow manipulation to limit recruitment in Glen Canyon and mechanical removal in the Little Colorado River reach itself are described in Section 3.5.3.4.

Brown Trout

As with rainbow trout, brown trout are not native to the Colorado River and were stocked in Grand Canyon in the first half of the 1900s. Brown trout are no longer stocked in the Colorado River downstream of Glen Canyon Dam and are now found primarily in and near Bright Angel Creek, which supports a naturally spawning population (Reclamation 2011e). Unlike rainbow trout, brown trout are not susceptible to infestations of whirling disease. A trout control project, using a combination of a fish weir trap and electrofishing to benefit native species in Bright Angel Creek and endangered humpback chub in the Colorado River, was implemented by the NPS during winters 2006–2007, 2010–2011, 2011–2012, 2012–2013, 2013–2014, and 2014–2015 under the 2006 and 2013 EAs and a Finding of No Significant Impact (FONSI; NPS 2006c, 2013d).

Overall, the abundance (based on electrofishing surveys) of brown trout in the Colorado River between Lees Ferry and Lake Mead declined from 2000 to 2006; abundance may have increased somewhat between 2007 and 2009 (Figure 3.5-7; Makinster et al. 2010). Because spawning by brown trout in the Grand Canyon occurs primarily in tributaries (e.g., Bright Angel Creek and Shinumo Creek), recruitment rates may be less affected by conditions in the mainstem than recruitment rates of rainbow trout. However, recent increases in brown trout recruitment in 2014–2015 have occurred in the Lees Ferry reach of the Colorado River in Glen Canyon (Stewart 2016). Brown trout were observed to be spawning near the 4-mi bar in Glen Canyon during the fall of 2014, and an increase in age-1 brown trout, likely as a result of spawning and recruitment in 2014, was observed in 2015 (Korman et al. 2015). Spawning of brown trout was also observed during October and November of 2015 near the 4-mi bar in Glen Canyon (Korman et al. 2015). It is unclear if flow operations, including recent fall HFEs, caused an increase in brown trout in recent years.

Some brown trout captured in Bright Angel Creek were originally tagged in other parts of the Colorado River, as much as 25 mi from Bright Angel Creek (Reclamation 2011e). Small numbers of brown trout are also found in other locations within the Grand Canyon, including in the vicinity of the Little Colorado River confluence and in Glen Canyon. An indication of the relative abundance of brown and rainbow trout in the vicinity of the Little Colorado River is provided by the numbers captured using electrofishing during trout removal efforts. Of 23,000 nonnative fish captured as part of removal efforts from 2003 to 2006, 19,020 were rainbow trout and 470 were brown trout (Reclamation 2011e). All brown trout captured during these efforts were removed from the river.

Although the number of brown trout is small relative to rainbow trout, Yard et al. (2011) found that on an individual basis, the brown trout is a more active predator on native fish in the Colorado River than rainbow trout (see Section 3.5.3.3). Yard et al. (2011) also found a significant positive correlation between temperature and the levels of piscivory by brown trout. Other studies have indicated that water temperature may influence the susceptibility of native fish to predation from brown and rainbow trout in different ways. For example, while the incidence of predation attempts increased, the success of predation of rainbow trout on YOY humpback chub decreased as temperatures increased from 10°C to 20°C (50°F to 68°F)

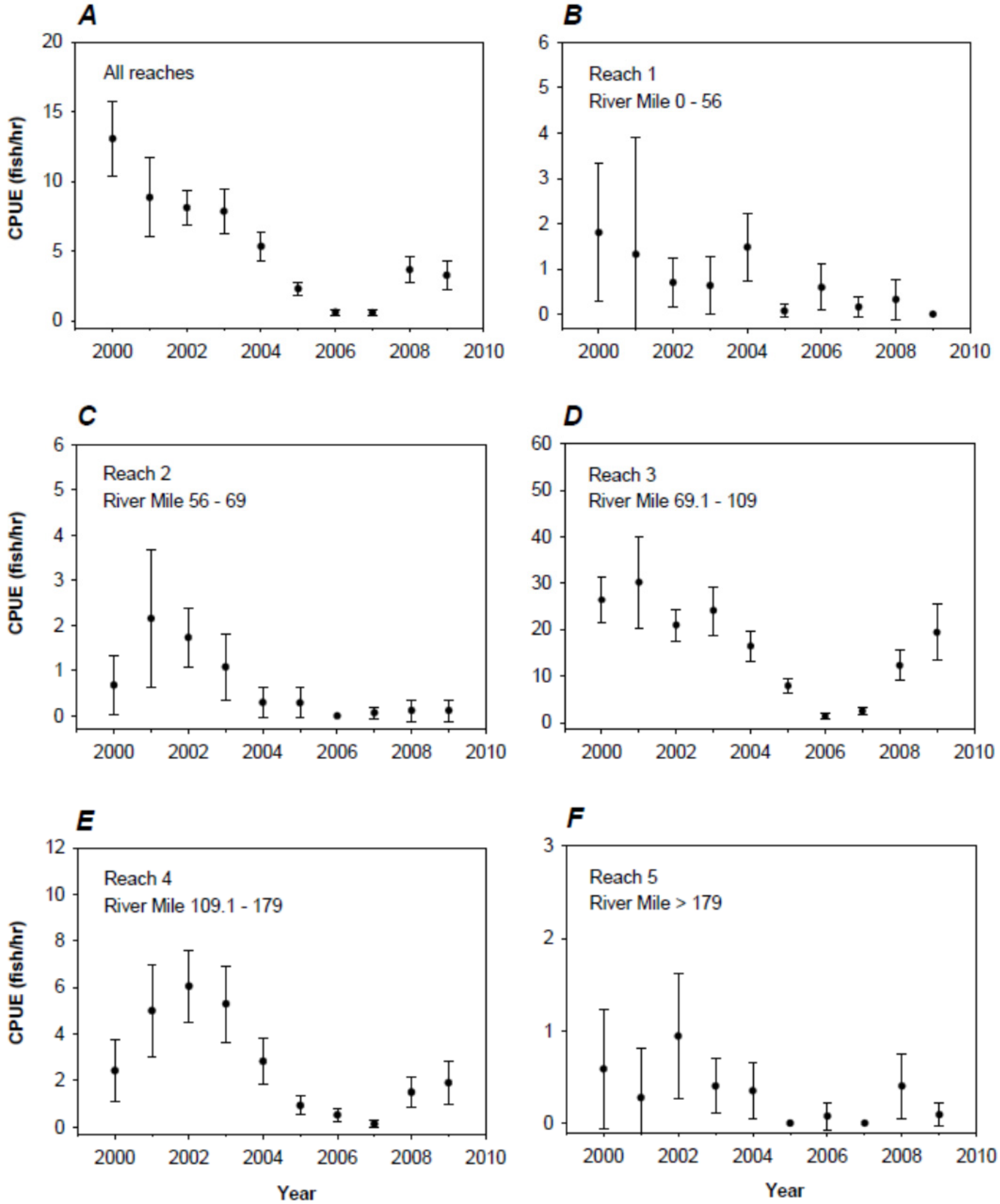

FIGURE 3.5-7 Mean (±2 SE) Electrofishing Catch Rates of Brown Trout in the Colorado River between Lees Ferry and Lake Mead, 2000–2009 (Note differences in scale among graphs A–F.) (Source: Makinster et al. 2010)

(Ward 2011). In contrast, the success of predation by brown trout did not change significantly over the same temperature range (Ward 2011).

3.5.3.2 Warmwater Nonnative Species

Surveys of the Colorado River and its tributaries between Glen Canyon Dam and the inflow to Lake Mead, as well as experimental fish removal studies, indicate the presence of 17 nonnative warmwater fish species (Trammell and Valdez 2003; Ackerman et al. 2006; Makinster et al. 2010; Coggins et al. 2011; Albrecht et al. 2014) (Table 3.5-2). Among the species collected, the common carp, fathead minnow, and red shiner are generally the most common warmwater species in the mainstem and tributaries (Rogers and Makinster 2006; Ward and Rogers 2006; Ackerman et al. 2006; Makinster et al. 2010; Coggins et al. 2011). Smaller warmwater nonnative species, such as fathead minnow, red shiner, plains killifish, and bullhead, are primarily found in tributaries, especially in the Little Colorado River, but may also be found in the mainstem below the Little Colorado River confluence (Johnstone and Lauretta 2007).

Warmwater nonnative species have been collected in low numbers and only sporadically in the Glen Canyon reach; species collected include the common carp, channel catfish, and fathead minnow (Johnstone and Lauretta 2007; Ackerman 2008). Other species collected from this reach include green sunfish, smallmouth bass, striped bass, redside shiner, golden shiner, and walleye (FWS 2008). During July 2015, a large, reproducing population of green sunfish was discovered in a slough at RM 12, approximately 3 mi downstream of Glen Canyon Dam. Neither the source nor mechanism of introduction for some of these species (e.g., green sunfish, smallmouth bass) into the Glen Canyon reach is known with certainty; however, the nearest source for a number of these species is Lake Powell.

Warmwater nonnative species collected from the mainstem Colorado River in the vicinity of the Little Colorado River confluence include smallmouth and striped bass, green sunfish, black and yellow bullhead, red shiner, and plains killifish (Trammell and Valdez 2003; Johnstone and Lauretta 2007; FWS 2008).

Based on surveys conducted below Diamond Creek (RM 226–276.5) in 2005, the most abundant nonnative fish species included red shiner, mosquitofish, channel catfish, and common carp (Ackerman et al. 2006). Albrecht et al. (2014) reported that native fishes composed approximately 98% of the total age-0 catch during 2014 surveys and dominated the total number of small-bodied fish captured during 2013–2014 surveys in the lower Grand Canyon (Lava Falls to Pearce Ferry); bluehead sucker, flannelmouth sucker, and speckled dace were the most common native species collected. Eight nonnative species were captured during 2013–2014 surveys, including brown trout, rainbow trout, common carp, channel catfish, fathead minnow, plains killifish, western mosquitofish, and red shiner (Albrecht et al. 2014). Bridge Canyon Rapid (RM 235.1) may provide a natural impediment to the upstream movement of many of the nonnative fish except striped bass, walleye, and channel catfish (Valdez and Leibfried 1999; Reclamation 2011a).

The Little Colorado River may represent a source for some nonnative fishes found in the mainstem Colorado River (Stone et al. 2007). As many as 20 species of warmwater nonnative fishes have been reported from the Little Colorado River watershed (Table 3.5-4). Warmwater species collected from the Little Colorado River below Chute Falls include common carp, red shiner, fathead minnow, plains killifish, black bullhead, and channel catfish (Table 3.5-3) (Ward and Persons 2006; FWS 2008). Standardized monitoring from 1987 to 2005 found that nonnative warmwater fish generally compose only a small percentage of the fish collected from the Little Colorado River, typically accounting for less than 10% of the total fish catch in any single year (Ward and Persons 2006). Six species of warmwater nonnative fish (common carp, fathead minnow, red shiner, channel catfish, yellow bullhead, and plains killifish) are known to reproduce in the Little Colorado River (Choudhury et al. 2004).

Climatologists predict that the Southwest will experience extended drought due to global climate change, and lower Lake Powell Reservoir elevations and warmer release temperatures are predicted (Seager et al. 2007; CCSP 2008a,b). Warmer water conditions could benefit warmwater nonnative fishes, result in invasions of new species, and cause greater proliferation of existing nonnative fish species (Rahel and Olden 2008).

3.5.3.3 Interactions with Native Species

Nonnative fish in the Colorado River are considered to adversely affect native fish in the system through predation and/or competition, and by serving as hosts for parasites (Minckley 1991; Coggins et al. 2002, 2011; Gloss and Coggins 2005; Olden and Poff 2005).

Predation and Competition. Piscivory by rainbow and brown trout has been suggested as a large source of mortality for native fish in the Colorado River and its tributaries below Glen Canyon Dam (Blinn et al. 1993; Marsh and Douglas 1997; Yard et al. 2011; Whiting et al. 2014). Near the confluence of the Little Colorado River, Yard et al. (2011) found that 90% of the vertebrate prey consumed by rainbow and brown trout were fish and estimated that rainbow and brown trout consumed over 30,000 fish in the vicinity of the Little Colorado River during a 2-year study period. The incidence of piscivory (proportion of individuals feeding on fish) by species was 70% for brown trout and only up to 3.3% for rainbow trout. However, rainbow trout were approximately 50 times more abundant during the study period, and it was estimated that they accounted for more than half of the total number of fish consumed in the study area (Yard et al. 2011). Overall, trout ate 85% more native fish than nonnative fish, even though native fish composed less than 30% of the small fish available as prey in the study area. Of ingested fish that were identifiable, 56% was composed of native fish, while another 28.8% was composed of unidentified suckers (presumably native flannelmouth and bluehead suckers). Of the identified native fish consumed by the trout, about 27% were humpback chub, 15% were speckled dace, 11% were flannelmouth sucker, and 3% bluehead sucker (Yard et al. 2011). Because the majority of humpback chub consumed by trout during the study were YOY and subadults (<3 years), predation on such fish could affect recruitment to the humpback chub population in the Grand Canyon (Coggins and Walters 2009; Yard et al. 2011). Because of differences in the levels of piscivory exhibited by brown and rainbow trout, current decisions to

TABLE 3.5-4 Nonnative Warmwater Fish Species Reported from the Little Colorado River Watershed[a,b]

Species	Below Chute Falls	Above Chute Falls
Black bullhead	X	X
Yellow bullhead	X	X
Common carp	X	X
Channel catfish	X	X
Green sunfish	X	X
Fathead minnow	X	X
Plains killifish	X	X
Red shiner	X	X
Threadfin shad	–	X
Goldfish	–	X
Golden shiner	–	X
Northern pike	–	X
Mosquitofish	–	X
Rock bass	–	X
Bluegill	–	X
Smallmouth bass	–	X
Largemouth bass	–	X
Black crappie	–	X
Yellow perch	–	X
Walleye	–	X

[a] X = present; – = absent.

[b] Fish reported from below and above Chute Falls within the 21-mi perennially flowing portion of the Little Colorado River corridor.

Sources: Ward and Persons (2006); Stone et al. (2007).

implement removal actions at the Little Colorado River to benefit humpback chub are triggered by levels of both brown trout and rainbow trout present in the reach, as well as consideration of the status (estimated size) of the humpback chub population.

In the Grand Canyon, brown trout, rainbow trout, channel catfish, and black bullhead are considered the primary predators of humpback chub, while common carp are a major humpback chub egg predator in the Little Colorado River (Marsh and Douglas 1997; Valdez and Ryel 1997; FWS 2008). Fathead minnow, red shiner, and plains killifish may be important predators and competitors of young humpback chub, especially in the Little Colorado River (Marsh and Douglas 1997; Valdez and Ryel 1997; FWS 2008). Marsh and Douglas (1997) examined predation of native fish by nonnative fish in the Little Colorado River and found rainbow and brown trout, channel catfish, and black and yellow bullhead to be predators of native fish. In stomachs from these species that contained food, native fish composed about 14% of the ingested materials, and ingested species included humpback chub, speckled dace, and bluehead and flannelmouth suckers. Whiting et al. (2014) evaluated diets of rainbow and brown trout from Bright Angel Creek, another tributary of the Colorado River in the Grand Canyon, and found that native fish (primarily speckled dace) composed approximately 4% of the diet for larger rainbow trout and 19% of the diet for larger brown trout.

While trout predation on humpback chub has been demonstrated, it is uncertain whether or not trout piscivory has had (or has) a population-level effect on the humpback chub (Yard et al. 2011). Although survival and recruitment of humpback chub have increased following trout removal in 2003 and 2006, it is not known if this increase is due to trout removal or other environmental factors, and further experimentation would be needed to tease apart other system-level dynamics that could have contributed to adult humpback chub population increases observed since 2000. For example, the temperature of water released from Glen Canyon Dam increased during the trout removal study period to temperatures that may have improved humpback chub growth and survival (Coggins et al. 2011). Ongoing studies have indicated that water temperature may influence the susceptibility of native fish to predation from brown and rainbow trout (e.g., Ward 2011; Ward and Morton-Starner 2015; see Section 3.5.3.1).

In addition to predation, nonnative fish may affect native fish through competition for resources that may be limited, such as food or appropriate habitat. Many of the small-bodied fish (including juveniles of larger species) in the Colorado River downstream of Glen Canyon Dam share similar habitats and food items, thereby increasing the potential for resource competition (Seegert et al. 2014). For example, nonnative fathead minnows are likely to compete with juvenile bluehead and flannelmouth suckers for resources, since they occupy the same habitat types and also have a high degree of overlap in the types of food items eaten (Seegert et al.2014. Diet evaluations and stable isotope analyses for fish from Bright Angel Creek found that the diets of rainbow trout and small (<150 mm total length) brown trout overlap with native fishes, suggesting competition for food resources (Whiting et al. 2014). Although the magnitude of species-level effects among the various native and nonnative species is poorly understood in most cases, it is likely that such competition has an effect on the abundance and survival of native species.

Research on the food web dynamics of the Grand Canyon provides further evidence that competition between native fish and nonnative fishes is likely occurring. Invertebrates, primarily blackflies and midges, are important food items for both humpback chub and nonnative fishes, particularly rainbow trout. Throughout Marble and Grand Canyons, invertebrate production is low, and fishes consume most of this production. Cross et al. (2013) hypothesized that an influx of rainbow trout from upstream, coupled with this limited resource base, may lead to strong competition among fishes in the Grand Canyon, and that dam operations that alter fish populations such as HFEs may exacerbate this effect.

Parasites and Diseases. The introduction and establishment of nonnative fish in the Colorado River below Glen Canyon Dam has also resulted in the introduction of several species of fish parasites that have the potential to adversely affect native fishes in the system

(Clarkson et al. 1997; Choudhury et al. 2004). Whirling disease, which affects rainbow trout but not the other native or nonnative species in the Colorado River below Glen Canyon Dam, was discussed above. The Asian tapeworm and the anchor worm have been found in native and nonnative warmwater fish in the Colorado River and its tributaries below Glen Canyon Dam, and the prevalence of these parasites is especially high in the Little Colorado River (Clarkson et al. 1997; Choudhury et al. 2004). For example, since first being identified from humpback chub in the Little Colorado River in 1990, reported infestation rates of the Asian tapeworm in native fish in the Little Colorado River were over 50% in some life stages of the humpback chub and as much as 60% in juvenile speckled dace (Clarkson et al. 1997). A 2-year seasonal study of fish parasites in the Little Colorado River reported 17 species of parasites from 4 native and 7 nonnative fish (Choudhury et al. 2004).

The effects of parasite infestation may be serious. For example, pathological effects of the Asian tapeworm have been reported to include intestinal abrasion and disintegration, as well as blockage and perforation of the gastrointestinal tract; chronic effects may include reduced growth and reproductive capacity, depressed swimming ability, and secondary bacterial infections (Clarkson et al. 1997). Fish larvae infested with the anchor worm may be killed, if vital organs are penetrated by the anchors, and secondary infections are possible at attachment points (Berry et al. 1991).

The effects of many of the parasites that have been reported for other fish species suggest that these parasites have the potential to adversely affect native fishes in the Colorado River below Glen Canyon Dam. The high prevalence of parasites in native and nonnative fish in the Little Colorado River may be especially of concern, given the importance of the Little Colorado River in the reproduction of the humpback chub and maintenance of the humpback chub population in the Colorado River below Glen Canyon Dam.

The potential for expansions and infestations of nonnative parasites may also be influenced by water temperatures. Rahel and Olden (2008) suggested that climate change could facilitate expansion of nonnative parasites. This may be an important threat to humpback chub. Optimal Asian tapeworm development occurs at 25–30°C (77–86°F) (Granath and Esch 1983), and optimal anchorworm temperatures are 23–30°C (73–86°F) (Bulow et al. 1979). Cold water temperatures in the mainstem Colorado River in Marble and Grand Canyons have likely prevented these parasites from completing their life cycles and limited their distribution. Warmer climate trends or operational alternatives could result in warmer overall water temperatures, thereby increasing the prevalence of these parasites, which can weaken humpback chub and increase mortality rates.

3.5.3.4 Nonnative Fish Control Activities and Effects of Flow Conditions

A number of management activities have been designed and implemented to test their efficacy for controlling and reducing the abundance and distribution of nonnative fishes in the Colorado River and its tributaries below Glen Canyon Dam. These control activities included (1) flow releases from Glen Canyon Dam designed to reduce trout recruitment, and (2) mechanical removal of trout and warmwater nonnative fish in the vicinity of the Colorado

River–Little Colorado River confluence (Reclamation 2011e). A series of HFEs was conducted in 1996, 2004, 2008, 2012, 2013, and 2014 to benefit sandbar resources, improve camping beaches, and potentially improve the quality of shoreline habitats for native fish in GCNP (Melis et al. 2010, 2012). Dodrill et al. (2015) reported that although experimental floods increased the prevalence and extent of backwaters, the effects were modest and would be expected to dissipate quickly. There was a large increase in rainbow trout early life stage survival rates and in the abundance of rainbow trout following the 2008 spring HFE; whether such increases would be supported by future spring HFEs is unclear, and the effects of fall HFEs on rainbow trout are less clear; however, preliminary analyses of recent studies indicate that the abundance of age-0 rainbow trout did not increase as a result of fall HFEs that occurred in 2012, 2013, and 2014 (VanderKooi 2015; Gimbel 2015). The potential effects of HFEs on trout are described below, as are the possible effects of equalization flows on trout.

Nonnative Fish Suppression Flows

Flows designed to reduce trout recruitment in Lees Ferry were tested in 2003–2005. These flows, conducted from January through March, were intended to dewater and expose rainbow trout redds in the Glen Canyon reach to lethal air temperatures for part of the day, thereby reducing the survival of trout eggs in the exposed redds (Korman et al. 2005; Korman, Kaplinski, et al. 2011; Korman and Melis 2011). The flow regimes tested during this period consisted of increasing the extent of daily flow variation during winter and early spring from the normal range of 10,000–18,000 cfs in January and 7,000–13,000 cfs in February–March to a range of 5,000–20,000 cfs in January–March; these operations also resulted in longer periods of dewatering for redds at lower elevations than would occur under normal operations. The fluctuating flows were determined to have resulted in increasing the incubation mortality rate from 5–11% under normal flow conditions to 23–49% under fluctuating flows (Korman et al. 2005; Korman, Kaplinski, et al. 2011; Korman and Melis 2011). However, no measurable reduction in age-0 abundance was observed, presumably due to increased survival of those rainbow trout that survived. These results suggest that the increased level of incubation mortality did not exceed compensatory survival responses (Korman, Kaplinski, et al. 2011). Because of these results, it has been suggested (Korman, Kaplinski, et al. 2011; Korman and Melis 2011) that a more limited fluctuating flow regime may be effective, targeting juvenile trout after the majority of density-dependent responses to egg incubation and hatching success have been realized, but before age-0 trout leave habitats that are potentially more sensitive to flow fluctuations. Testing flow regimes under which flow variation is increased during late spring and summer months when small age-0 trout are utilizing potentially flow-sensitive, low-angle habitat has been suggested (Korman et al. 2005; Korman and Melis 2011).

Nonnative Fish Removal

The removal of predatory nonnative fish has been conducted in various locations in the upper and lower basins of the Colorado River since the mid-1990s with varying degrees of success (Mueller 2005). Removal of nonnative fish in the Colorado River near the Little Colorado River confluence was conducted from 2003 to 2006, and in 2009 (Korman et al. 2005;

Makinster et al. 2009; Coggins et al. 2011). Fish removal activities in 2003–2006 captured more than 36,000 fish, of which 23,266 were nonnative species (including 19,020 rainbow trout) (Korman et al. 2005; Coggins et al. 2011). The removal of trout was estimated to have reduced rainbow trout abundance in this reach from about 6,500 in January 2003 to about 620 in February 2006. Immigration and recruitment account for the difference between the number of trout removed and the abundance estimates. During the 2003–2006 removal activities, large increases in the abundance of fathead minnow and black bullhead were reported beginning in September 2005, suggesting increases in immigration, survival, or both. The observed increase may have been due to increased emigration from the Little Colorado River where these species spawn, or because the combination of reduced rainbow trout numbers and increasing water temperatures may have caused these species to be more abundant and susceptible to capture (Coggins et al. 2011).

Coincident with the 2003–2006 removal activities, the humpback chub population stabilized and increased, suggesting that the nonnative fish removal (especially the removal of rainbow trout) may have allowed higher survival and recruitment by humpback chub (Coggins and Walters 2009; Coggins et al. 2011). However, the relationship between trout removal and survival of humpback chub is not clear because there was a system-wide decrease in rainbow trout abundance and drought-induced increases in river water temperatures during the time of the removal activities that could also have led to increased survival and recruitment of juvenile native fish (Coggins et al. 2011). As indicated in Figure 3.5-3, stabilization and increases in the adult humpback chub population may have begun as early as 2002, prior to the nonnative fish removal actions. Because changes in the adult humpback chub population rely, in part, on survival and recruitment of juvenile humpback chub, increases in survival rates may have occurred for several years prior to the fish removal activities. Further, even though the abundance of trout appeared to return to pre-removal levels by 2009, the estimated adult abundance of humpback chub continued to increase (Figure 3.5-3)

Nonnative fish removal was also conducted in 2009, the results of which indicated that rainbow trout abundance in the vicinity of the Little Colorado River had rebounded from the declines observed in 2006–2007 (Coggins et al. 2011; Reclamation 2011a). The number of rainbow trout in the vicinity of the Little Colorado River prior to the 2009 removal activities was estimated to be similar to the high densities estimated in 2002 (prior to the 2003 fish removal activities) (Wright and Kennedy 2011).

Nonnative fish removal is also being conducted in Shinumo and Bright Angel Creeks to restore and enhance the native fish communities and to reduce predation and competition on endangered humpback chub from nonnative fish. These removals are being conducted to implement conservation measures identified in the 2008 Biological Opinion, the 2009 Supplement, and the 2011 Biological Opinion on the operation of Glen Canyon Dam (FWS 2008, 2009; Reclamation 2011a). Nonnative fish (primarily rainbow trout) are being removed from Shinumo Creek to minimize predation upon newly translocated humpback chub and to reduce competition. From 2009 through 2014, 5,569 rainbow trout were removed from Shinumo Creek using netting, angling, and electrofishing. Brown trout do not occur in Shinumo Creek above a waterfall barrier near the mouth, but a few brown trout were removed below the waterfall. Rainbow trout densities were reduced between summer 2011 and winter 2012, but rebounded with a strong cohort in June 2012 (likely a "compensatory response"). Abundance of bluehead sucker increased in the lower reaches downstream of translocation areas and speckled dace increased throughout Shinumo Creek as rainbow trout densities were reduced. A sequence of headwater fires and floods occurred in the summer of 2014 that almost eliminated all nonnative and native fish from Shinumo Creek. NPS plans to remove the remaining nonnative trout and monitor the native fish. Nonnative fish, primarily rainbow trout, occur in small numbers in Havasu Creek and are also removed when encountered (Healy et al. 2014).

From 2010 to 2012, trout reduction efforts in Bright Angel Creek included the installation and operation of a fish weir trap and backpack electrofishing in the lower portion of the creek, including the confluence of Bright Angel Creek to Phantom Creek. From 2012 to 2015, removals were expanded to encompass the entire length of Bright Angel Creek (approximately 16 km) and Roaring Springs (approximately 3 km). The operation of the weir was also extended from October through February to capture greater temporal variability in the trout spawning migration. From 2010 to December 2014, about 28,000 brown trout and 4,800 rainbow trout were removed from Bright Angel Creek from both the weir and by electrofishing. Data on early 2015 removals and native fish response are still being analyzed, but trout abundance appears to have been reduced and native fish distribution has expanded upstream. These data are preliminary and may change slightly with further analysis (Healy et al. 2014; Nelson et al. 2012, 2015). As determined through consultation with Traditionally Associated Tribes and others, and consistent with the Memorandum of Agreement between the NPS and the Arizona State Historic Preservation Office, trout removed from the creeks were preserved and distributed for beneficial use through human consumption, or for use by the Tribes for other purposes.

In July of 2015, AZGFD biologists discovered an unusually large, reproducing population of green sunfish in a backwater slough connected to the mainstem Colorado River approximately 3 mi downstream of Glen Canyon Dam. Although the downstream end of the slough is connected to the main channel under the typical range of releases from Glen Canyon Dam, the upstream end of the slough is isolated from the main channel except during high flows. Green sunfish are known to be prolific, with a single female capable of producing up to 10,000 eggs. Green sunfish are considered likely predators of small-bodied native fish and native fish eggs. Biologists with the AZGFD, NPS, USGS, FWS, and Reclamation have determined that green sunfish pose a threat to native fish, including the humpback chub. Two removal efforts using electrofishing, seine netting, and trapping were conducted in August of 2015, but failed to deplete the population despite removing more than 3,000 fish. Biologists from the NPS and AZGFD constructed and installed a large block net at the downstream end of the main slough to minimize the escapement of green sunfish. After analyzing alternative methods for control, the agencies authorized a short-term targeted treatment of the slough with the fish toxin rotenone. Information available as of mid-November 2015 indicates that the eradication efforts appear to have been successful at controlling this population.

In August of 2016, NPS biologists discovered an additional small number of green sunfish in the slough. At the time of preparation of this EIS, mechanical removal efforts with beneficial use were being conducted.

Tribal Perspectives on Nonnative Fish Removal

Both the Hopi Tribe and the Pueblo of Zuni have expressed concerns to the U.S. Department of the Interior (DOI) regarding management actions described above involving fish suppression flows and mechanical removal of nonnative fish. The Hopi have expressed concern regarding the mechanical removal of large numbers of trout and trout management flows, while also expressing an understanding of the need to effectively manage nonnative populations if necessary to prevent the extinction of humpback chub. The Hopi stated their concern of conflicting management objectives to maintain a trout fishery while also minimizing threats to humpback chub. The Pueblo of Zuni consider these actions to be the taking of life without a beneficial use.

During the important Zuni migrations in Grand Canyon many culturally and historically important events occurred. One such specific event occurred in Zuni history which defines the Zuni's familial relationship to aquatic life and provides the fundamental basis for the Zuni objection to the mechanical removal of fish from the confluence of the Colorado and the Little Colorado rivers. In the late nineteenth century, Frank Hamilton Cushing recorded this historical event as it was narrated to him by the Zuni. Cushing labeled the event as the "Abode of the Souls" and the following is a condensed version of that event:

Shortly after Emergence, men of the Bear, Crane, and Seed clans strode into the red waters of the Colorado River and waded across. The men of the clans all crossed successfully. The women travelling with the men carried their children on their backs and they waded into the water. Their children, who were unfinished and immature (because this occurred shortly after Emergence), changed in their terror. Their skins turned cold and scaly and they grew tails. Their hands and feet became webbed and clawed for swimming. The children fell into the swift, red waters. Some of the children became lizards, others turned into frogs, turtles, newts and fish. The children of these clans were lost to the water. The mothers were able to make it to the other side of the river, where they wailed and cried for their children. The Twins heard them, returned, and advised the mothers to cherish their children through all dangers. After listening to the Twins, those people who had yet to pass through the river took heart and clutched their children to them and safely proceeded to the opposite shore. The people who successfully made it out of the river rested, calmed the remaining children, and then arose and continued their journey to the plain east of the two mountains with great water between. Thence, they turned northward to camp on the sunrise slopes of the uppermost mountains.

High-Flow Experiments

A number of HFEs have been conducted in the Colorado River below Glen Canyon Dam (1996, 2004, 2008, 2012, 2013, and 2014) to improve camping beaches and potentially improve the quality of shoreline habitats for native fish in GCNP (Melis et al. 2010, 2012). Rainbow trout abundance was found to increase following the spring HFEs in 1996 and 2008 (Makinster et al. 2011; Kennedy and Ralston 2011). In particular, the 2008 cohort was the largest on record up to that date, while the 2009 cohort was very strong compared to other years (Korman, Kaplinski, et al. 2011; Korman and Melis 2011). While fish hatched before and up to

1 month after the HFE showed lower early survival rates, fish hatched more than 1 month after the HFE showed a large increase in their early survival rate, with age-0 fish abundance being four times higher than expected (Melis et al. 2010; Korman and Melis 2011).

It is thought that cohorts produced after the HFE were not exposed to high flows and emerged into better quality habitat with better food availability (Rosi-Marshall et al. 2010). Concentrations of invertebrate prey in the drift following the spring 2008 HFE showed some prey items such as midge and blackflies (primary preferred food of rainbow trout) to have increased as much as 400% to 800%, and elevated levels in the drift continued for as much as 15 months following the HFE (Melis 2011). The observed changes in rainbow trout abundance following these two HFEs suggest that spring HFEs may benefit rainbow trout populations (Kennedy and Ralston 2011).

In contrast to the increased abundance of rainbow trout following the spring HFEs in 1996 and 2008, trout abundance was reduced following the fall (November) HFE in 2004 (Kennedy and Ralston 2011). However, rainbow trout in the Glen Canyon reach were showing a general population decline that started 2 years prior to the 2004 HFE, and, therefore, results in uncertainty regarding the inferences about the influence of the fall 2004 HFE on rainbow trout abundance and whether the response to fall HFEs is different from those associated with spring HFEs. Preliminary analyses indicate that the abundance of age-0 rainbow trout did not increase as a result of fall HFEs that occurred in 2012 and 2013 (VanderKooi 2015; Gimbel 2015). In addition, the relative overall abundance of rainbow trout in the Glen Canyon reach declined from 2012 to 2013 (Figure 3.5-6) due to declines in abundance of fish in smaller size classes.

Equalization Flows

There is also a potential for the abundance of YOY rainbow trout to be affected by the high, steady, and sustained flows that result from equalization flows as required by the 1968 Colorado River Basin Project Act. A substantial increase in numbers of age-0 trout was observed in 2011 following a period of sustained high flows required for equalization (Korman, Persons, et al. 2011). It has been hypothesized that the high, steady flows associated with equalization operations could benefit age-0 rainbow trout by inundating additional habitat for spawning, incubation of eggs, and production of food resources, and that these factors resulted in the observed increase in the numbers of age-0 trout.. Implementation of equalization flows is separate and distinct from LTEMP and would not be affected by LTEMP.

3.6 VEGETATION

Terrestrial plant communities along the Colorado River from Glen Canyon Dam to Lake Mead are highly diverse due to great variations in landforms, geologic features, and physical characteristics such as topography, elevation, and aspect. Plant communities along the Colorado River are greatly influenced by flow characteristics.

3.6.1 Historic and Remnant Riparian Plant Communities

A natural riverine environment existed along the Colorado River corridor prior to the modifications in flow regime and sediment transport that resulted from the construction of Glen Canyon Dam (Turner and Karpiscak 1980). Conditions within riparian habitats were constantly changing and highly unstable, with wide variations in annual flood flows as well as annual periods of low flow (Clover and Jotter 1944; Turner and Karpiscak 1980). Seasonal floods, averaging about 86,000 cfs, but frequently exceeding 100,000 cfs (Johnson 1991), resulted from snowmelt and spring rains; while sporadic floods from tributaries resulted from local storms, particularly during the summer monsoon season. Flood flows provided soil moisture which created opportunities for the establishment of species adapted to wet or moist soils near the river across a highly variable range of stage elevation (Clover and Jotter 1944). Floods were also sources of disturbance, removing plants by drowning or scouring across that elevation range (Clover and Jotter 1944). While well-established willows in some locations of the lower Grand Canyon could reach a height of 30 to 40 ft, these willows could be partially or completely removed by floods (Clover and Jotter 1944). Vegetation was typically sparse in areas that were frequently flooded; however, when a number of years passed between flood events, denser growth could develop. In broader reaches of the canyon, scouring was somewhat diminished, allowing some perennial plants to become established in sediment deposits near the river (Turner and Karpiscak 1980).

A zone of riparian vegetation, referred to as the Old High Water Zone, was well established just above the pre-dam scour zone (at and just above the approximately 100,000-cfs stage elevation) (Carothers and Brown 1991). Following dam construction, annual high flows have been limited to approximately 45,000 cfs or lower, except for four higher flow years (1983–1986) since 1965. These relatively low annual high flows have permitted riparian vegetation to develop below the Old High Water Zone in what has become known as the New High Water Zone. Before the dam, annual high flows carried large sediment loads through Glen and Grand Canyons, scouring nearly all vegetation below the Old High Water Zone (Carothers and Brown 1991; Kearsley and Ayers 1999; Ralston 2005).

The principal species[8] of the Old High Water Zone in Glen Canyon included New Mexico olive (*Forestiera pubescens*), Apache plume (*Fallugia paradoxa*), and netleaf hackberry (*Celtis reticulata*), and in Glen and upper Marble Canyons included apache plume, netleaf hackberry, western redbud (*Cercis occidentalis*), live oak (*Quercus turbinella*), and New Mexico olive. The Grand Canyon lacks the latter two species in the river corridor, and catclaw acacia (*Acacia greggii*) and mesquite (*Prosopis glandulosa*) are dominant, with desert broom (*Baccharis sarothroides*) becoming important downstream from RM 127 (Spence 2006; Carothers and Brown 1991; NPS 2005a). Pre-dam sediment terraces occupy the upper levels of the Old High Water Zone and support species adapted to dry soil conditions. High terraces in Glen Canyon support dense stands of four-wing saltbush (*Atriplex canescens*); however, in the Grand Canyon, catclaw acacia, brittlebush (*Encelia* spp.), barrel cactus

8 Plant names in this section use the Flora of North America (FNA 2014) and TROPICOS (Tropicos 2014) nomenclatures.

(*Ferocactus cylindraceus*), bursage (*Ambrosia dumosa*), creosote (*Larrea divaricata*), ocotillo (*Fouquieria splendens*), and other Mojave-Sonoran desert species also occur (Spence 2006).

Surfaces that were subject to frequent floods prior to dam construction ranged from barren to sparsely vegetated (Turner and Karpiscak 1980). Some of the species that occurred prior to the dam in this sparsely vegetated zone included tamarisk, also known as salt cedar (*Tamarix* spp.); seepwillow (*Baccharis* spp.); arrowweed (*Pluchea sericea*); and coyote willow (*Salix exigua*). Tamarisk, a species of Eurasian origin, was described in the 1930s as occurring along the river in "thickets near the eastern end of the park," "fringing the river near the mouth of Bright Angel Creek" (Dodge 1936), and "along the river from Nankoweap Creek to the base of Tanner Trail" (GCNHA 1936). Historic photos from Lees Ferry show tamarisk had established by 1923 (Graf 1978). Clover and Jotter (1944) noted tamarisk occurred in scattered locations (in moist sand near the river's edge) along the length of the river except for a large section of Marble Canyon; it was observed at and above Lees Ferry, below Vasey's Paradise, at the mouth of Saddle Canyon, Lava Pinnacle, and at Separation Rapids. Based on analyses of pre-dam photographs, tamarisk probably occurred as widespread isolated individuals (Turner and Karpiscak 1980).

3.6.2 Existing Riparian Vegetation Downstream from Glen Canyon Dam

The response of riparian vegetation to the operation of Glen Canyon Dam has been well studied, as summarized by Ralston (2012) and Sankey, Ralston, et al. (2015). Most evidence indicates that riparian vegetation composition, structure, distribution, and function are closely tied to ongoing dam operations. "Riparian vegetation" includes all plants found within the Fluctuating, New High Water, Old High Water, and Pre-Dam Flood Terrace hydrologic zones of the mainstem Colorado River downstream from Glen Canyon Dam, as described below.

Following construction of Glen Canyon Dam and the regulation of flows, including the reduction in annual flood peaks and increased year-round water availability at lower stage elevations, riparian vegetation expanded into the newly stable habitat and increased substantially (Ralston 2010; Kennedy and Ralston 2011; Webb et al. 2011; Sankey, Ralston, et al. 2015; Turner and Karpiscak 1980). The overall trend since completion of the dam has been the encroachment of New High Water Zone vegetation onto sandy beaches (Kearsley et al. 1994; Webb et al. 2002). At the same time, water availability decreased or was eliminated at higher elevations above the average annual daily maximum flows. The overall trend in the Old High Water Zone has been increased mortality of species such as mesquite and hackberry (Kearsley et al. 2006; Anderson and Ruffner 1987; Webb et al. 2011).

Plant communities present along the river have developed through associations of species with similar responses to moisture gradients, tolerance to water stress, and modes of reproduction (Kearsley et al. 2006; Stevens et al. 1995; Ralston et al. 2014; Ralston 2012). Such species associations occur on geomorphic surfaces of debris fan-eddy complexes, such as reattachment bars and separation bars, as well as on channel margins between these complexes, and respond dynamically to changes in flow characteristics. Geomorphic setting, substrate type/texture, hydrology, and species life history characteristics affect the temporal and spatial occurrence of plant communities (Ralston et al. 2014; Merritt et al. 2010). Because of historical patterns of dam releases, communities below the 25,000-cfs elevation on these surfaces differ somewhat from those above that level. Seven plant community types have been identified as occurring on these geomorphic surfaces (Ralston et al. 2014) and are given in Table 3.6-1.

Vegetation zones along the river reflect the frequency of inundation and disturbance (Ralston 2010, 2012; Kennedy and Ralston 2011). The Fluctuating Zone (Figure 3.6-1) supports flood-tolerant marsh species such as sedges, rushes, cattail, horsetail, and common reed. These species occupy return current channels and successional backwaters that are inundated daily for at least part of the year (i.e., up to the elevation of the average annual daily maximum discharge of about 20,000 cfs). The New High Water Zone lies within the influence of dam operations but above daily fluctuation levels (Carothers and Brown 1991). Vegetation in the Fluctuating and New High Water Zones are greatly influenced by river flow and dam operations but above daily fluctuation levels (Carothers and Brown 1991). Vegetation in the Fluctuating and New High Water Zones are greatly influenced by river flow and dam operations. (Stevens et al. 1995; Porter 2002; Kearsley and Ayers 1999; Kearsley et al. 2006; Ralston 2005, 2012).

The New High Water Zone, inundated by flows up to 45,000 cfs, supports woody riparian species, many herbaceous obligate riparian species (e.g., *Carex* spp., *Juncus* spp., *Equisetum* spp., *Phragmites australis*, and *Typha* spp.) with bunchgrasses such as sand dropseed and shrubs such as spiny aster at upper elevations. The dominant woody species of the Glen Canyon and Grand Canyon New High Water Zone scrub communities include tamarisk, coyote willow, arrowweed, and seepwillow (*Baccharis* spp.), along with desert broom downstream from RM 162 (Spence 2006). Wide, alluvial reaches have greater vegetation cover than narrow, confined reaches (Kennedy and Ralston 2011).

The Old High Water Zone, above 60,000 cfs to approximately 200,000 cfs, supports pre-dam drought-tolerant riparian species found in riparian and upland habitats, such as honey mesquite, catclaw acacia, netleaf hackberry, Apache plume, New Mexico olive, and mountain pepperweed (*Lepidium montanum*), along with desert species such as Mormon tea (*Ephedra* spp.), prickly pear (*Opuntia* spp.), creosote, ocotillo, and brittlebush. Mortality of Old High Water Zone plants is occurring, and some species such as mesquite and hackberry are no longer recruiting in this zone because of the lack of sufficiently high flows and nutrient-rich sediment inputs; however, mesquite and catclaw acacia are now recruiting in the New High Water Zone (Kearsley et al. 2006; Anderson and Ruffner 1987; Webb et al. 2011; Ralston 2005). Because flows do not exceed 45,000 cfs with normal dam operations, the upper margins of this zone are moving downslope, resulting in a narrowing of the zone. Desert species occupy pre-dam flood terraces and windblown sand deposits above the Old High Water Zone.

Vegetation on the geomorphic surfaces along the river (below about the 45,000-cfs stage elevation) has changed since construction of the dam as a function of river flows and climate (precipitation), as well as a result of factors such as increased soil salinity and increased sand coarseness (Carothers and Aitchison 1976; Kearsley et al. 2006; Sankey, Ralston, et al. 2015). Return channel-eddy complexes support many of the largest and better developed riparian patches (Spence 2006). Fluvial marsh wetlands were scarce prior to the construction of the dam and were associated only with perennial tributaries and springs (Webb et al. 2002); however,

TABLE 3.6-1 Plant Communities Occurring on Reattachment Bars, Separation Bars, and Channel Margins

Plant Community	Dominant Species	Geomorphic Surfaces
Common reed temperate herbaceous vegetation	Common reed (*Phragmites australis*), cattail (*T. latifolia, T. domingensis*), common tule (*Schoenoplectus acutus*), creeping bent grass (*Polypogon viridis*)	Lower reattachment bar
Coyote willow-Emory seep willow shrubland/horsetail herbaceous vegetation	Coyote willow, Emory seepwillow (*Baccharis emoryi*), horsetail (*Equisetum laevigatum*), common three-square (*Schoenoplectus pungens*), common spike-rush (*Eleocharis palustris*), alkali muhly (*Muhlenbergia asperifolia*)	Lower channel margin, lower reattachment bar
Tamarisk temporarily flooded shrubland	Tamarisk; in Glen Canyon also desert broom	All surfaces
Cottonwood/coyote willow forest	Coyote willow, cottonwood (*Populus fremontii*), Goodding's willow (*Salix gooddingii*), seepwillow (*Baccharis salicifolia*), salt grass (*Distichlis spicata*), alkali muhly, common reed, horsetail (*Equisetum* spp.), rush (*Juncus* spp.), sedge (*Carex* spp.), Russian olive (*Elaeagnus angustifolia*), tamarisk, creepingbent grass (*Agrostis stolonifera*), sweet clover (*Melilotus* spp.)	Lower separation bar, lower channel margin
Arrowweed seasonally flooded shrubland	Arrowweed (*Pluchea sericea*) in pure stands, or with seepwillow (*Baccharis* spp.), mesquite, or coyote willow	Lower reattachment bar, upper separation bar, upper channel margin, upper reattachment bar
Mesquite shrubland	Mesquite (*Prosopis glandulosa* var. *torreyana*), with seepwillow (*Baccharis* spp.), arrowweed	Lower channel margin, upper separation bar, upper channel margin, upper reattachment bar
Bare sand	Less than 1% vegetation cover	All surfaces

Source: Ralston et al. (2014).

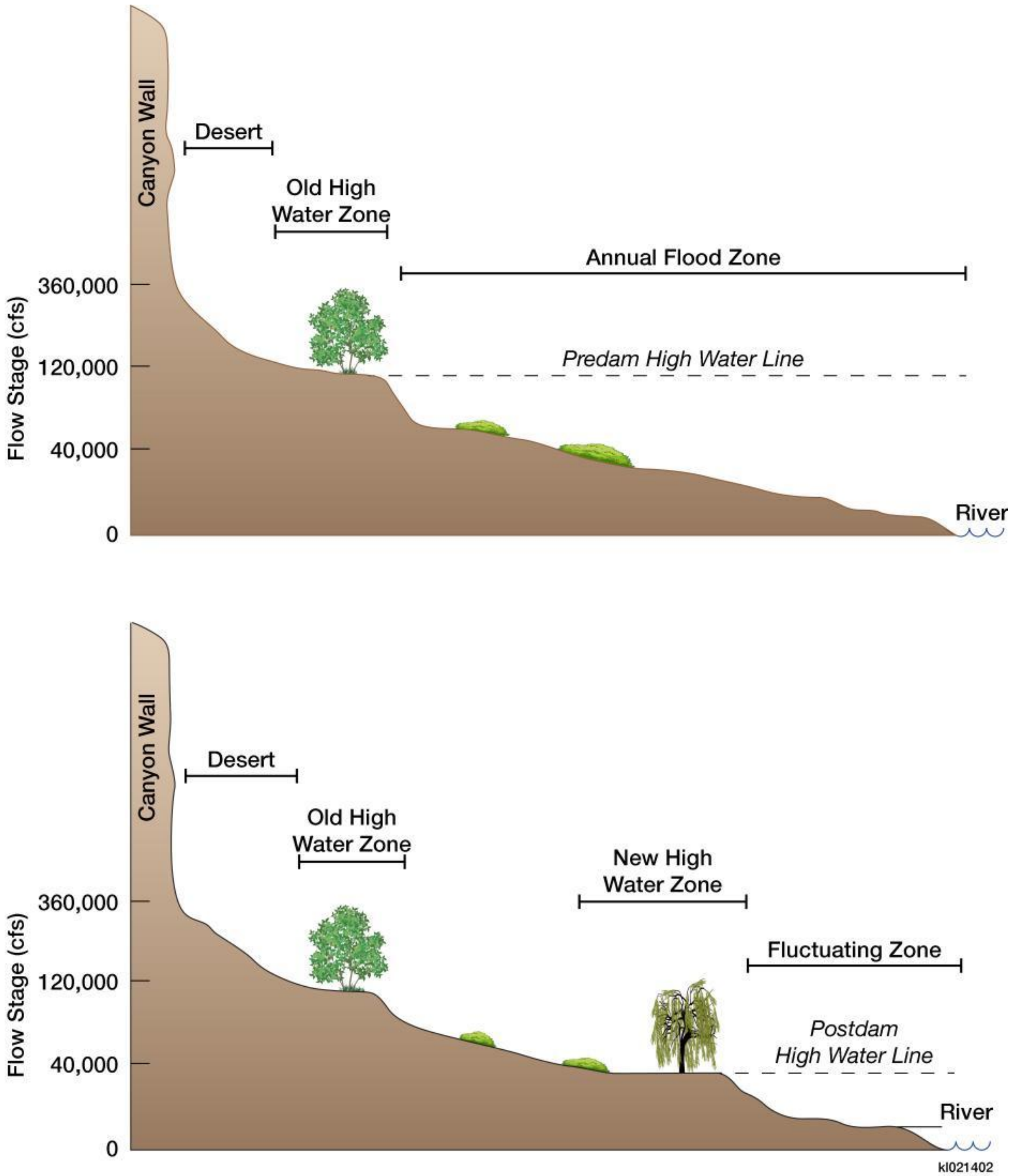

FIGURE 3.6-1 Riparian Vegetation Zones along the Colorado River below Glen Canyon Dam (adapted from Reclamation 1995)

widespread marsh development occurred following the reductions of spring floods, with the number increasing downstream (Stevens et al. 1995). Of the 1,625 ac of riparian vegetation mapped in the New High Water Zone, approximately 5 ac represent marshes, or about 0.3% (because of the typically small size of fluvial marshes, they are underrepresented in the current map, which has a minimum mapping unit of 0.5 ha). Areas mapped as wetland vegetation, including cattails and common reed, in 2002 totaled roughly 10 ac (Ralston 2012; Kennedy and Ralston 2012). Marsh communities are generally dominated by a few species, varying by soil texture and drainage. Wet marsh communities occur on fine-grained silty loams on lower areas of eddy complex sandbars that are frequently inundated and are dominated by cattail and common reed. Loamy sands support an association of horseweed (*Conyza canadensis*), knotweed (*Polygonum aviculare*), and Bermuda grass (*Cynodon dactylon*) (Carothers and Aitchison 1976; Kearsley et al. 2006). Shrub wetland communities (with coyote willow, Emory seep willow, and horsetail the dominant species) occur on sandy soils of reattachment bars and channel margins, below the 25,000-cfs stage, that are less frequently inundated. Clonal wetland species such as cattail, common reed, and willow are adapted to burial and regrowth and recover after burial following HFEs (Kearsley and Ayers 1999; Kennedy and Ralston 2011). On areas of higher stage elevations, short-lived plant species such as longleaf brickellbush, brownplume wirelettuce (*Stephanomeria pauciflora*), broom snakeweed (*Gutierrezia microcephala*), brittlebush, and Emory seepwillow colonize recently disturbed surfaces (Bowers et al. 1997; Webb and Melis 1996). While longer-lived species, such as Mormon tea, cactus (*Opuntia* spp.), and catclaw acacia (*Acacia greggii*), are not as quick to colonize disturbed areas, they are expected to continue to expand into lower stage elevations in the absence of disturbance. These species are found on surfaces that have not been disturbed for 7 to 28 years.

The population of Goodding's willow along the river below Glen Canyon Dam appears to have been affected by the reduction in flood flows on upper riparian terraces, has been in decline, and either no longer occurs at or does not reproduce at two-thirds of the sites where it previously existed (GCWC 2011; Mortenson et al. 2008). Along with the coarsening of substrates, the lack of springtime recruitment floods threatens remaining stands; however, high flows during the mid-1980s resulted in some establishment of Goodding's willow in the Grand Canyon (Mortenson et al. 2012; Ralston 2012). Restoration of Goodding's willow and several other native species has been a focus of NPS revegetation efforts.

Beavers (*Castor canadensis*) have reduced Goodding's willow within the canyon and may influence the invasion of resultant open areas (as well as areas of coyote willow herbivory) by tamarisk (Mortenson et al. 2008). Beavers may be more common along the river now due to the increase in post-dam availability of woody plants (Turner and Karpiscak 1980). In addition, Fremont cottonwood (*Populus fremontii*) recruitment along the river is nearly eliminated each year by beaver foraging on cottonwood seedlings, and very few Fremont cottonwood occur along the river below the dam (GCWC 2011).

Arrowweed, a dominant native woody species of both the Old and New High Water Zones, is adapted to burial by sediments deposited by floods (Ralston 2012). This drought-tolerant clonal species responds to burial by resprouting from roots, buried stems, and rhizomes, and subsequent vegetative growth (Ralston 2012). Arrowweed has characteristics of a primary colonizer and quickly occupies open sandbar areas. It spreads laterally by underground rhizomes and is commonly found in dense monotypic stands with few individuals of other species intermixed (Ralston et al. 2014), thereby reducing species diversity in areas occupied. Because arrowweed interferes with meeting a management objective of open sand beaches in some areas, the NPS has removed it from targeted campsites.

A number of nonnative plant species, many of which are invasive species, occur throughout the riparian zone; among the most common species are tamarisk, camelthorn (*Alhagi maurorum*), Russian thistle (*Salsola tragus*), ripgut brome (*Bromus diandrus*), red or foxtail brome (*Bromus rubens*), cheatgrass (*Bromus tectorum*), yellow sweetclover (*Melilotus officinalis*), spiny sow thistle (*Sonchus asper*), Ravenna grass (*Saccharum ravennae*), perennial peppergrass (*Lepidium latifolium*), and Bermuda grass (Reclamation 2011d; NPS 2005a). Ralston concludes that operations since the 1996 ROD; Reclamation 1996) have facilitated the recruitment, establishment, and expansion of both native and exotic plant species (e.g., tamarisk) throughout the river corridor. Furthermore, a recent analysis of vegetation data collected by NPS staff from 2007 to 2010 demonstrated an overall increase in exotic plant cover, particularly in the New High Water Zone (Zachmann et al. 2013).

Tamarisk, a shrub or small tree usually less than 20 ft in height, has long been the most prominent of these invasive species. As noted above, tamarisk was present along the river long before construction of Glen Canyon Dam. Tamarisk along the Colorado River is a hybrid of at least two distinct species (including *T. ramosissima* and *T. chinensis*) (Ralston 2010). It has an advantage over native species that require access to groundwater, such as cottonwood and willow, in areas where salinities are elevated or where water tables are lowered (Reclamation 2011b). Tamarisk plants accumulate salt on their leaf surfaces, which then accumulates in the surface layer of soil from dropped leaves (Ladenburger et al. 2006). The germination and establishment of native species can be adversely affected as surface soils increase in salinity, which can occur particularly in the absence of annual flooding and scouring, such as along regulated rivers.

High annual floods during the mid-1980s resulted in high tamarisk mortality, with surviving tamarisk located on upper riparian zone terraces; however, those floods also resulted in high levels of tamarisk establishment on elevations well above current river levels (Mortenson et al. 2012). Tamarisk establishment can increase when flood flows coincide with seed releases during spring and early summer (peaking in late May and early June); floods outside of that period result in little tamarisk recruitment (Mortenson et al. 2012; Stevens and Siemion 2012). Seedling survival is greatest when establishment is above the elevation of subsequent floods (Mortenson et al. 2012).

The tamarisk leaf beetle (*Diorhabda* spp.) has had a marked impact on the ecology of riparian zones in the Grand, Marble, and Glen Canyons in recent years. The beetle was discovered in 2009 near Navajo Bridge and at RM 12 and several locations, including Lees Ferry, in 2010; by 2011, it had become established along the Colorado River, occurring discontinuously from Glen Canyon Dam to RM 213, but primarily upstream of RM 27 and from RM 127 to RM 180, with an estimated 70% defoliation at some sites (Johnson et al. 2012). Permanent monitoring plots established in 2010 near Lees Ferry show evidence of mortality in smaller individuals, plus defoliation rates of 75 to 100%. By late 2012, the tamarisk leaf beetle was widely distributed in the Grand Canyon; as of 2015, there were reports of the beetle downstream past Diamond Creek. The splendid tamarisk weevil (*Coniatus* spp.) also occurs in the Grand Canyon), but much less is known about its abundance, distribution, and impacts. The beetle causes early and repeated defoliation of tamarisk during the summer months (Snyder et al. 2010; Hultine et al. 2010), which may eventually result in mortality after several successive years of defoliation. The long-term effects of the tamarisk leaf beetle and splendid tamarisk weevil on tamarisk abundance and distribution in Glen and Grand Canyons are currently not known; however, plant communities in which tamarisk is currently a dominant species will likely undergo compositional change (Shafroth et al. 2005). The extent of mortality within a tamarisk stand varies by site and may not be extensive; tamarisk may persist despite annual defoliation and may fluctuate with beetle populations (Nagler et al. 2012; Nagler and Glenn 2013). Both native and nonnative plant species may become established on sites of tamarisk mortality, although native species establishment may be slow, and future community composition and habitat characteristics would depend on a variety of site-specific factors, including site hydrology and microclimate, changes in nutrient dynamics, available seed sources, and active restoration efforts (Belote et al. 2010; Hultine et al. 2010; Shafroth, Merritt et al. 2010; Reynolds and Cooper 2011; Uselman et al. 2011; Johnson et al. 2012; Bateman et al. 2013).

Past flow regimes and past flow experiments provide evidence for the types and scale of potential impacts on vegetation from dam operations. The dynamics of large daily fluctuations on vegetation are known from dam operations prior to 1991. Large daily fluctuations increase the wetted area and thus the sandbar area available for colonization by wetland species; however, erosion exacerbated by fluctuations may limit the available bar area (Stevens et al. 1995). Increases in mean daily flow and daily inundation may remove low stage elevation vegetation and coarsen soil texture. Daily fluctuations also flatten vegetation within the range of fluctuating flows, export leaf litter, and coat leaf surfaces with silt (Stevens et al. 1995).

As a result of interim flows and MLFF, riparian vegetation moved into newly exposed areas and a shift to more upland species in most New High Water Zone vegetation patches was observed in Marble Canyon and Grand Canyon (Kearsley and Ayers 1996). The reduction of daily inundation frequency may increase colonization of wet marsh species at low stage elevations and promote the transition of higher elevation cattail/reed marshes to tamarisk/arrowweed vegetation (Stevens et al. 1995).

As noted above, riparian vegetation communities can be affected by dam operations through scouring and erosion during high flows, drowning, burial by new sediments, and reductions in soil moisture levels; consistent availability of water at low elevations (e.g., below 25,000 cfs) from elevated base flows can promote vegetation growth. Responses of riparian vegetation are affected by the timing, frequency, duration, and magnitude of the river's hydrology, as well as the variability between years and sequencing of flows (Ralston et al. 2014; Merritt et al. 2010). Additional factors related to flow that influence riparian vegetation include characteristics of deposited sediments (such as water-holding capacity, aeration, and nutrient levels), depth to groundwater, and anoxia in the root zone (Merritt et al. 2010). Flood flows during the mid-1980s resulted in a reduction of more than 50% in woody riparian vegetated area below the 60,000-cfs stage elevation due to scouring and drowning, with shallow-rooted species, such as coyote willow, Emory seepwillow, and longleaf brickellia, experiencing the highest mortality (Ralston 2012). The export of sediments (particularly silts and clays and organic matter) coarsened substrates, affected nutrient concentrations, and reduced opportunities for subsequent recruitment of tamarisk and native shrubs, such as coyote willow and Emory seepwillow (Ralston 2012).

HFEs up to 45,000 cfs rework and rebuild riparian vegetation substrates on sandbars, rocky slopes, debris fans, and return-current channels (Kennedy and Ralston 2011). HFEs also make alluvial groundwater more available to plants growing near and above the 45,000-cfs stage elevation (see Section 4.6.2.1). Seed germination is generally maximized with damp-soil or shallow-water conditions. Floods enhance species diversity, reset successional stages, and prevent monocultures in marsh and wetland habitats, and periodic flooding and drying in wetlands is beneficial to diversity and productivity (Reclamation 2011d; Stevens et al. 1995). Following the first HFE in 1996, total vegetative cover on sandbars was reduced approximately 20%, but there was no significant change in wetland or woodland/shrubland area 6 months later (Kearsley and Ayers 1999). Vegetation may return quickly to sandbars following HFEs; herbaceous plant cover doubled within 6 months after the 2008 HFE, and clonal wetland plants such as common reed quickly established on sandbars and shorelines after the 1996 and 2008 HFEs (Kennedy and Ralston 2011). Over the period of HFEs (since 1996), the long-term trend for vegetation on low stage-elevation sandbars has been one of rapid expansion in spite of the HFEs (Sankey, Ralston et al. 2015).

HFEs may result in minor short-term scouring of plants in the river channel and return current channel marsh communities followed by a rapid recovery, generally in around 6 months (Reclamation 2011b). HFEs, however, do not remove higher elevation vegetation (above 20,000 cfs; Ralston 2010). A September 2000 habitat maintenance flow of 31,000 cfs removed 57% of tamarisk seedlings, while native flood-adapted species increased, potentially by vegetative reproduction (Porter 2002; Ralston 2011). Although some near-shore wetland plants were removed by the 1996 and 2008 HFEs, woody riparian plants were not (Kennedy and Ralston 2011). Very little change occurred in a Glen Canyon cattail/sedge marsh as a result of the 1996 HFE (Spence 1996). Minor increases in the height and cover of vegetation were observed, along with the appearance of three nonnative species that may have been dispersed by the HFE.

Low-elevation grass and shrub species in marshes in Marble Canyon and Grand Canyon may become buried with coarse sediment, followed by recovery within 6 to 8 months (Reclamation 2011b). Coyote willow, seepwillow, tamarisk, and some low-lying grasses and forbs were partially or completely buried by sediment during the 1996 and 2008 HFEs (Kennedy and Ralston 2011). Many wetland species are adapted to burial and regrowth; some, such as cattail, common reed, and willow, thrived after burial following the 1996 HFE (Kearsley and Ayers 1999), and coyote willow recovered quickly after the 2008 HFE (Kennedy and Ralston 2011). Burial during HFEs may favor such species and alter the riparian community structure (Kennedy and Ralston 2011). Soil seed banks can be reduced, as following the 1996 HFE when approximately 45% of the seeds and 30% of the species richness of seeds available for germination in near-surface soils was lost, due primarily to burial under sediment (Kearsley and Ayers 1999). Coarsening of sand grain size on sandbars as a result of sequential

HFEs tends to favor clonal species such as arrowweed, coyote willow, and common reed (Reclamation 2011b).

Although tamarisk has increased throughout the riparian corridor since construction of the dam, HFEs do not necessarily result in the spread of tamarisk. The 1996 and 2008 HFEs occurred in spring before tamarisk seed production. Tamarisk seedling establishment was uncommon following both HFEs (Kennedy and Ralston 2011; Kearsley and Ayers 1999). Tamarisk seedling establishment could be higher if HFEs occur during the time of seed production (Mortenson et al. 2012); however, native species such as willows can also benefit from HFEs during their seed production period (Kennedy and Ralston 2011). There was no evidence of spread of camelthorn, another nonnative riparian species, in study sites after the 1996 HFE (Kennedy and Ralston 2011; Kearsley and Ayers 1999).

Low steady flows have been shown to have effects on vegetation. Low steady flows can isolate some marsh patches and cause them to dry out (NPS 2005a). Mortality of horsetail at higher elevations above the water table was 55% during low steady flows in June through August of 2000 (Porter 2002). Those flows, which were preceded by higher spring flows, also resulted in prolific tamarisk seedling establishment on recently exposed sandbars at low and intermediate elevations in the Grand Canyon due to water availability and lack of competition (Porter 2002; Ralston 2011; Mortenson et al. 2012). Seedling production of native riparian species would have occurred prior to (willows) or later than (arrowweed, mesquite, and seepwillow [*Baccharis* spp.]) the low steady flows (Ralston 2011). Native plants also became established in low-elevation areas, but at a slower rate than tamarisk, potentially by vegetative reproduction (Porter 2002; Ralston 2011).

3.6.2.1 Tribal Perspectives on Vegetation

Vegetation plays an important role in the traditional cultural ties maintained by indigenous peoples within the Canyons. The American Indian Tribes with the closest ties to the Canyons have all identified culturally important plants in the Canyons. For example, plants are perceived by the Zuni as a vital part of the landscape and are sacred to the Zuni people. All plants were given to the Zuni by the ancestral, celestial, supernatural beings. The Zuni view all plants as the offspring of Mother Earth because it was she who gave the plants to the Zuni (Stevenson 1993). Native plants at *Chimik'yana'kya'de'a* are especially sacred as a result of their association with the Zuni emergence and migration. Zuni fraternities and esoteric groups consider these plants significant because of their past and present cultural importance and usage. Today, these plants are collected and used for ceremonial, religious, subsistence, and medicinal purposes.

Zunis use literally hundreds of plants for medicinal, cultural, or religious purposes. Stevenson (1914) documented 123 plants being used for various purposes. This amount vastly underestimates the true number of plants and their respective uses, because not all the uses of all plants are known to all Zuni people. General plant usage for consumption or other everyday use is commonly known to most Zunis. However, knowledge about some plants may be possessed only by the members of a particular religious or medicine society, and in some cases specific esoteric uses may be known only by a particular Zuni individual. Plants played key roles in aiding the Zuni during their search for the middle place, as recounted in the Zuni emergence and migration narrative.

Zunis continue to rely on medicinal plants, herbs, fetishes, and other remedies that have served them through the ages. Camazine (1978) identified nearly 100 plants still used by Zunis for medical treatments. As a result of four previous monitoring trips through the Grand Canyon, the Zuni religious leaders preliminarily identified 32 plants of cultural importance in the spring during which these trips were taken; however, medicinal plants and plants with religious importance can be gathered as well during the other three seasons (winter, fall, and summer).

Hualapai monitoring programs have identified a number of issues that are negatively affecting Hualapai ethnobotanical resources along the Colorado River corridor. These include the disruption of riparian and nearshore plant ecology due to fluctuating river flows resulting from Glen Canyon Dam operations, as well as the related increased human activity that results in impacts such as trail-making and camping. Furthermore, changes in plant communities themselves are not the only causes of concern. The effects of these changes on all of the various forms of animal life that depend on plant communities for food, cover, nesting, and overall habitat must also be considered. Understanding of the intricate web of nature is often elicited through the study of Traditional Ecological Knowledge, one aspect of which acknowledges the past as a time when people and animals understood one another, and are still considered relatives

Many of the natural resources in the Canyons are considered cultural resources by the Tribes. Plants have an important role in Hopi culture; they are used in ceremonies and serve as clan totems, as medicines, in farming and food production, and for innumerable utilitarian purposes. During Hopi ethnobotanical research in the Canyons, 141 plant species were identified as culturally significant. Many important plant species specifically associated with water are found throughout the Canyons. Beyond the direct role plants play in human life, they are also recognized by the Hopi as a vital component of the ecosystem, which provides a habitat for many forms of animal life

According to the Navajo guiding principles, or teachings about plants, first and foremost, plants are people, and like people they move around, and they are male and female. To collect them, you must know them and talk with them. Even the use of plants in the food category involves prayers and offerings, which are also essential for medicinal plants. To know plants is to be familiar with the landscape, the seasons, cosmology, and the history of the area, and the movements and the genealogy of Navajo people. Plants have kept people alive. In the old days, if the corn did not grow or a drought occurred, or an enemy descended on you, knowledge of plants would guide you to water, provide nourishment, and indicate the time of the season. Like ceremonies, knowledge of plants encompasses all of these disciplines (Roberts et al. 1995). More than 57 plants that are utilized in Navajo ceremonies for traditional purposes and to support the overall health and well-being of the Navajo people have been identified in Navajo cultural resource inventory reports, as well as during annual monitoring trips (NNHPD 2015).

The many different kinds of plants that are present in and around the canyon provide food, medicine, homes, tools, and other items to the Navajo people. Many of the plants found within the Grand Canyon are considered Navajo medicines. For example, Ntl′ iz (offerings) were planted, specifically Baaashzhinii (jet), which then created nididlidii, Indian Rice Grass; the seed of this plant is black, and it is baashzhinii. Dootlizhii (Turquoise) was planted next and up grew Diwozhii Libaha; next abalone was planted and up grew Tl′ oh′ alts′ ozi; and next white shell was planted, and up grew Gahtsoh daa'. These plants provided food for sheep and horses (Roberts et al. 1995).

3.6.3 Special Status Plant Species

A number of special status plant species are known to occur along the Colorado River from Glen Canyon Dam to Lake Mead (Table 3.6-2). None of these species are federally listed, proposed for listing, or candidates for listing. Several special status species are potentially within the influence of Glen Canyon Dam operations. Satintail (*Imperata brevifolia*), rice cutgrass (*Leersia oryzoides*), and American bugleweed (*Lycopus americanus*) are all located within the range of daily operations. The Grand Canyon evening primrose (*Camissonia specuicola* ssp. *hesperia*), Mohave prickly pear (*Opuntia phaeacantha* var. *mohavensis*), giant helleborine (*Epipactis gigantea*), and lobed daisy (*Erigeron lobatus*), located above the level of daily flows but below the 45,000-cfs stage elevation, could be affected by HFEs. The main populations of the primrose, helleborine, and daisy are in springs up tributaries away from the river. Mohave prickly pear is also found in sandy flats above the 45,000-cfs stage elevation. Marble Canyon spurge (*Euphorbia aaron-rossii*) and hop-tree (*Ptelea trifoliata*) are located above the level of HFEs but potentially within their influence. Sticky buckwheat (*Eriogonum viscidulum*), Geyer's milkvetch (*Astragalus geyeri*), and Las Vegas bear poppy (*Arctomecon californica*) could be affected by changes in the elevation of Lake Mead.

Several special status species occurring within the Colorado River corridor are located outside of dam operational effects (Makarick 2015) and therefore were dismissed from consideration in the impact analysis. These include Grand Canyon cave-dwelling primrose (*Primula specuicola*), Grand Canyon beavertail cactus (*Opuntia basilaris* var. *longiareolata*), Kaibab agave (*Agave utahensis* ssp. *kaibabensis*), McDougall's yellowtops/Grand Canyon flaveria (*Flaveria mcdougallii*), Narrow phacelia/narrow scorpion weed (*Phacelia filiformis*), Desert rose/Grand Canyon rose (*Rosa stellata* ssp. *abyssa*), Canyonlands sedge/Kaibab sedge (*Carex curatorum*), Ragged rock flower (*Crossosoma parviflorum*), Button brittlebush/resin brittlebush (*Encelia resinifera*), Heermann's buckwheat (*Eriogonum heermannii* var. *argense*), Willow glowweed/burroweed (*Lorandersonia salicina*), Ringstem (*Anulocaulis leiosolenus* var. *leiosolenus*), Chaparral yucca/Our Lord's candle (*Hesperoyucca whipplei*), and Pillar false gumweed (*Chrysothamnus stylosus*). Sentry milk-vetch (*Astragalus cremnophylax* var. *cremnophylax*), a federally listed endangered species, is known only from the South Rim of the Grand Canyon near pinyon-juniper woodlands and therefore outside of dam operational effects.

TABLE 3.6-2 Special Status Plant Species Known to Occur along the Colorado River from Glen Canyon Dam to Lake Mead

Scientific Name	Common Name	State Status[a]	Federal Status[b]	Habitat/Location
Camissonia specuicola ssp. *hesperia*	Grand Canyon evening primrose, Kaibab suncup	None	GCNP-SC	Sandy or gravelly beaches and dry washes, often on limestone substrates (Brian 2000); located below the 45,000-cfs stage elevation, potentially affected by HFEs; Lower Granite Gorge, below Diamond Creek, Separation Canyon to Spencer Canyon (AZGFD 2013).
Eriogonum viscidulum	Sticky buckwheat	NCE	BLM-S, GCNP-SC	Mojave mixed scrub; Lake Mead shoreline (Reclamation 2000, 2007a); affected by increases in reservoir elevation.
Astragalus geyeri	Geyer's milkvetch	NCE	BLM-S	Creosote bush scrub; Lake Mead shoreline (Reclamation 2000, 2007a); affected by increases in reservoir elevation.
Arctomecon californica	Las Vegas bear poppy	NCE, ASR	GCNP-SC, BLM-S	Desert scrub; near RM 45, Lake Mead shoreline (Reclamation 2000, 2007a); affected by increases in reservoir elevation.
Opuntia phaeacantha var. *mohavensis*	Mohave prickly pear	ASR	GCNP-SC	River level, length of Colorado River (Brian 2000); located below the 45,000-cfs stage elevation; potentially affected by HFEs.
Erigeron lobatus	Lobed daisy, lobed fleabane	None	GCNP-SC	Rocky slopes, beaches, in sandy soils; located below the 45,000-cfs stage elevation; potentially affected by HFEs; RM 15–237 (Brian 2000).
Epipactis gigantea	Giant helleborine	ASR	GCNP-Rare	Moist soil on seepage slopes, cliff bases, along rivers, hanging gardens and seeps; located below the 45,000-cfs stage elevation; potentially affected by HFEs; from Vasey's Paradise to Grand Wash Cliffs (RM 32–277) (Brian 2000).

TABLE 3.6-2 (Cont.)

Scientific Name	Common Name	State Status[a]	Federal Status[b]	Habitat/Location
Euphorbia aaron-rossii	Marble Canyon spurge, Ross spurge	None	GCNP-Rare	Loose, sandy soil of old river bars and dunes, occasional talus slopes and rocky ledges located above the 45,000-cfs stage elevation, but potentially within influence of HFEs in Glen Canyon; also RM 3.5–53 (Brian 2000; AZGFD 2013).
Imperata brevifolia	Satintail	None	GCNP-Rare	Rocky canyons and wet places; located within the influence of daily operations, Clear Creek to Diamond Creek (RM 83.5–225) (Brian 2000).
Leersia oryzoides	Rice cutgrass	None	GCNRA-Rare	Wet marshes; located within the influence of daily operations; one patch at Leopard Frog Marsh RM –8.8L (NPS 2014b).
Lycopus americanus	American bugleweed	None	GCNRA-Rare	Wet marshes; located within the influence of daily operations; one patch at Leopard Frog Marsh RM –8.8L (NPS 2014b).
Ptelea trifoliata	Hop-tree	None	GCNRA-Rare	Located above the 45,000-cfs stage elevation, but potentially within influence of HFEs; RM –7 terrace, 1 small stand (NPS 2014b)

[a] State status codes include ASR = salvage restricted, Arizona Department of Agriculture; NCE = critically endangered, Nevada.

[b] Federal status codes include BLM-S = Bureau of Land Management sensitive; GCNP-Rare = Grand Canyon National Park rare; GCNP-SC = Grand Canyon National Park species of concern; GCNRA-Rare = Glen Canyon National Recreation Area rare; USFS-S = U.S. Forest Service sensitive.

3.7 WILDLIFE

This section describes those animal species found in the Colorado River Ecosystem downstream of Glen Canyon Dam to Lake Mead in both the riparian zone and adjacent upland vegetation communities. Along the river corridor, 90 mammals, 373 birds, 9 amphibians, 47 reptiles, and several thousand invertebrate species have been identified (NPS 2014b; Reclamation 1995; Stevens and Waring 1986b). Many wildlife species are habitat generalists, using ecosystems from both the riparian zone and upland communities to meet basic requirements. Some species are habitat specialists, requiring specific vegetation composition and structural components to meet their needs, and therefore may only occur within specific habitats within the river corridor. There is an ecological relationship between river flow and habitat for riparian and terrestrial wildlife, as illustrated in Figure 3.7-1 using birds as an example. Any changes to shoreline vegetation can affect wildlife habitat. In general, many wildlife species, including invertebrates, have benefited from increased riparian vegetation along the Colorado River corridor (King 2005).

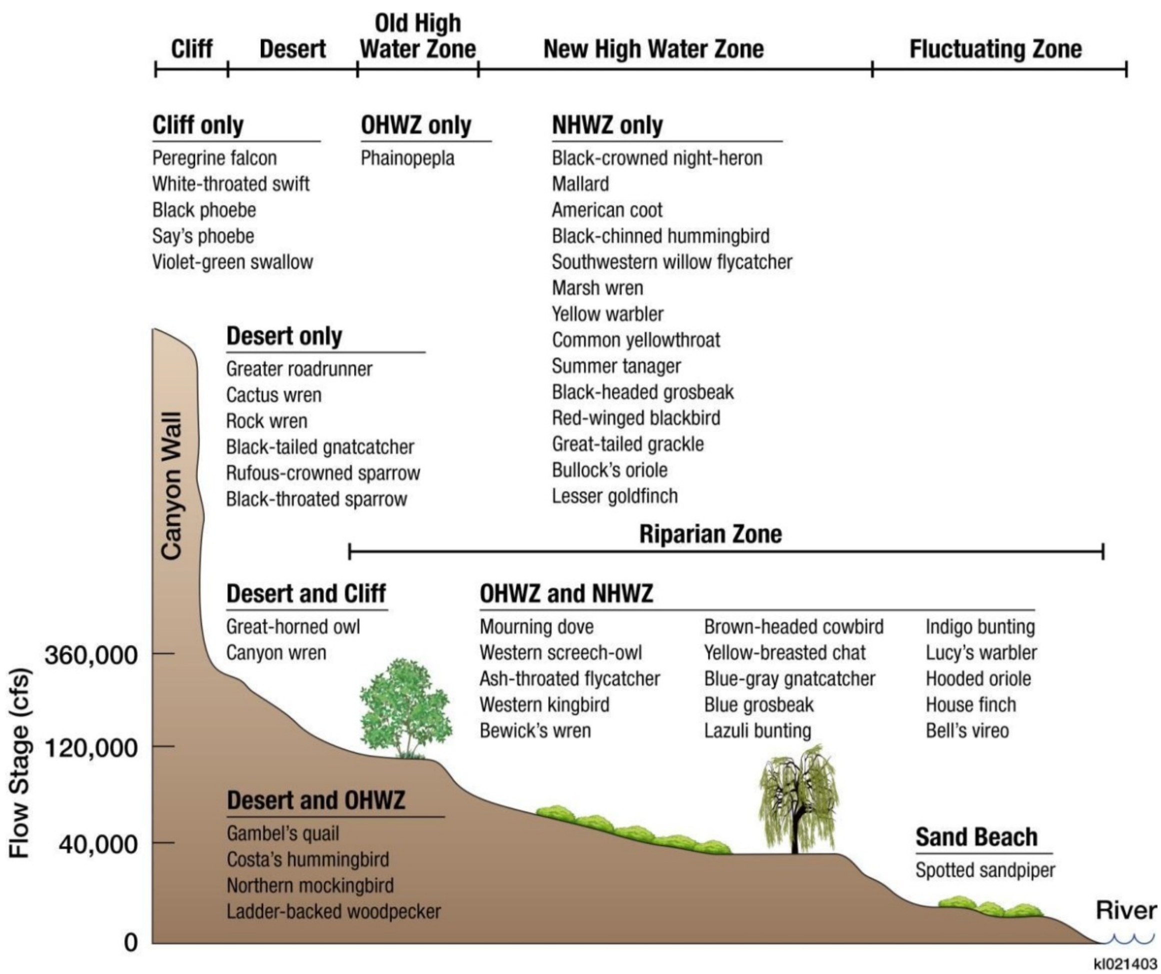

FIGURE 3.7-1 Riparian Zones Used by Nesting Birds (modified from Reclamation 1995)

3.7.1 Invertebrates

The riparian and terrestrial habitats along the Colorado River corridor through Glen, Marble, and Grand Canyons support a large and diverse invertebrate community. The increase in post-dam riparian vegetation increased the amount of habitat and forage for riparian and terrestrial invertebrates (Stevens and Waring 1986b). After construction of the dam, terrestrial insect populations were more abundant and diverse in the riparian zone than in the surrounding desert environment (Carothers and Aitchison 1976). Thousands of invertebrate species from over 260 families of arthropods are known to occur in the riparian corridor of the Grand Canyon (Stevens and Waring 1986b; Reclamation 1995). These invertebrate taxa are numerically dominated by terrestrial flies and adult forms of aquatic flies, herbivorous insects (especially cicadas, leafhoppers, and aphids), ground-dwelling forms of spiders and scorpions, beetles, and many different species of wasps, bees, and ants. These invertebrates fill a variety of ecological roles and serve as pollinators, regulate populations of other invertebrates, and provide food resources for many terrestrial and aquatic wildlife species. Invertebrates are discussed here based on the habitats they use. Threatened, endangered, and sensitive invertebrate species that may occur along the river corridor are discussed in Section 3.7.5.1.

Aquatic invertebrates downstream of Glen Canyon Dam form the food base for fish and other species at higher trophic levels. Dominant aquatic invertebrates include midges, blackflies, and the amphipod *Gammarus lacustris* (Section 3.5.1). Invertebrate species, particularly midges and blackflies, which develop in the river and emerge to complete their life cycles among riparian and terrestrial habitats, serve important ecological functions as potential prey to both aquatic and terrestrial organisms. For example, light trap sampling reveals that midge emergence peaks in lower Marble Canyon, but midge emergence is abundant throughout the river, both close to and distant from tributaries. Adult midges contribute to the terrestrial prey base from May through October (Kennedy, Muehlbauer, et al. 2014).

Most invertebrate species life cycles are entirely terrestrial. Ground-dwelling invertebrates, such as harvester ants (*Pogonomyrmex californicus*), occur at or just below the ground surface and are known to colonize camping beaches and other sandy areas. In addition to harvester ants, scorpions are also found on beaches (Carothers and Brown 1991). Before construction of the dam, annual flooding would remove invertebrate species from beach areas.

Other terrestrial invertebrates that inhabit riparian vegetation and open sand communities include cicadas, leafhoppers, armored scale insects, and robber flies. Invertebrate abundance and species richness among riparian vegetation largely depend on the supporting vegetation. For example, tamarisk is the most abundant woody plant along the river corridor, but it generally supports only four or five species of insects. Coyote willow, on the other hand, supports many species of insects. Occasional high invertebrate biomass in tamarisk communities results from outbreaks of leafhoppers (Carothers and Brown 1991), which provide an important food source for other invertebrates, amphibians, reptiles, birds, and mammals. In summer, insect biomass on tamarisk is often greater than in other riparian plant communities due to high flower numbers that attract insect pollinators. Therefore, tamarisk could increase overall biomass and diversity of arthropods (van Riper et al. 2008).

The tamarisk leaf beetle was intentionally introduced in the western United States in 2001 (Nagler and Glenn 2013) to help control or eradicate tamarisk, and were first observed downstream of Glen Canyon Dam in 2009 (Section 3.6.2). The beetle, which defoliates tamarisk, has been effective in killing large numbers of tamarisk along the river corridor downstream of Glen Canyon Dam. This die-off may have both negative and positive impacts for nesting bird species. For example, leaf beetle defoliation of tamarisk may reduce the suitability of available nest sites among tamarisk stands, but leaf beetles may also represent an important food source for birds (Nagler and Glenn 2013). However, along the Dolores River in southwestern Colorado, the diet of insectivorous birds consists of few tamarisk leaf beetles (2.1% by abundance and 3.4% by biomass) even though the beetles composed 24% and 35.4% of arthropod abundance and biomass, respectively, in the study area (Puckett and van Riper 2014).

3.7.2 Amphibians and Reptiles

More than 55 reptile and amphibian species occur downstream of Glen Canyon Dam, including 3 amphibian and 24 reptile species documented in the riparian zone of the river (Carothers and Brown 1991; Kearsley et al. 2006). The highest densities and diversity of amphibians and reptiles tend to occur in riparian areas nearer the river's edge due to the presence of water, abundant vegetation, and invertebrate food. The amphibian species along the river corridor are the canyon treefrog (*Hyla arenicolor*), red-spotted toad (*Bufo punctatus*), and Woodhouse's toad (*Anaxyrus woodhousii*) (NPS 2014c). Amphibian breeding, egg deposition, and larval development generally occur in backwaters or along the shallow water of aquatic and riparian habitats. The northern leopard frog (*Lithobates pipiens*), identified as an AZ-SGCN (AZGFD 2012), is discussed in Section 3.7.5.2.

The most common lizard species along the river corridor are the side-blotched lizard (*Uta stansburiana*), western whiptail (*Aspidoscelis tigris*), desert spiny lizard (*Sceloporus magister*), and tree lizard (*Urosaurus ornatus*) (Kearsley et al. 2006). Tree lizards use shoreline habitats proportionally more than other reptile species (Kearsley et al. 2006). Within the New High Water Zone, lizards feed on harvester ants and other insects in close proximity to the river's edge (Carothers and Brown 1991). Warren and Schwalbe (1985) noted that lizard numbers in the New High Water Zone were lowest in dense tamarisk sites. Lizards in the New High Water Zone may prefer relatively open areas such as rocks and boulders, bare soil, sand, or litter. Other lizard species, such as the zebra-tailed lizard (*Callisaurus draconoides*), may be associated with sand substrates (Stevens 2012), the availability of which can be influenced by Glen Canyon Dam flows. The high and moderate densities of lizards along the shoreline and riparian habitats, respectively, are probably due to food availability on debris along the shoreline and in riparian plants (Warren and Schwalbe 1985).

Three chelonian species occur in the area: the spiny softshell (*Apalone spinifera*), Agassiz's desert tortoise (*Gopherus agassizii*), and Morafka's desert tortoise (*Gopherus morafkai*). The spiny softshell was an introduced species into the Colorado and Gila Rivers in Arizona, and now also occurs in California, Utah, Nevada, and New Mexico (Riedle 2006). It occurs in the lower Grand Canyon/upper Lake Mead area. The Agassiz's desert tortoise (formerly known as the desert tortoise – Mojave population), a federally threatened species, inhabits the north side and west end of the Grand Canyon (NPS 2005a). It inhabits Mojave desertscrub. The Morafka's desert tortoise (formerly known as the desert tortoise – Sonoran population) occurs along the southwestern end of the Grand Canyon and around Lake Mead. It generally inhabits creosote bush flats in basins and mountain bajadas, occasionally occurring on rocky slopes. The Joshua tree forest along the rim of the Lower Gorge is an important component of its habitat (NPS 2005a). As both species spend much of their lives in burrows, neither occurs in areas inundated by Colorado River flows.

More than 20 snake species occur within the greater Grand Canyon area (NPS 2014c). The more common species in riparian areas downstream of Glen Canyon Dam include the Grand Canyon pink rattlesnake (*Crotalus viridis abyssus*), speckled rattlesnake (*Crotalus mitchellii*), black-tailed rattlesnake (*Crotalus molossus*), common king snake (*Lampropeltis getula*), and gopher snake (*Pituophis catenifer*) (Kearsley et al. 2006; NPS 2014c).

3.7.3 Birds

Spence et al. (2011) reported 316 bird species from the GCNRA, and Gatlin (2013) reported 362 species from the Grand Canyon. NPS (2014c) reported that 373 bird species have been recorded in the greater Grand Canyon region, with 250 species documented from the river corridor. Riparian habitats along the river provide breeding habitat, migratory stopover sites, and wintering areas for birds throughout the year (Spence 2006; Spence et al. 2011; Gatlin 2013). Several of the species that breed along the river corridor are considered obligate riparian species. These species include the Lucy's warbler (*Oreothlypis luciae*), Bell's vireo (*Vireo bellii*), common yellowthroat (*Geothlypis trichas*), yellow warbler (*Dendroica petechia*), yellow-breasted chat (*Icteria virens*), and black-chinned hummingbird (*Archilochus alexandri*). The brown-headed cowbird (*Molothrus ater*), a brood parasite, is also relatively common during the breeding season (Spence 2006; Spence et al. 2011; Gatlin 2013).

Birds that nest in the riparian zone along the river corridor (Figure 3.7-1) are directly and indirectly affected by Colorado River flows. River flow influences the distribution and composition of riparian vegetation, which affects invertebrate abundance (prey) and nest site availability (Carothers and Brown 1991). Only the species that nest right at the water's edge are directly influenced by fluctuating flows (Spence 2006). Important correlates with bird species richness and abundance include canopy cover, size and shape of riparian patches, and canopy volume and structure (Sogge et al. 1998; Spence 2006). The abundance of many bird species that use riparian areas (in the lower Colorado River) was highest at intermediate tamarisk levels (40–60%). In tamarisk-dominated habitats, the highest number of birds per census point occurred in areas where native vegetation composed 20–40% of the habitat. Bird numbers continue to increase with increasing amounts of native vegetation up to about 60%, but did not increase in numbers beyond that point (van Riper et al. 2008). Wintering birds did not show a significant relationship with the amount of tamarisk in the habitat. They are not strongly associated with vegetation structure but rather with habitats that provide abundant food sources of fruit and seeds (van Riper et al. 2008).

Of the 30 bird species that nest in the riparian zone, at least 23 eat insects or feed insects to their young. Other birds that do not nest in the riparian zone may still feed on insects within this zone. Yard et al. (2004) examined the diets of six insectivorous bird species along the Colorado River in GCNP. All species consumed similar quantities of caterpillars and beetles, but use of other prey taxa varied. Nonnative leafhoppers (*Opsius stactagolus*) that inhabit tamarisk made up a large portion of Lucy's warbler diets (49%); ants made up 82% of yellow-breasted chat diets; and the adult stage of aquatic midges made up 45% of yellow warbler diets. Overall, terrestrial insects made up 91% of bird diets compared to 9% of prey from adult insects that emerged from aquatic habitats (Yard et al. 2004).

The winter terrestrial bird community is diverse, with 75 species recorded. Diversity peaks in the lower portion of the Grand Canyon, particularly below RM 205 (Spence 2006). The most common wintering terrestrial species are migrants, with ruby-crowned kinglet (*Regulus calendula*) being most abundant followed by white-crowned sparrow (*Zonotrichia leucophrys*), dark-eyed junco (*Junco hyemalis*), and song sparrow (*Melospiza melodia*). Most of the winter terrestrial birds feed primarily on fruit and seeds (Schell 2005; van Riper et al. 2008).

More than 40 waterbird species inhabit the river corridor (Spence 2006; Spence et al. 2011; Gatlin 2013). Waterbirds include waterfowl (e.g., ducks and geese), wading birds (e.g., herons), and shorebirds (e.g., sandpipers and killdeers). Waterfowl are present mainly during the winter months, while wading birds and shorebirds occur primarily as migrants or during summer (Stevens, Buck, et al. 1997). The winter waterfowl density in portions of the Grand Canyon can be large; 31 species have been reported between Lees Ferry and Soap Creek, at a density of up to 250 individuals per mile (Spence 2014b). Common waterfowl species include American coot (*Fulica americana*), American widgeon (*Anas americana*), bufflehead (*Bucephala albeola*), common goldeneye (*B. clangula*), common merganser (*Mergus merganser*), gadwall (*A. strepera*), green-winged teal (*A. crecca*), lesser scaup (*Aythya affinis*), mallard (*A. platyrhynchos*), ring-necked duck (*Aythya collaris*), and Canada goose (*Branta canadensis*). Other than great blue heron (*Ardea herodias*) and spotted sandpiper (*Actitis macularia*), which are fairly common winter and summer residents along the river, wading birds and shorebirds are rare in this area (Kearsley et al. 2003; Spence 2006). Increased waterfowl numbers downstream of Glen Canyon Dam developed in response to increased aquatic productivity and open water, which provides wintering habitat for aquatic birds (NPS 2013b). Fish-eating birds in the Grand Canyon include herons, gulls, mergansers, bald eagles (*Haliaeetus leucocephalus*), and osprey (*Pandion haliaetus*) (Wasowicz and Yard 1993).

Several bird species appear to benefit from increased riparian habitat and river clarity and productivity resulting from Glen Canyon Dam operations. For example, the increase in riparian vegetation resulting from dam operations is believed to have resulted in the range expansion of breeding songbirds such as Bell's vireo (Brown et al. 1983; LaRue et al. 2001). Increases in abundance and species richness of aquatic bird populations have been attributed to increased river clarity and productivity associated with Glen Canyon Dam operations (Spence 2006). The majority of waterfowl tend to concentrate in the upper portion of the Grand Canyon due to the greater primary productivity that benefits dabbling ducks and greater water clarity for diving ducks. Recently, a large great blue heron rookery was established on both sides of the Colorado River just below Glen Canyon Dam. In May 2013, there were 22 active nests and an estimated

60 to 80 individuals. These birds benefit from the increased availability of prey from higher trout productivity of recent years and the increased water clarity. A pair of ospreys successfully nested at the base of Glen Canyon Dam in 2014 (Spence 2014a,b).

Threatened, endangered, and sensitive bird species that may occur along the river corridor are discussed in Section 3.7.5.3.

3.7.4 Mammals

More than 90 mammal species occur downstream of Glen Canyon Dam (NPS 2014c), of which approximately 34 species occur along the river corridor (Carothers and Aitchison 1976; Suttkus et al. 1978; Kearsley et al. 2006). Only three mammal species in the project area require aquatic habitats: beaver (*Castor canadensis*), muskrat (*Ondatra canadensis*), and river otter (*Lontra canadensis*). Muskrats are extremely rare in the Grand Canyon, but are occasionally observed in the Little Colorado River (Reclamation 2011d). They construct bank dens or use dens of other animals (Erb and Perry 2003). Despite occasional reports of river otters in the Grand Canyon, no reliable documentation of their presence has occurred since the 1970s (Kearsley et al. 2006). River otters are classified as extirpated in the Grand Canyon (Reclamation 2011d) despite the apparent presence of suitable habitat (Carothers and Brown 1991).

Beaver occur throughout the river corridor, from Glen Canyon Dam to the Grand Wash Cliffs where riparian vegetation is well established. Beavers cut willows, cottonwoods, tamarisk, and shrubs for food and can substantially affect riparian vegetation (Carothers and Brown 1991; Dettman 2005). For example, Mortenson et al. (2008) hypothesized that beaver may indirectly promote the invasion of nonnative tamarisk in riparian communities by preferentially feeding on native competitors such as coyote willow. Beavers in the Grand Canyon excavate lodges in the banks of the river, with the entrance located underwater and a tunnel leading up under the bank to a living chamber. Increases in the population size and distribution of beavers in Glen Canyon and the Grand Canyon have occurred since the construction of the dam. These increases are likely due to the increase in riparian vegetation and relatively stable flows (Carothers and Brown 1991; Kearsley et al. 2006).

Small mammal abundance and richness are greatest in the Old High Water Zone where steeper slopes, rock falls, and canyon wall crevices provide greater structure for wildlife habitat (NPS 2005a). Rodents (mice) are the most abundant small mammals within the riparian zone. Common species include the cactus mouse (*Peromyscus eremicus*), rock pocket mouse (*Chaetodipus intermedius*), and rock squirrel (*Spermophilus variegatus*) (Carothers and Brown 1991). The deer mouse (*Peromyscus maniculatus*) is the only mouse species that depends directly on the riparian zone (Reclamation 1995).

A least 20 species of bats are documented downstream of Glen Canyon Dam (NPS 2014c). Bats in the Grand Canyon typically roost in rock crevices, caves, and trees of desert uplands but forage on insects along the Colorado River and its tributaries. The most common bat species along the river corridor are the western pipistrelle (*Pipistrellus hesperus*), American free-tailed bat (*Tadarida brasiliensis*), pallid bat (*Antrozous pallidus*), Yuma myotis (*Myotis yumanensis*), and California myotis (*Myotis californicus*). Bats are also important prey for raptors such as the peregrine falcon (*Falco peregrinus*) (Carothers and Brown 1991).

A number of mammal species occur below Glen Canyon Dam. These include cougar (*Puma concolor*), coyote (*Canis latrans*), bobcat (*Lynx rufus*), gray fox (*Urocyon cinereoargenteus*), American badger (*Taxidea taxus*), raccoon (*Procyon lotor*), striped skunk (*Mephitis mephitis*), western spotted skunk (*Spilogale gracilis*), American hog-nosed skunk (*Conepatus leuconotus*), ringtail (*Bassariscus astutus*), and long-tailed weasel (*Mustela frenata*). Omnivorous scavengers such as the ringtail and western spotted skunk have likely increased in numbers due to an increase in riparian habitat and, more importantly, increases in campers and river runners (Dettman 2005).

Large ungulates occurring in the Grand Canyon include the desert bighorn sheep (*Ovis canadensis nelsoni*) and mule deer (*Odocoileus hemionus*). The Grand Canyon contains one of the largest and most continuous naturally persisting populations of desert bighorn sheep in North America (Bendt 1957; Guse 1974; Wilson 1976; Walters 1979; Holton 2014). GCNP has prioritized the need to inventory and monitor bighorn sheep, and AZGFD lists desert bighorn sheep as an AZ-SGCN (AZGFD 2012). The Navajo Nation listed this subspecies as Group 3 (highly likely to become extinct throughout its range on the Navajo Nation).

Bighorn sheep in the Grand Canyon occupy an environment that is unique relative to other desert bighorn sheep ranges. Most desert bighorn sheep populations occupy arid mountain ranges with limited (largely point) water sources and are near enough to other populations for effective dispersal and interbreeding. By contrast, bighorn sheep in the Grand Canyon live in a comparatively isolated, very deep canyon with abundant free water along the bottom (Holton 2014). Bighorn sheep routinely use free water and do not often move farther than 1.2 to 5 mi from water sources (Turner et al. 2004; Epps et al. 2007; Longshore et al. 2009). Bighorn sheep in the Grand Canyon routinely come to the river to drink and forage during the summer months (Carothers and Brown 1991). Holton (2014) reported that most ewes in the Grand Canyon remained near the river year-round, rarely moving more than a few hundred yards above the river.

Human-related barriers that restrict or eliminate dispersal to and colonization of suitable ranges affect the viability of desert bighorn sheep (Bleich et al. 1990; Epps et al. 2007). Swift wide rivers are noted to effectively delimit bighorn ranges (Graham 1980; Wilson et al. 1980; Smith and Flinders 1991). The Colorado River likely serves as a natural impediment for interbreeding and connectivity between populations (Holton 2014). Bighorn in the Grand Canyon have not been seen crossing the Colorado River since construction of Glen Canyon Dam. However, some individual bighorns have been more genetically similar to bighorn herds from the opposite side of the river, suggesting that recent ancestors crossed the river (Holton 2014). Prior to construction of the dam, seasonally low water along the Colorado River likely allowed movement across the river. Early naturalists at the Grand Canyon speculated that a bighorn, before the dam was built, could perhaps boulder-hop across the Colorado River without ever touching water. Consistent high flows of the Colorado River have likely created a formidable barrier, eliminating seasonal movements of bighorn sheep across the river and potentially restructuring the population in GCNP over the last 50 years (Holton 2014).

Studies also indicate that bighorn sheep populations may be limited through resource competition with feral burros (*Equus asinus*). In areas of sympatry, the shared foods consumed by burros may be twice the amount consumed by bighorn sheep. The burro is apparently a superior competitor compared to bighorn sheep. Following competitive equilibrium, the bighorn sheep would be relegated mainly to surviving in the most rugged habitats that could not be efficiently exploited by burros (Seegmiller and Ohmart 1981). Carothers (1977) reported that burros had affected natural communities in the three distinct plant associations (pinyon-juniper woodlands, high desert blackbrush community, and Mojave Desert vegetation type) that occur below the rims of the Grand Canyon. The most widespread impact of burro-related change was the reduction and elimination of palatable grasses and their replacement by unpalatable shrubs. Burro activity also increased soil compaction and accelerated soil loss (Carothers 1977). Burro control has been conducted in the Grand Canyon in an attempt to prevent them from denuding plateaus of grass and other forage plants consumed by native big game species such as bighorn sheep (Wright 1992). Low numbers of burros remain in the western portion of GCNP and are removed whenever possible (NPS 2005a).

Mule deer occur in relatively low densities along the river corridor as compared to the densities on the North and South Rims of the Grand Canyon. Small herds of deer are commonly seen along the river in the upper reaches of the canyon, from Buck Farm to Kwagunt Canyons. Anecdotally, mule deer have been observed swimming across the river (NPS 2014c).

3.7.5 Special Status Wildlife Species

Threatened, endangered, and sensitive wildlife species include species that may occur along the Colorado River corridor between Glen Canyon Dam and Lake Mead and that are any of the following:

- Listed or proposed for listing as threatened or endangered plant and wildlife species under the ESA (including experimental, nonessential populations) and designated and proposed designated critical habitat;
- Candidates for listing as threatened or endangered species under the ESA;
- State of Arizona Species of Greatest Conservation Need (AZ-SGCN); or
- Bald or golden eagles protected by the Bald and Golden Eagle Protection Act of 1940 (BGEPA).

Eleven threatened, endangered, and sensitive wildlife species may occur along the Colorado River corridor between Glen Canyon Dam and Lake Mead. These species and their critical habitats are discussed below.

3.7.5.1 Invertebrates

The Kanab ambersnail (*Oxyloma haydeni kanabensis*) (Table 3.7-1) is the only threatened, endangered, or sensitive invertebrate species that occurs along the Colorado River in the Grand Canyon. The Kanab ambersnail was listed as an endangered species under the ESA on April 17, 1992 (FWS 1992). However, recent evidence from anatomical and molecular genetics studies indicates that this is a geographically widespread taxon whose listing under the ESA may have been incorrect (Littlefield 2007). In a study of *Oxyloma* specimens collected from 12 locations throughout the western United States, including Kanab ambersnail from the Grand Canyon, morphometric and genetic results indicated that the Kanab ambersnail can be regarded as a member of the same species as the other *Oxyloma* populations analyzed (Culver et al. 2013). However, until this taxonomic change occurs, the Kanab ambersnail remains a listed species (FWS 2011b). No critical habitat is designated for this species.

Globally, the Kanab ambersnail is only found in three locations. Two of these are within the Grand Canyon: the riparian vegetation at Vasey's Paradise and Elves Chasm. Vasey's Paradise is at RM 31.5 and Upper Elves Chasm is at RM 116.6. The latter population was created from snails translocated from Vasey's Paradise (Sorensen and Nelson 2000; FWS 2008). The locations of these sites within the Grand Canyon are shown in Figure 3.7-2. The third location for the Kanab ambersnail is Three Lakes near Kanab, Utah (FWS 1995a).

The Kanab ambersnail lives in association with watercress (*Nasturtium officinale*), cardinal monkeyflower (*Mimulus cardinalis*), cattails (*Typha*), sedges (*Carex*), and rushes (*Juncus*). Populations within the Grand Canyon occur in areas with water sources originating from limestone or sandstone geologic strata (Spamer and Bogan 1993; FWS 1995a). The increase in cover, reduction in beach-scouring flows, and introduction of the nonnative watercress led to a >40% increase in suitable Kanab ambersnail habitat area at Vasey's Paradise compared to pre-dam conditions (Stevens, Protiva, et al. 1997).

Kanab ambersnails live 12 to 15 months and are capable of self-fertilization. Mating and reproduction occur from May to August. Subadults dominate the overwinter population. Snails enter dormancy in October–November and become active in March–April. Overwinter mortality ranges between 25 and 80% (Stevens, Protiva, et al. 1997; IKAMT 1998). During mild winters, they can continue their life cycle without dormancy or may go in and out of dormancy several times throughout the winter (Sorensen and Nelson 2002).

Based on annual survey data, live counts of Kanab ambersnails at Vasey's Paradise declined in 2011 from previous years, although the ambersnail habitat at Vasey's Paradise was in overall good condition in 2011. At Elves Chasm, live counts of ambersnails remained higher in 2011 than previous years, and habitat at this location was in good condition in 2011 (Sorensen 2012). The population at Vasey's Paradise generally occurs at elevations above 33,000-cfs flows. However, as much as 7.3% of the Vasey's Paradise population occurs below the elevation of 33,000 cfs flow and as much as 16.4% of the population occurs below the elevation of 45,000 cfs flow. The Elves Chasm population is located above the elevation of 45,000-cfs flow (Reclamation 2011d).

TABLE 3.7-1 Habitat and Distribution of Threatened, Endangered, and Sensitive Wildlife Species along the Colorado River Corridor between Glen Canyon Dam and Lake Mead

Common Name	Scientific Name	Status[a]	Habitat and Distribution Downstream from Glen Canyon Dam
Invertebrates			
Kanab ambersnail	*Oxyloma haydeni kanabensis*	ESA-E; AZ-SGCN	Known at only two locations within the Grand Canyon: Vasey's Paradise and Elves Chasm. These spring-fed sites occur along the river corridor. Lives in association with watercress (*Nasturtium*), monkeyflower (*Mimulus* spp.), cattails (*Typha* spp.), sedges (*Carex* spp.), and rushes (*Juncus* spp.).
Amphibians and Reptiles			
Northern leopard frog	*Lithobates pipiens*	AZ-SGCN	Presumably extirpated from Glen and Grand Canyons.
Birds			
American peregrine falcon	*Falco peregrinus*	AZ-SGCN	Common along the river corridor in summer, with about 100 pairs nesting along the cliffs of the inner Grand Canyon. Most migrate south in winter. In the Grand Canyon, common prey items in summer include riparian bird species, many of which feed on invertebrates that emerge out of the Colorado River and the adjacent riparian zone. In winter, a common prey item is waterfowl.
Bald eagle	*Haliaeetus leucocephalus*	AZ-SGCN; BGEPA	Wintering populations are known to occur in Marble Canyon and the upper half of the Grand Canyon. Wintering individuals are known to occur at tributary confluences.
California condor	*Gymnogyps californianus*	ESA-XN; AZ-SGCN	An experimental nonessential population occurs within the Grand Canyon. Releases of condors near the Grand Canyon began in 1996. The beaches of the Colorado River through the Grand Canyon are frequently used by condors for drinking, bathing, preening, and feeding on fish carcasses. An increase in interactions between condors and recreationists within the Grand Canyon has been observed.
Golden eagle	*Aquila chrysaetos*	AZ-SGCN; BGEPA	Rare to uncommon permanent resident and a rare fall migrant. Prefer rugged terrain of cliffs and mesas, and nests on cliff ledges. Migrants use sheer cliffs of the Glen Canyon area to hunt. Feeds on mammals, birds, and reptiles.

TABLE 3.7-1 (Cont.)

Common Name	Scientific Name	Status[a]	Habitat and Distribution Downstream of Glen Canyon Dam
Birds (Cont.)			
Osprey	*Pandion haliaetus*	AZ-SGCN	Large numbers use the Colorado River corridor during fall migration, usually August–September with a peak in late August. An osprey pair successfully nested near the base of Glen Canyon Dam in 2014.
Ridgway's rail (Yuma)	*Rallus obsoletus yumanensis*	ESA-E; AZ-SGCN	Casual summer visitor to marshy mainstem riparian habitats below Separation Canyon (e.g., in the Spencer Canyon and Burnt Springs areas near RM 246 and RM 260, respectively). Sight records in the study area are quite distant from its breeding range on the lower Colorado River.
Southwestern willow flycatcher	*Empidonax traillii extimus*	ESA-E; AZ-SGCN	Observed throughout the Grand Canyon in riparian habitats along the river corridor, including those dominated by invasive tamarisk. In recent years, flycatchers have consistently nested along the river corridor as new riparian habitat, primarily tamarisk, has developed in response to flow regimes. Resident birds have been documented in a small stretch of Marble Canyon and the lower Canyon near the inflow of Lake Mead.
Western yellow-billed cuckoo	*Coccyzus americanus occidentalis*	ESA-T; AZ-SGCN	Known to occur at a number of sites in the Grand Canyon near the Lake Mead National Recreation Area delta. The riparian community at these sites is primarily made up of willow, tamarisk, and seepwillow. In 2006, cuckoos occupied and bred in these sites. However, surveys for this species at these sites resulted in no detections in 2007.
Mammals			
Spotted bat	*Euderma maculatum*	AZ-SGCN	Rarely encountered throughout the State of Arizona, but may occur in areas near cliffs and water sources. Roosts primarily in crevices and cracks in cliff faces. Bats have been known to roost in cliff faces along the river corridor. Foraging may occur in riparian areas in the action area.

[a] ESA = Endangered Species Act; E = listed as endangered; T = listed as threatened; XN = experimental nonessential population; AZ-SGCN = Arizona Species of Greatest Conservation Need; BGEPA = Bald and Golden Eagle Protection Act.

Sources: AZGFD (2001c, 2002d–h, 2003b, 2006b, 2008, 2011a–b, 2012); FWS (1967; 1992; 1995a,b; 1996; 2014b); Gatlin (2013); NatureServe (2014); NPS (2015a); Reclamation (1995, 2007d).

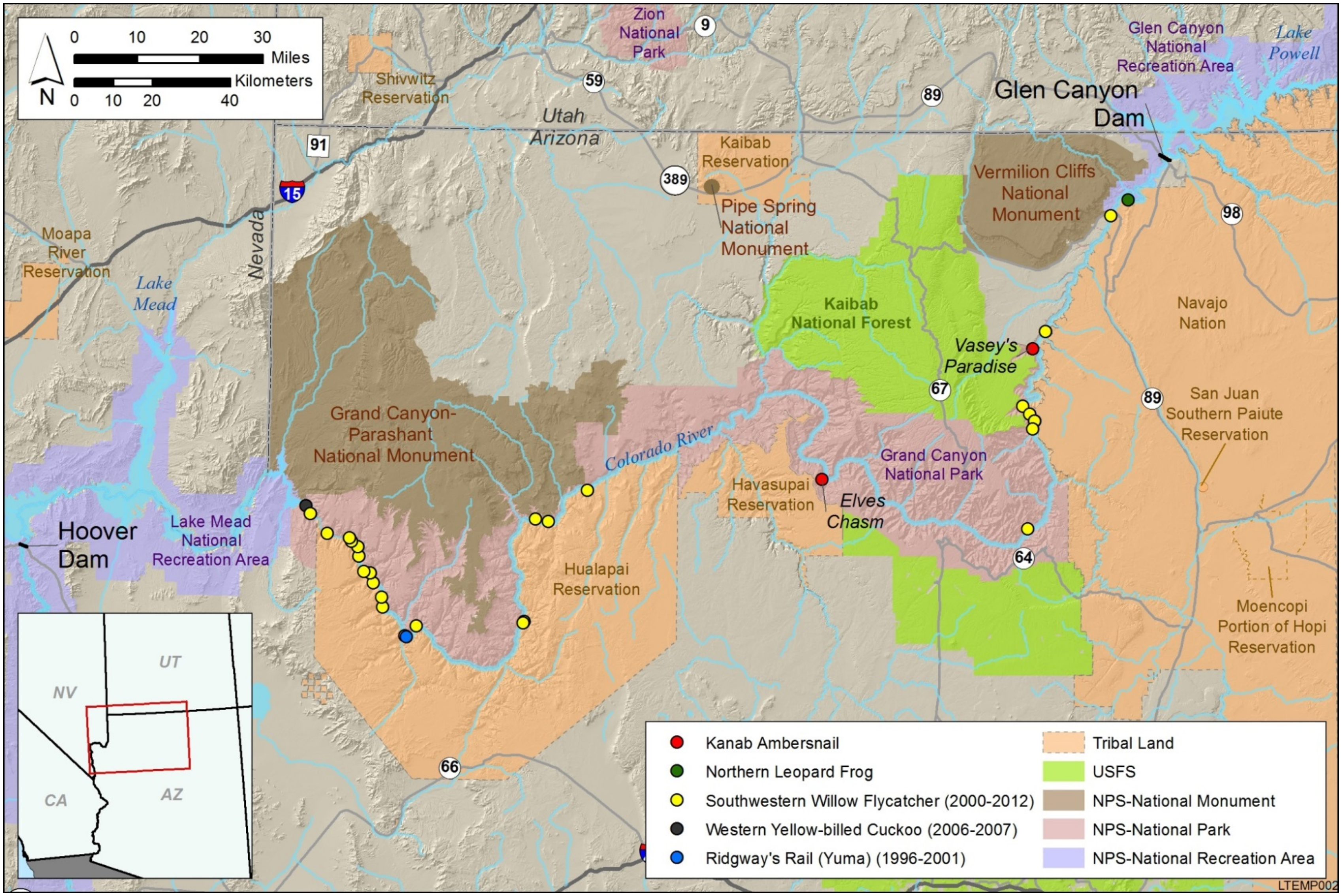

FIGURE 3.7-2 Threatened, Endangered, and Sensitive Species Observed along the Colorado River Corridor (Sources: Drost et al. 2011; FWS 2011b; Johnson et al. 2008; NPS 2013e; Stroud-Settles 2012, 2013)

3.7.5.2 Amphibians and Reptiles

The northern leopard frog (*Lithobates pipiens*) is the only threatened, endangered, or sensitive amphibian or reptile species that occurred recently along the Colorado River downstream from Glen Canyon Dam (Table 3.7-1). Although the northern leopard frog is not listed under the ESA, it is identified as an AZ-SGCN (AZGFD 2012). In 2006, the FWS was petitioned to list the frog in 18 western states but, in 2011, the agency found that listing of this species was not warranted (76 FR 61896). The northern leopard frog occurs in northeastern and north-central Arizona in and near permanent water with rooted aquatic vegetation (AZGFD 2002h). Populations of the northern leopard frog along the lower Colorado River have declined since the construction of Glen Canyon Dam. Leopard frogs have disappeared from 70% of the known sites above and below Glen Canyon Dam, and there appear to be declines among some of the remaining populations (Drost 2005; Drost et al. 2011). Populations above the dam are declining for a number of reasons, particularly due to the introduction of nonnative fishes and changes in habitat. In years when the reservoir is full, nonnative fishes can move into tributary canyons occupied by the northern leopard frog in Glen Canyon.

The leopard frog breeds from mid-March to early June. Females lay up to 5,000 eggs. The tadpoles hatch in about a week and metamorphosis occurs in about 3 months (AZGFD 2002g). Tadpoles consume algae, plant tissue, organic debris, and small invertebrates; while adults prey on invertebrates and rarely small vertebrates (AZGFD 2002h).

The only known population of the northern leopard frog below the dam was located in Glen Canyon in a series of off-channel pools at RM 8.8 (Figure 3.7-2). Marsh habitat at this location was fed by a natural spring. Dominant vegetation included water sedge (*Carex aquatilis*) and southern cattail (*Typha domingensis*). Inundation at this site occurs at approximately 21,000 cfs. Following the experimental flood of 1996, the number of frogs at this location was estimated at a high of 177 individuals (Reclamation 2008c). Since that time, the population size has decreased. In 2004, only two adults were found (Drost 2005), and the northern leopard frog has not been observed since (Drost et al. 2011). It is assumed that the northern leopard frog population at this site has been lost due to loss of pond and marsh habitat. The species is presumed extirpated in Glen and Grand Canyons (downstream from Lees Ferry).

No listed or sensitive reptile species occur in the river corridor downstream of Glen Canyon Dam.

3.7.5.3 Birds

Threatened, endangered, and sensitive bird species that may occur in the aquatic and riparian habitats along the Colorado River downstream of Glen Canyon Dam include the American peregrine falcon (*Falco peregrinus*), bald eagle (*Haliaeetus leucocephalus*), California condor (*Gymnogyps californianus*), golden eagle (*Aquila chrysaetos*), osprey (*Pandion haliaetus*), Ridgway's rail (Yuma) (*Rallus obsoletus yumanensis*), southwestern willow flycatcher (*Empidonax traillii extimus*), and western yellow-billed cuckoo (*Coccyzus americanus occidentalis*). The distribution, habitat, and population trends of these species along the river corridor downstream of Glen Canyon Dam are described below and summarized in Table 3.7-1. The Mexican spotted owl (*Strix occidentalis lucida*; federally listed as threatened) is known to occur in the Grand Canyon but typically inhabits higher elevation forested side canyons above the river corridor (Bowden 2008).

American Peregrine Falcon

The American peregrine falcon was listed as endangered under the ESA on June 2, 1970. Following restrictions on organochlorine pesticides in the United States and Canada, and implementation of various management actions, including the release of approximately 6,000 captive-reared falcons, recovery goals were substantially exceeded in some areas, and on August 25, 1999, the falcon was removed from the federal list of threatened and endangered species (FWS 1999). This species is identified as an AZ-SGCN (AZGFD 2012).

Although peregrine falcons are uncommon year-round residents in the project area, the population has gradually increased since the 1970s (Carothers and Brown 1991). Peregrine falcons, which generally mate for life, nest regularly in Marble Canyon between Lees Ferry and the Little Colorado River confluence where cliffs >150 ft are abundant (Schell 2005). About 100 pairs of peregrine falcons nest along the cliffs of the inner Grand Canyon (NPS 2014c). In Arizona, peregrine falcons return to breeding areas from mid-February to mid-March, with egg laying occurring anytime from mid-March through mid-May. Fledging occurs from May to August (AZGFD 2002g). In the Grand Canyon, common prey items in summer include the white-throated swift (*Aeronautes saxatalis*), swallows, other song birds, and bats (Carothers and Brown 1991; Stevens et al. 2009). In winter, most adult falcons migrate south. For those falcons that remain for the winter, waterfowl is a common prey item (Schell 2005).

Bald Eagle

The bald eagle was originally listed as an endangered species under the ESA in 1967 and down-listed to threatened status in 1995. It was removed from the federal list of threatened and endangered species on July 9, 2007 (FWS 2007b). It is still federally protected under the BGEPA. This species is identified as an AZ-SGCN (AZGFD 2012).

A wintering concentration of bald eagles was first observed in the Grand Canyon in the early 1980s, and numbers had increased by 1985 (Brown et al. 1989; Brown and Stevens 1997). Territorial behavior, but no breeding activity, has been observed in the canyon. This wintering population was monitored through the 1980s and 1990s in Marble Canyon and the upper half of the Grand Canyon. The number of Grand Canyon bald eagles during the winter (late February and early March) ranged from 13 to 24 birds between Glen Canyon Dam and the Little Colorado River confluence from 1993 to 1995 (Sogge et al. 1995). A concentration of wintering bald eagles often occurred in late February at the mouth of Nankoweap Creek, where large numbers of rainbow trout congregated to spawn (Gloss et al. 2005). However, a flash flood destroyed the trout spawning habitat and separated the tributary mouth from the Colorado River, so the eagles no longer congregate at that tributary. Small numbers of wintering eagles (1–3) have also been noted around Bright Angel Creek, presumably also preying on nonnative fish. Since 1996, the number of wintering bald eagle observations in the Grand Canyon has declined.

California Condor

The California condor was listed as an endangered species under the ESA on March 11, 1967 (FWS 1967), and is identified as an AZ-SGCN (AZGFD 2012). By the 1930s, it was considered extirpated from the State of Arizona (NPS 2014c). A captive rearing program was initiated in 1983 to assist in recovery efforts. On October 16, 1996, it was announced that a nonessential population of condors would be established in northern Arizona (FWS 1996). On October 29, 1996, six condors were released at Vermillion Cliffs near Glen Canyon. Since that time, there have been additional releases, and the experimental population that inhabits the Grand Canyon as of September 2014 included 76 individuals (NPS 2014c). California condors are opportunistic scavengers, preferring carcasses of large mammals, but they will also feed on rodents and fish. Depending on weather conditions and the hunger of the bird, a California condor may spend most of its time perched at a roost. Roosting provides an opportunity for preening, other maintenance activities, and rest, and possibly facilitates certain social functions (FWS 1996). Nest sites often occur in caves and rock crevices (NPS 2014c).

California condors often use traditional roosting sites near important foraging grounds. Cliffs and tall conifers, including dead snags, are generally used as roost sites in nesting areas. Although most roost sites are near nesting or foraging areas, scattered roost sites are located throughout their range. California condors frequent beaches of the Colorado River through the Grand Canyon (Reclamation 2011b). Activities include drinking, bathing, preening, and feeding on fish carcasses. Condor monitors noted an increase in interaction between rafters and condors in 2002 as rafting parties sought out unused beaches for lunch stops, exploration, and close observance of condors. There have been several instances of immature condors approaching campsites.

Golden Eagle

The golden eagle is federally protected under the BGEPA and is identified as an AZ-SGCN (AZGFD 2012). It is a rare to uncommon permanent resident and a rare fall migrant throughout the region (Gatlin 2013). Preferred habitat is rugged terrain of cliffs and mesas, with nests built of large sticks on cliff ledges (NPS 2015a). Nesting has been documented from several areas of GCNRA. From November through March, the golden eagle can be observed on the high cliffs around Lake Powell (NPS 2015a). Winter aerial surveys have documented 3 to 25 individuals per survey. Since 2002, there has been a steady decline in golden eagle numbers within the Glen Canyon region (Spence et al. 2011). The golden eagle generally feeds on small mammals (e.g., rabbits and ground squirrels), but it also preys on large insects, birds, reptiles, and carrion, and can feed on mammals up to the size of small deer (NatureServe 2014; NPS 2015a).

Osprey

Although the osprey is not listed under the ESA, it is identified as an AZ-SGCN (AZGFD 2012). Reclamation (1995) stated that the osprey was a rare fall, spring, or accidental transient in the Grand Canyon. However, large numbers of ospreys now use the Colorado River corridor during fall migration, usually August–September with a peak in late August. There can be 10 to 12 individuals between Glen Canyon Dam and Lees Ferry on any given day during that period. An osprey pair nested near the base of Glen Canyon Dam in 2014 and 2015. In 2014, three eggs were laid and, although all three hatched, only one hatchling survived to fledge (Spence 2014a). One hatchling also fledged in 2015. Because nest sites are typically used for many years (AZGFD 2002f), this nest may be used in the future. The osprey feeds almost exclusively on fish, although it will also prey on snakes, frogs, shorebirds, and waterfowl (AZGFD 2002f).

Ridgway's Rail (Yuma)

The Yuma clapper rail (now known as the Ridgway's rail [Yuma]) was listed as endangered under the ESA in 1967 (FWS 1967) and is identified as an AZ-SGCN (AZGFD 2012). It inhabits marshes dominated by emergent plants. Emergent plant cover is more important than the plant species or marsh size. Areas with high coverage by surface water, low stem density, and moderate water depth are used for foraging; sites with high stem density and shallower water near shorelines are used for nesting (Reclamation 2008d). Generally, it is associated with dense riparian and marsh vegetation dominated by cattails and bulrush with a mix of riparian tree and shrub species (NPS 2013e). It is a casual summer visitor to marshy mainstem riparian habitats along the Colorado River below Separation Canyon (Figure 3.7-2). These sightings are far from the species' breeding range on the lower Colorado River (Gatlin 2013). Individuals were recorded in GCNP from 1996 to 2001. The Ridgway's rail (Yuma) was observed between Spencer Canyon (RM 246) and the GCNP boundary (RM 277), with nesting confirmed in 1996. Individuals have also been observed near Burnt Springs (near RM 260). It is not known whether cattail habitat is present in sufficient quantities to support nesting (NPS 2013e). Ridgway's rails (Yuma) feed on a variety of aquatic and terrestrial invertebrates, and on small fish and amphibians. A minor component of its diet consists of plant matter (e.g., seeds and twigs) (Reclamation 2008d). Threats to rails come from fluctuating flows during the breeding season (March–August) when there are eggs, less-mobile young birds, or flightless adults in the molting season (August).

Southwestern Willow Flycatcher

The southwestern willow flycatcher (flycatcher) is a neotropical migrant that nests in dense riparian habitats in the six southwestern states of California, Nevada, Utah, Colorado, Arizona, and New Mexico. The Pacific lowlands of Costa Rica appear to be a key winter location for the southwestern willow flycatcher, although other countries in Central America may also be important (Paxton et al. 2011). This subspecies of the willow flycatcher was listed as endangered under the ESA in 1995 (FWS 1995b). It is identified as an AZ-SGCN

(AZGFD 2012). Historically, the range of the flycatcher in Arizona included portions of all major watersheds (FWS 2002b); however, these watersheds have changed in many cases. As a result, most of the areas where flycatchers were locally abundant now support few or no individuals (FWS 2002b). Habitat and population numbers of southwestern willow flycatchers have declined in recent decades due to several factors, including loss, degradation, and fragmentation of riparian habitat; invasion by nonnative plants; brood parasitism by brown-headed cowbirds; and loss of wintering habitat (Stroud-Settles et al. 2013). Under the species recovery plan (FWS 2002b), the Colorado River downstream of Glen Canyon Dam falls within the Middle Colorado Management Unit delineated within the Lower Colorado Recovery Unit. Critical habitat for the southwestern willow flycatcher has not been designated by the FWS between Glen Canyon Dam and Lake Mead (FWS 2005, 2013b).

The southwestern willow flycatcher eats insects and needs riparian habitats to complete its life cycle. It breeds and forages in dense, multi-storied riparian vegetation near saturated soils, slow-moving water, or surface water (Sogge et al. 1995). The southwestern willow flycatcher breeds across the lower southwest from May through August (Reclamation 2007d). The southwestern willow flycatcher arrives on the breeding grounds throughout May and early June, eggs are generally laid beginning in May, and fledging occurs between June and August (Sogge et al. 1997, 2010). Occupied sites most often have a patchy interior of dense vegetation or dense patches of vegetation intermingled with openings. Most often, this dense vegetation occurs within the first 3 to 4 m above the ground (FWS 2002b). The structures of occupied patches vary, with a scattering of small openings, shorter vegetation, and open water. Occupied patches can be as small as two acres and as large as several hundred acres, but are typically >10 m wide (Reclamation 2007d).

The southwestern willow flycatcher historically nested in native plants such as willows, buttonbush, boxelder, and seepwillow (Stroud-Settles et al. 2013). It also nests in patches dominated by exotic plant species such as tamarisk and Russian olive (Sogge et al. 1997; Stroud-Settles et al. 2013). The Grand Canyon does not provide extensive stands of dense riparian habitat suited for breeding willow flycatchers. The majority of habitat patches in the Grand Canyon lack a consistent, dependable source of water for maintaining moist/saturated soil conditions and/or slow-moving or standing surface water (Stroud-Settles et al. 2013). As a result, the majority of flycatcher habitats in the Grand Canyon are marginal and, unless current hydrological conditions change, these patches will likely continue to decline. Furthermore, the recent arrival of the tamarisk leaf beetle has transformed and will continue to transform the patches of dense tamarisk into unpredictable, diminished patches (Stroud-Settles et al. 2013).

Surveys for the flycatcher have occurred in the Grand Canyon, mainly along the main stem of the river corridor, since 1982. The number of nesting flycatcher detections have declined since the 1980s, and nesting flycatchers have not been confirmed in the Grand Canyon since 2007. Except for 2008, when no nests were identified, nest surveys were not conducted between Lees Ferry and Phantom Ranch between 2007 and 2012. No nest surveys occurred between Phantom Ranch and Diamond Creek between 2005 and 2012, and no nest surveys occurred between Diamond Creek and Pearce Ferry between 2009 and 2012 (no nests were observed during surveys made in 2008) (Stroud-Settles et al. 2013). There is little information on the number of flycatchers present along the river before the construction of Glen Canyon Dam.

However, what data are available suggest that historically flycatchers were not common breeders along the Colorado River in the Grand Canyon (Sogge et al. 1997; Stroud-Settles et al. 2013). Studies conducted along the river from 1982 to 1991 and from 1992 to 2001 detected 14–15 breeding pairs per decade of surveys between Lees Ferry and Phantom Ranch (Stroud-Settles et al. 2013).

The river stretch from Lees Ferry to Phantom Ranch has been surveyed most consistently since 1982 and best represents the potential trend of the flycatcher in Grand Canyon (Stroud-Settles et al. 2013). There has been a noticeable decrease in the detection of breeding pairs since the 1990s along this stretch of river. The river stretch from Phantom Ranch to Diamond Creek has infrequent habitat patches. Surveys did not occur along this stretch until the 1990s and have produced minimal detections. The previous studies along the Diamond Creek–Pearce Ferry river stretch have varied considerably. A 5-year boost in detections along this stretch of river that occurred from 1997 to 2001 is likely due to favorable water levels of Lake Mead in combination with increased survey effort (Stroud-Settles et al. 2013). Surveys for the presence of southwestern willow flycatchers were conducted between Lees Ferry and Pearce Ferry in spring and early summers of 2010 through 2012. Ten individuals were detected during this period. All detections occurred on single occasions at a site, and not detected again in subsequent surveys. Detections were made at RMs 28.5, 50.3–50.7, 51.8–52, 183.5, 196.4, 217.6, 218, and 275. Although nest surveys were not conducted, 46 sites within the Grand Canyon were assessed for their suitability as southwestern willow flycatcher breeding habitat. Ten sites were designated as suitable habitat and 20 as potential habitat. These sites were located between RM 28.5 and RM 275 (Stroud-Settles et al. 2013).

The Colorado River corridor continues to provide essential habitat for migrating southwestern willow flycatcher, but the presence of breeding flycatchers is less common. Suitable habitat patches below Diamond Creek need to be surveyed more frequently, and any suitable sites should be at the forefront for habitat improvement and restoration work (Stroud-Settles et al. 2013).

Western Yellow-billed Cuckoo

The western yellow-billed cuckoo distinct population segment was designated as a threatened species under the ESA on October 3, 2014 (FWS 2014b). This species is also identified as an AZ-SGCN (AZGFD 2012). Proposed designated critical habitat does not occur between Glen Canyon Dam and Lake Mead. A 24-km continuous segment of the Colorado River between the upstream end of Lake Mead and the Kingsmen Wash area in Mohave County is the closest unit of proposed designated critical habitat (FWS 2014a).

The western yellow-billed cuckoo is a neotropical migrant bird that breeds and summers in northern Mexico and the western United States. Cuckoos were once considered abundant throughout the riparian floodplain along the lower Colorado River (Table 3.7-1). However, cuckoo populations have suffered severe range contractions during the last 80 years; currently western populations breed in localized areas of California, Arizona, New Mexico, western Texas, and northern Mexico, with irregular breeding in Utah and western Colorado

(Johnson et al. 2008). Factors that have contributed to population declines of the western yellow-billed cuckoo include habitat loss, fragmentation, and degradation of native riparian breeding habitat; possible loss of wintering habitat; limited food availability; and pesticide use (Johnson et al. 2010; FWS 2014a).

The western yellow-billed cuckoo requires structurally complex riparian habitats with tall trees and a multi-storied vegetative understory. It rarely nests (2.5% of nests) in areas dominated by tamarisk (Johnson et al. 2010; Schell 2005). In Arizona, western yellow-billed cuckoo occur most often in sites dominated by native tree species and at lower numbers in habitats consisting of mixed native or >75% tamarisk cover (Johnson et al. 2010). It forages almost entirely in native riparian habitat, as the large caterpillars on which it feeds depend on cottonwoods and willows and do not occur on tamarisk (FWS 2014a). It may be unreasonable to expect the Grand Canyon to serve as functional breeding habitat for the western yellow-billed cuckoo due to inadequate riparian vegetation conditions (Schell 2005). Suitable habitat may have been limited, as pre-dam floodplain terraces were neither abundant nor generally sufficiently wide in the Grand Canyon.

The western yellow-billed cuckoo is known to occur at a number of sites in the lower Grand Canyon near the Lake Mead delta (Figure 3.7-2). The riparian community at these sites is primarily made up of willow, tamarisk, and seepwillow. In 2006, cuckoos occupied and bred in these sites. However, drops in Lake Mead water levels lower the water table and stress the vegetation at these sites. Surveys for this species at these sites resulted in 29 cuckoo detections in 2006 and no detections in 2007 (Johnson et al. 2008).

3.7.5.4 Mammals

The only threatened, endangered, or sensitive mammal species that may occur in riparian areas within the action area is the spotted bat. The spotted bat is not federally listed but is identified as an AZ-SGCN (AZGFD 2012). It is rarely encountered in Arizona, but may occur in areas where cliffs and water sources are nearby. Most individuals are observed in dry, rough desert shrublands or in pine forest communities. Roost sites are presumed to be crevices and cracks in cliff faces (AZGFD 2003b). The spotted bat is active in winter, particularly if hibernacula have low humidity. It tends to be relatively solitary but may hibernate in small clusters (AZGFD 2003b). Dominant prey items are moths, but also include June beetles and sometimes grasshoppers that are taken while on the ground (AZGFD 2003b).

3.7.6 Tribal Perspectives on Wildlife

Riparian and terrestrial wildlife play an important role in Tribal culture and religion. The loss of animals or plants may have a negative cultural impact on the life of the Tribes in the region.

In the Zuni belief system, as Winston Kallestewa explained (in Dongoske and Seowtewa 2013), “All animals are our ancestors that have come back to life in a different form—

that is why all living beings, even the smallest insect, are important to the Zuni people." Dickie Shack explained (in Dongoske and Seowtewa 2013) that common animals such as lizards play a role in Ant Medicine Society prayers, prayers so ancient that they are spoken in an archaic language, learned when the Zunis were on their migration. In addition, animals, plants, and insects play a fundamental role in Zuni clan identity and collectively as Zuni people. All animals came out of the underworld with the Zunis. They are all important because they have a purpose explained in Zuni religion and cannot be killed indiscriminately. Wildlife are the spiritual beings of the ancestors for the Zuni people and are mentioned in prayers and songs (Dongoske and Seowtewa 2013). Birds are incorporated into nearly every aspect of Zuni life (Ladd 1963). Because they are viewed as messengers from the ancestral celestial beings, their appearance is closely watched. Consequently, Zunis are generally excellent ornithologists. In discussing the cultural importance of birds with Zuni cultural advisors, one becomes quickly amazed at the accuracy and consistency with which they distinguish closely related species, and are able to relate precisely the season when each species is present. Throughout the migration of the Zuni people to find the Middle Place, they were also helped by birds: a raven took the bitterness away from the corn the Zunis had harvested and made it palatable; an owl helped them by making the corn which they had harvested soft enough to eat. Although birds are probably the most important animals to Zuni, they are far from the only animals that Zunis view as religiously or culturally important. All animals have their place of reverence in Zuni cosmology (Tyler 1964). As mentioned above, even if Zunis did not need to collect any of these animals, their appearance is emblematic and auspicious of natural events, or human's response to them. During the Zunis' effort to emerge and reach the upper world, they were helped by small creatures: a locust who, like the three birds before him, attempted to reach the upper world, and a spider and a water strider who eventually direct the Zuni people to Halona-itiwana, the Middle Place. Zunis have a special relationship with water creatures, and this stems from events during their search for the Middle Place.

The Navajo perspective is that bighorn sheep, deer, wild horses, beaver, foxes, mountain lions, red-tailed hawks, owls, eagles, yellowbirds, bluebirds, black tipped birds, vultures, crows, butterflies, and many other species of wildlife were and continue to be hunted for food, ceremonial equipment, and other uses for the Navajo people. Wildlife are essential to all aspects of Navajo life. The river forms a natural boundary that protects the Navajo and helps to define the extent of Navajo land; it protects the Navajo and provides many things to Navajo people. Offerings are made to the river for protection. The water is used in a lot of ways and can lead to a good way of life for all people, and that is why people make offerings to the river. If this is not done, then the people will scatter. The offerings are much like the ones offered to the sacred mountains (Roberts et al. 1995).

For the Hopi, snakes and other reptiles play valued cultural roles in history and ceremonial activities. The presence of the Snake and Lizard clans at Hopi testifies to their ongoing importance. The Snake ceremony has its origins in the Canyons and is associated with the journeys of Tiyo down the Colorado River (Eggan 1971). Birds are a valuable cultural resource to the Hopi people. Feathers of a great many species are used in ceremonial and ritual contexts. Of particular importance are eagles, whose nests are viewed as shrines and used as receptacles for prayer offerings. Maintaining healthy populations of birds is part of the overall balance of the world.

Bighorn sheep are revered and culturally significant for nearly every Tribe with historical ties to the Grand Canyon. Historically, they were important for food, hides, and materials used in making tools and implements. The Havasupai have a close cultural affinity with the bighorn sheep and do not hunt them. The ram horns feature in the Tribal seal and Tribal identity. They furthermore figure prominently in cosmology and star lore, and are considered relatives that, when the need arises, give up their life to provide sustenance.

3.8 CULTURAL RESOURCES

Cultural resources are typically categorized as archeological resources, historic and prehistoric structures, cultural landscapes, traditional cultural properties, ethnographic resources, and museum collections. Many natural resources, such as plants and plant gathering areas, water sources, minerals, animals, and other ecological resources, are also considered cultural resources, as they have been integral to the identity of Tribes in various ways. For some Tribal people, archaeological resources are considered to be markers left by their ancestors, the embodiment of those who came before and are imbued with the spirits of the ancestors. They represent a physical link to the past. The physical attributes of cultural resources are often nonrenewable, especially archaeological sites, which often represent ancestral homes for the park's traditionally associated Tribes.

The National Historic Preservation Act (NHPA) is the overarching law concerning the management of historic properties on federal lands. Numerous other regulatory requirements pertain to cultural resources and are presented in Chapter 1. Historic properties are a subset of cultural resources. Historic properties are defined in the NHPA (16 USC § 470w(5)) as any "prehistoric or historic district, site, building, structure, or object included in, or eligible for inclusion on, the National Register of Historic Places, including artifacts, records, and material remains related to such a property or resource." Historic properties must be taken into consideration during the planning of federal projects. Historic properties can be either man-made or natural physical features associated with human activity and, in most cases, are finite, unique, fragile, and nonrenewable. For example, historic properties can include traditional cultural properties (TCPs), which are properties that are important to a community's practices and beliefs and that are necessary for maintaining the community's cultural identity. Historic properties can also include certain archeological sites or historic districts, such as the Lees Ferry and Lonely Dell Ranch Historic District, containing multiple interrelated archaeological or historic elements. Under the NHPA, the American Indian Religious Freedom Act, and Executive Order 13007, federal agencies are also required to consider the effects of their actions on sites, areas, and other resources (e.g., plants) that are of cultural and religious significance to Native Americans, Native Alaskans, and Native Hawaiians. Native American graves, funerary objects, sacred objects, or objects of cultural patrimony are protected by the Native American Graves Protection and Repatriation Act. Also under the GCPA, cultural resources were identified as one of the resources that must be protected, mitigated, and improved, in a manner fully consistent with and subject to Section 1802(b) of the GCPA.

Historic properties on federal lands are managed primarily through the application of laws, regulations, executive orders, and policies. Guidance on the application of these laws is provided through various means. Most federal agencies have published guidance on how to appropriately manage historic properties on their lands. Guidance for historic property management in all NPS units comes from the *NPS Management Policies 2006* (NPS 2006d) and NPS-28, *Cultural Resource Management Guideline* (NPS 1998). Park-specific guidance for GCNP and GCNRA is provided through both parks' General Management Plan and the GCNP Colorado River Management Plan (CRMP). Additional direction in GCNP is derived from the 2010 Foundation Statement and, for GCNRA, the 2015 Foundation Statement. The Reclamation policy concerning cultural resources is outlined in Policy LND P01, which ensures compliance with existing cultural resource law and Directives and Standards LND 02-01, which identifies Reclamation's roles and responsibilities as they relate to cultural resources.

The management of historic properties along the Colorado River in GCNP and GCNRA is guided by NHPA and NPS-28. Several agreements have been executed resulting from environmental studies concerning the operation of Glen Canyon Dam and the management of the resources in the two national park units. The 1995 EIS for operations of Glen Canyon Dam (Reclamation 1995) was accompanied with the signing of an NHPA Section 106 Programmatic Agreement (PA) in 1994. The agreement was among the Arizona State Historic Preservation Office, the Advisory Council on Historic Preservation, Reclamation, NPS, the Hopi Tribe, Hualapai Tribe, Kaibab Paiute Tribe, Navajo Nation, Shivwits Paiute Tribe, and the Pueblo of Zuni. The 1994 PA addressed management of more than 300 cultural resources that could be affected by dam operations. These sites included the 323 sites that compose the Grand Canyon River Corridor Historic District. As agreed to by the signatories of the 1994 PA, a new PA is being developed in conjunction with the LTEMP EIS based on research and monitoring along the river and the resulting new information accumulated since 1996. This draft PA currently is being developed as allowed in Title 36, *Code of Federal Regulations,* Part 800.14(1) (ii) (36 CFR 800.14 b(1) (ii)) when effects on historic properties cannot be fully determined prior to approval of the undertaking. The draft PA outlines general and specific measures Reclamation (as lead federal agency for operation of Glen Canyon Dam and with responsibility for the NHPA Section 106 mitigation of effects from dam operations) and the NPS will take to fulfill their responsibilities regarding the protection of historic properties under the NHPA.

The NHPA applies to federal undertakings and undertakings that are federally permitted or funded. The regulations implementing Section 106 of the NHPA, codified at 36 CFR Part 800, define the process for identifying historic properties and for determining if an undertaking will adversely affect those properties. The regulations also establish the processes for consultation among interested parties, the agency conducting the undertaking, the Advisory Council on Historic Preservation (ACHP), State Historic Preservation Officers (SHPOs), Tribal Historical Preservation Officers (THPOs), and for government-to-government consultation between federal agencies and American Indian Tribal governments. The NHPA, in Section 106, addresses the appropriate process for mitigating adverse effects. The implementing regulations also address the process for mitigating adverse effects.

3.8.1 Area of Potential Effect

NHPA compliance includes the definition of an Area of Potential Effect (APE), which is defined in 36 CFR 800.16(d) as:

> Area of potential effects means the geographic area or areas within which an undertaking may directly or indirectly cause alterations in the character or use of historic properties, if any such properties exist. The area of potential effects is influenced by the scale and nature of an undertaking and may be different for different kinds of effects caused by the undertaking.

The undertaking is the proposed operation of Glen Canyon Dam for a period of 20 years under the LTEMP, including any related non-flow actions that could affect historic properties. Dam operations under the LTEMP are anticipated to continue to include recurring flows that may fully utilize the capacity of the powerplant turbines and bypass tubes (i.e., HFEs). The undertaking may include LTEMP activities other than Glen Canyon Dam operations (i.e., non-flow actions such as vegetation management, nonnative fish monitoring, and fish control).

Regulations by the Council on Environmental Quality (CEQ) encourage, "[t]o the fullest extent possible" that National Environmental Policy Act of 1969, as amended (NEPA) documents be "integrated with environmental impact analyses and related surveys and studies required by the . . . National Historic Preservation Act of 1966" (Section 1502.25 in CEQ 1978). Regulations by the ACHP contain similar goals (Section 800.8 in ACHP 2004). Accordingly, this LTEMP EIS describes the compliance process that is ongoing pursuant to Section 106 of the NHPA.

While the NHPA process is described in this LTEMP EIS, NHPA and NEPA each require a different consultation process, different legal standards, and different concluding documents, even though some aspects are similar. NEPA analyzes the impact of "proposed actions" and their alternatives (here, Glen Canyon Dam operations and non-flow actions identified in the LTEMP) on the "affected environment." The "affected environment" includes a broad range of resources, such as biological, socioeconomic, aquatic, cultural, and recreation resources.

The NHPA focuses on effects on "historic properties" (properties that are eligible for or listed on the *National Register of Historic Places* [NRHP]) rather than NEPA's focus on the effects on a broader range of resources. Specifically, the NHPA requires consultation on the potential for an "undertaking" (here, Glen Canyon Dam operations and non-flow actions identified in the LTEMP) to affect "historic properties" within a designated "area of potential effect."

The APE for NHPA purposes may be geographically different from the affected environment for NEPA purposes. Here, several of the Tribes participating in the NHPA consultation process have indicated that the Canyons as a whole are a place of great cultural importance and requested an APE for the undertaking that extends "rim-to-rim" of the affected Canyons. This APE is geographically different than the affected environment defined in the

LTEMP EIS, and it specifically focuses on analyzing effects on historic properties rather than NEPA's analysis of the effects of an action on a broader array of resource conditions. The NHPA undertaking will be addressed within the geographic scope of the APE per NHPA standards, just as the NEPA proposed action will be addressed within the geographic scope of the affected environment per NEPA standards. A different geographic scope for the APE under the NHPA is limited to NHPA purposes and does not expand the scope of the affected environment for NEPA purposes.

For the purposes of the Section 106 process, Reclamation has defined the APE in the draft PA (available at the time of printing of this final EIS) as:

> …the area of direct or indirect effects to the character or use of historic properties on the Colorado River Corridor in Glen, Marble, and Grand Canyons from Glen Canyon Dam to the western boundary of Grand Canyon National Park, including direct or indirect effects that may be caused to historic properties by the Undertaking from rim to rim of the canyons.

There are a number of ways in which dam operations may affect cultural resources, including the periodicity of inundation and exposure, changing vegetation cover, streambank erosion, slumping, and influencing the availability of sediment. Direct and repeated inundation/exposure may affect resources such as the Spencer Steamboat, which is in the active channel (Figure 3.8-1), or Pumpkin Springs, a TCP along the bank that is subject to inundation during high flows (e.g., equalization flows and HFEs). Streambank erosion, slumping, flow-related deposition, and indirect effects of deposition may affect cultural resources contained within terrace contexts in proximity to inundated areas. Fine sand or sediment can be blown from flow-deposited source areas and deposited on cultural sites (East et al. 2016) (Figure 3.8-2). The effects of deposition or erosion may be negative or positive depending on the nature of the site. One important recent finding is that sandbars created by high-flow events at Glen Canyon Dam can provide sources of windblown sand that can cover archaeological sites (East et al. 2016) as well as anneal, or reverse, the formation of gullies (Sankey and Draut 2014). In this context, changes in dam operations can affect erosion rates on archaeological sites (East et al. 2016, Collins et al. 2016). In addition, bank deposition and aeolian transport of sediment can affect the character of other types of TCPs. The activities of research and monitoring may also have the potential to negatively affect the character-defining elements of archaeological sites and TCPs.

For purposes of this analysis, a review of sites inventoried and monitored as of 2016, and additional analysis performed by Reclamation and NPS working with USGS and GCMRC researchers using their classification system cited above,[9] it was determined that up to

[9] USGS and GCMRC developed a system for classifying the geomorphic settings of archaeological sites, based on the degree to which they can receive windblown sand from deposits from recent HFEs, to address how archeological sites are linked to modern river processes (East et al. 2016). Surveys have documented approximately 300 to 500 archaeological sites in the river corridor of Glen, Marble, and Grand Canyons. As of January 2015, USGS had examined 358 sites in GCNP to establish the potential effects of windblown sands at these locations. This review did not include a small number of sites in GCNRA, which are expected to be classified by GCMRC in 2016.

FIGURE 3.8-1 Spencer Steamboat (Photo by Susanna Pershon, Submerged Cultural Resources Unit, NPS)

FIGURE 3.8-2 A Roasting Pit Feature (Prehistoric Food Preparation Location) in a Grand Canyon Dune

220 archeological and historic site properties could be affected by dam operations or non-flow aspects of this NEPA action. Determinations of eligibility have been completed for all known properties. Additional information, including inventory and monitoring, data recovery activities, and completion of determinations of eligibility for sites along the river, are continuing to provide up-to-date information on sites potentially affected.

3.8.2 Description of Cultural Resources and Site Types

Glen, Marble, and Grand Canyons are significant for their human history and their ongoing roles in the lives and traditions of today's American Indians of the Colorado Plateau. Archaeologists generally divide the nearly 12,000 years of human history of the Grand Canyon region into six broad periods: Paleoindian, Archaic, Formative, Late Prehistoric, Protohistoric, and Historic. The human story is represented in each of these periods along the Colorado River from Glen Canyon Dam to Lake Mead. What follows is a description of the Western Euro-American (i.e., non-Tribal) view of the types of cultural resources and the time frames into which those resources fall (see Section 3.9 for the Tribal view of the history and meaning of the Grand Canyon).

3.8.2.1 Archaeological Resources

Archaeological resources are defined as "any material remains or physical evidence of past human life or activities which are of archeological interest, including the record of the effects of human activities on the environment. They are capable of revealing scientific or humanistic information through archeological research" (NPS 2006b).

Archaeological research along the Colorado River corridor in Glen and Grand Canyons began in 1869 with the first report of ruins by John Wesley Powell (Powell 1875). In the early 1930s, professional archeology began in the region with Julian Steward's work in the Lees Ferry area (Steward 1941). Later, in 1953, Walter Taylor began work along the Colorado River in the Grand Canyon (Taylor 1958). From 1956 through 1963, one of the largest single archeological salvage projects in the United States was undertaken in the Glen Canyon region to mitigate for the construction of Glen Canyon Dam (Jennings 1966). Because dam construction predated the passage of NHPA in 1966, pre-dam mitigation was conducted under the auspices of the Historic Sites Act of 1935 and then the Reservoir Salvage Act of 1960. Pre-dam mitigation was performed by the University of Utah, the Museum of Northern Arizona, and the NPS.

For the pre-dam mitigation effort, archeological salvage was limited to the north and south sides of the Colorado River above the dam up to Hite, Utah, and to portions of the San Juan River. No survey and excavation occurred below the site of Glen Canyon Dam. A complete archaeological inventory of the river corridor, encompassing all traversable terrain between Glen Canyon Dam and Separation Canyon from the river up to and including pre-dam river terraces, was completed in 1991 for the 1995 Glen Canyon Dam EIS (Fairley et al. 1994). This and subsequent survey efforts have documented nearly 500 properties in the near-shore environment of the river from Glen Canyon Dam to Lake Mead.

To help understand what they encounter, archaeologists divide human history into sequential periods on the basis of distinctive changes in technology, subsistence practices, and/or sociopolitical organization. Below are descriptions of these periods and the types of archaeological resources typical for those periods that are found along the Colorado River from Glen Canyon to Lake Mead. The following discussion is based on chronological divisions in general use in the American Southwest, as modified for the Grand Canyon region by Fairley (2003). Details of individual sites and determinations concerning which sites could be affected and how many potential effects may be mitigated will be addressed through the PA process.

Classifications and distinctions described in this section are based on physical archeological evidence and do not incorporate ethnohistoric data. Many Tribes' oral histories and perspectives do not necessarily agree with the classifications and distinctions described in this section.

PaleoIndian Period (10,000–6,000 BC)

Sites from this time period are characterized by very distinctive spear points used to hunt large animals such as mammoth, sloth, bear, and wolf. These distinctive spear points are found across Arizona, New Mexico, and Texas. Three locations within GCNP have yielded fragmentary spear points dating from this Clovis and Folsom tradition. Three additional sites in the western Grand Canyon are also believed to contain Paleoindian artifacts. Within GCNRA, Paleoindian points have been found at six sites. Five were found in the northernmost part of the park and one west of Lees Ferry. These sites reflect characteristics of the Clovis, Folsom, and Plano technological complexes of the Paleoindian period.

Archaic Period (6,000–500 BC)

Sites dating from this time period contain smaller, but distinctive, projectile points (dart points). There is also evidence of experimentation with cultivating plants. Artifacts include small processing stones such as one-handed manos and grinding slabs, and abundant plant remains found in a trash context. These items suggest increased activities toward plant processing and more reliance on plants as a food source than was evident during the Paleoindian Period. Elaborate multicolored rock art and split-twig figurines found in cave settings are hallmarks of the Grand Canyon Archaic Period. Archaic Period sites include hunting blinds, lithic scatters at meadow edges and water holes, temporary camps, rock art, and split-twig figurine caches (Figure 3.8-3). Another distinctive aspect of the Archaic cultural history along the Colorado River corridor in GCNRA during the Archaic Period is a certain distinctive style of petroglyphs known as the Glen Canyon Linear Style (Figure 3.8-4).

Formative: Basketmaker Period (500 BC–700 AD)

This period is distinguished by extensive use of baskets, sandals, and textiles, and some important technological advancements, such as the development of the bow and arrow and the

FIGURE 3.8-3 An Archaic Period Site on the Colorado River in GCNP

FIGURE 3.8-4 Glen Canyon Linear Style Petroglyph in GCNRA

beginnings of pottery manufacture. Habitations are often single pit houses with bell-shaped pits dug for storage. There is evidence of increased reliance on cultivated plants, primarily corn and squash. The western Grand Canyon has the largest concentration of sites from this time period within the Grand Canyon.

Formative: Ancestral Puebloan and Cohonina (700–1300 AD)

Typical of these periods are the distinctive masonry structures and apartment-like dwellings (pueblos) that the ancestral Puebloan people lived in during this time (Figure 3.8-5). This period is characterized by more permanent settlements and reliance on agriculture—most notably beans, corn, squash, and cotton—and pest-resistant storage features. Evidence of craft specialization, including distinctive ceramic designs, allows archaeologists to attribute occupation dates to sites and associated deposits with specific cultural groups. The majority of GCNRA and GCNP sites are of Puebloan age. Puebloan people were occupying the area north (Virgin Branch), south and east (Kayenta Branch) of the Colorado River during the Formative Period. Modern Puebloan Indians consider themselves to be descendants of these ancestral people.

FIGURE 3.8-5 Puebloan Era Architecture along the Colorado River in GCNP

The Cohonina people were a distinctive cultural group living in a discreet area running east to west between the San Francisco Peaks and the Grand Wash Cliffs, and north to south from the Colorado River to the Mogollon Rim during AD 700–1175. Both their home sites and distinctive ceramics identify them as culturally separate from the neighboring Puebloan groups. Cohonina sites in the Grand Canyon consist of settlements located on both sides of the river, use of multiple areas for resource procurement, and small camps or hamlets. The Hopi, Hualapai, and Havasupai consider themselves descendants of the Cohonina archaeological culture.

Late Prehistoric (1250–1540 AD)

Current evidence indicates that ancestral Puebloan populations moved out of the Canyons as the Southwest became drier and cooler in the 13th century, while people from the west continued to expand their land base and further incorporated the Canyons into their seasonal hunting and gathering cycles. These groups were less sedentary and less reliant on crops, and they lived in smaller camps, built brush structures, and used communal roasting features and small clusters of fire pits. The ancestral Pai and Southern Paiute were well established in the Canyons during this time. Archaeologists have identified different pottery types of both local and imported varieties that are characteristic of cultural transitions during this period.

Protohistoric Period (1540–1776 AD)

The Protohistoric Period contains evidence of incursions by white settlers and miners: European explorers, specifically Spanish expeditions in search of gold and wealth, but with an ancillary mission of converting native people along the way to Christianity. Although the experience of indigenous groups with these contacts varied widely, much of the region immediately in the vicinity of the Grand Canyon and Colorado River was not greatly affected, especially in the western canyon country. Growing familiarity with horses and items of European manufacture was likely, however. This period witnessed the greatest expansion of the Pai and Southern Paiute into the Grand Canyon and along the river corridor. Archaeological evidence suggests that the ancestral Puebloan peoples who had previously occupied the Canyon had already shifted settlements to the east by this time.

3.8.2.2 Historic Resources

Historic resources represent the period from 1776 to the present. The period is characterized by incursions by Europeans and later by Euro-American exploration along the Colorado River. In GCNRA, the Dominquez-Escalante Expedition in 1776 crossed the Colorado River at what is now Lees Ferry. That same year, Fr. Francisco Garces led a separate Spanish expedition from the southwest, up the lower Colorado River, and then overland; he visited Hualapai and Havasupai settlements in the western Grand Canyon area, even relying on Hualapai guides for part of his journey (Coues 1900). Euro-American expeditions include the 1869 Powell expedition and the 1889–1890 Stanton expedition, among others. The historic period ends with the engineering tests for the Marble Canyon Dam site in the late 1950s.

During the 19th century, in response to the growing pressures brought by the increasing numbers of European and Euro-American settlers, some indigenous groups retreated to smaller territories, formed aggregate villages, and used side canyons as places of refuge. Small bands of Hualapai and Southern Paiute wishing to avoid conflict with the U.S. Army stayed in western Grand Canyon, largely out of reach of soldiers on horseback. Havasupai Indians lived at Indian Garden along the Bright Angel Trail and in a permanent settlement in the South Rim Village area. Southern Paiute bands used large areas across the Tuweep Valley for habitation and resource procurement. Navajo lived along the south, east, and north rims and within the Canyon for seasonal and religious purposes. Ultimately, however, the designation of permanent reservations by treaty or executive order led to the forced or coerced relocation of Tribes out of vast areas of their ancestral territories.

Native American sites from the Historic Period in the Grand Canyon are characterized by a blending of the old and traditional with the new and innovative. Pottery and tools made of stone and bone are found along with metal and glass projectile points. Metal buckets, kitchen cutlery, and canned food and beverage containers are found in at such sites.

Types of historic resources found along the mainstem of the Colorado River include artifact caches and isolated occurrences, abandoned boats, dwellings, remnants of mining operations, camps, ranching, features related to dam site development, trails, inscriptions, and plaques. Historic era American Indian use of areas along the Colorado River is evidenced from numerous locations along the riverbanks. Remnants of hogans, extraction sites (i.e., mines) and small camps are remnants of this time. Of the total number of identified archeological sites along the mainstem Colorado River, at least 71 have a Euro-American historical component (Fairley et al. 1994; Reclamation 1995).

In GCNRA, Lees Ferry was settled by John D. Lee who established one of the primary river ferry crossings at this location (Figure 3.8-6). The remains of the Charles H. Spencer Steamboat, a steamboat launched in 1912, which transported coal to Lees Ferry, located in the bed of the river at Lees Ferry, was listed on the NRHP in 1974 as part of the Lees Ferry and Lonely Dell Ranch Historic District (Figure 3.8-1). A separate nomination was prepared for the steamboat, which was listed as an individual property in 1989. Historic campsites, corrals, and inscriptions are evidence of historic ranching and sheepherding. In response to mass unemployment during the Depression, the Civilian Conservation Corps (CCC) built structures, fire towers, and historic trail and road features that all constitute remains of activities intended to facilitate visitor use, as well as resource protection. The Marble Canyon Dam site, the physical remains of engineering tests for a dam that was not built, constitutes a significant part of the recent past. The site and related encampments have been determined eligible for listing on the NRHP.

FIGURE 3.8-6 Lees Ferry and Lonely Dell Ranch Historic District Located in GCNRA

3.8.2.3 Cultural Landscapes

As defined in the NPS *Cultural Resource Management Guideline* (NPS 1998), cultural landscapes are settings that humans have created in the natural world. They are intertwined patterns of things both natural and constructed, expressions of human manipulation and adaptation of the land (see Section 3.9 for a description of the Tribal perspective on cultural landscapes). One type of cultural landscape, the historic vernacular landscape, which is a landscape that evolved through use by the people whose activities or occupancy shaped it, is represented in the Colorado River corridor at both Lees Ferry and Phantom Ranch.

At Lees Ferry, the Colorado River briefly flows free of canyon walls, historically the only place in over 400 mi that it could be accessed on both banks by wagon. This natural attribute has influenced the site's history for 130 years. Today, historic buildings and a cemetery, shade trees, an orchard, fields, trails, and dugways carved into the river bluffs combine with more contemporary structures to illustrate the site's use as a farm and a vital ferry link between settlements in Utah and Arizona. The establishment of USGS gaging stations that are used today to fulfill terms of the Colorado River Compact, a dude ranch, and an access point for river runners are also present at Lees Ferry.

At Phantom Ranch, major side canyons and perennial tributaries provided the natural context for what would become the nexus of a cross-canyon corridor and the most popular site in the inner Canyon. Here, historic guest lodges and NPS buildings, livestock structures, cottonwood trees, a campground, bridges across Bright Angel Creek and the Colorado River, and a network of trails document 80 years of recreational activity at the very bottom of the Grand Canyon.

On a broader scale, the entire river corridor can be viewed as a cultural landscape in which American Indians for millennia have farmed, hunted, gathered plants and minerals, and performed rituals. Ancient trails, remnants of stone structures, traces of fields, and prayer objects enshrined in travertine and salt are enduring evidence of a subtly altered landscape. Integral to this landscape are the animals, plants, and minerals traditionally used and valued by American Indians. Aspects of American Indian cultural landscapes are discussed in Sections 3.8.2.4 and 3.9 and throughout this document.

3.8.2.4 Traditional Cultural Properties and Ethnographic Resources

"A traditional cultural property, then, can be defined generally as one that is eligible for inclusion in the NRHP because of its association with cultural practices or beliefs of a living community that (a) are rooted in that community's history, and (b) are important in maintaining the continuing cultural identity of the community" (Parker and King 1990). Like historic properties, TCPs are given consideration under the NHPA of 1966, as amended. During research related to Glen Canyon Dam operations and sponsored by Reclamation, five Tribes identified cultural resources of importance to them in the river corridor that are TCPs. This includes Grand, Marble, and Glen Canyons, and the Colorado and Little Colorado Rivers.

Ethnographic resources often overlap with archaeological sites and other resources of ongoing traditional cultural importance. "Park ethnographic resources are the cultural and natural features of a park that are of traditional significance to traditionally associated peoples. These peoples are the contemporary park neighbors and ethnic or occupational communities that have been associated with a park for two or more generations (40 years), and whose interests in the park's resources began before the park's establishment" (NPS 2006d).

American Indian people consider the broader area of Glen and Grand Canyons to be of traditional, even sacred, importance (Hopi CPO 2001; Dongoske 2011a; Maldanado 2011; Coulam 2011). More information regarding the perspective of the Canyons as a TCP is presented in Section 3.9. This information has been furnished by interested Tribes at the request of Reclamation and NPS, in order to aid in public understanding of their concerns.

3.9 TRIBAL RESOURCES

The Colorado River, as it flows through the Glen, Marble, and Grand Canyon (the Canyons), has a prominent place in the traditional cosmology of the indigenous peoples of the Southwest and continues to have an important place in contemporary American Indian cultures and economies. The Fort Mojave Tribe, Havasupai Tribe, Hopi Tribe, Hualapai Tribe, Navajo Nation, Pueblo of Zuni, and Southern Paiute Tribes all have strong cultural ties to the Colorado River and the Canyons, and these Tribes have provided information on the determination of eligibility of the Colorado River and the Canyons as TCPs.

For these Tribes, the Canyons are more than just beautiful scenery. The Canyons are alive. The Colorado River, the canyons it has carved, and the resources it supports over a vast landscape are all considered sacred to these Tribes. Many Tribal members regard the Canyons as sacred space, the home of their ancestors, the residence of the spirits of their dead, and the source of many culturally important resources. They are important to the genesis of the Tribes and to their contemporary ways of life rooted in traditions engendered by those experiences. Many Tribes see themselves as connected to the Colorado River and its Canyons and as stewards over the living world around them, including water, earth, plant life, and animal life.

Although archaeological data can provide significant evidence of past lifeways, it tells only part of the story. Within this landscape are culturally important natural resources and significant cultural landscapes that serve as the settings for Tribal histories and spiritual narratives. Many Tribes have adapted their role as stewards to the modern environment by submitting documentation to support their contention that portions of the Colorado River and the Canyons through which it flows should be considered a TCP. Various elements within this boundary are considered contributing elements to the TCP (Hopi CPO 2001; Dongoske 2011b; Maldanado 2011; Coulam 2011). This documentation provides information supporting a determination of the eligibility of the TCP and many, but not all, associated elements located in or along the Colorado River for listing on the *National Register of Historic Places*. These TCPs have been determined eligible by the Arizona SHPO (Reclamation 2011a). Some of the elements of these TCPs have been disclosed and other elements are considered confidential, but all are considered significantly important. Traditional narratives of Tribal history and understandings of traditional landscapes, combined with archaeological data, provide a comprehensive representation of American Indian lifeways.

The following discussion of the importance of the Canyons and the Colorado River for the Fort Mojave Tribe, Havasupai Tribe, Hopi Tribe, Hualapai Tribe, Navajo Nation, Pueblo of Zuni, and Southern Paiute Tribes, and their monitoring of these resources was written, for the most part, by the LTEMP EIS staff and edited and approved by Tribal representatives from each Tribe. Tribal representatives from the Hopi, Hualapai, Navajo, and Zuni contributed their own text.

3.9.1 Fort Mojave Indian Tribe

The *Pipa Aha Macav*, or "people by the River" (Fort Mojave 2012), are the northernmost of the Yuman-speaking Tribes who established themselves along the banks of the Colorado River well downstream from the Canyons. Traditionally, they lived in sprawling settlements adjacent to and above the Colorado River floodplain, moving to the floodplain in the spring after seasonal floods receded. Taking advantage of fresh moist silt deposited by river flooding, they planted and harvested corn, beans, and squash, but also ranged widely, hunting, fishing, gathering mesquite, and trading. They established the Mojave Trail and participated in a trading network that stretched from the Pacific Coast to the Pueblos of the Southwest (Stewart 1983). Although they ranged widely, their cultural center remained the river, which was created by *Mutavilya* along with all plants and animals, which were drawn from the water (Fort Mojave 2012; Otero 2012). Like their upstream neighbors, the Tribe views the river as a living being to which they are connected. In the words of one Tribal member, "The river is the basis of who we are" (Otero 2012). In the Mojave worldview, members of the Tribe are related to the natural world by family ties and have stewardship responsibilities for its plants and animals. For the Mojave, some trails have spiritual as well as temporal significance. The Salt Song Trail, an important ritual trail tied to the afterlife, includes portions of the Grand Canyon.

The construction of dams along the Colorado River fundamentally changed the Mojave lifeway. No longer could they make use of the river's annual floods to refresh their fields, but even as they have adapted to changing circumstances, the river and their relationship to the natural world based on spiritual ties have remained. The Mojave continue to be concerned about the declining numbers of plants and animals in their homeland and the increase in nonnative species. Created from the water, the natural world is affected by the way the river flows. Living downstream from the project area, they are concerned about the effects of dam operation on water quality and pollution (Otero 2012).

3.9.2 Havasupai

The Havasupai Tribe and Tribal members have a history interwoven with that of GCNP since creation of the park from within the Havasupai aboriginal territory. Members of the Havasupai Tribe have access to locations of importance within GCNP guaranteed by the 1919 Act establishing Grand Canyon National Park (40 Stat. 1175, 1919) and the 1975 Grand Canyon Enlargement Act (88 Stat. 2089, 1975). The members of the Havasupai Tribe have statutory rights of access to areas on public lands, including any sacred or religious places or burial grounds, native foods, paints, materials, and medicines (16 USC 228i(c)).

The Havasupai view everything in and around the Grand Canyon as sacred in all aspects of their cultural, spiritual, and traditional life (Reclamation 1995). The Havasupai were signatories to the 1994 PA (Reclamation 1994), yet chose not to participate in the GCDAMP. The Tribe works closely with the NPS for protection of cultural sites, historic locations, and water resources. They are a member of the Native Voices on the Colorado River, a group that works with the Grand Canyon Colorado River Outfitters Association to increase understanding of Tribal relationships with the Grand Canyon from their own perspective (NVCR undated). Members of the Havasupai Tribe have worked as interpreters in GCNP.

3.9.3 Hopi

Hopi culture begins with the emergence of people into the present world from the *Sipapuni*, a spring located in the bottom of the Grand Canyon (Yeatts 2013). After emergence, the ancestral Hopi people (*Hisatsinom*) migrated in all directions around what is now the southwestern United States. During the migration period, the Hopi Clans formed and ultimately came together at the center of their universe: the Hopi Mesas. For many of the clans, the Canyons served as a home during a portion of their travels.

The Hopi ancestors have been in the Grand Canyon region for more than a thousand years (Yeatts 2013). Their presence in the Canyons (*Öngtupqa*) is well documented in the archaeological record. These ancestral archaeological sites are considered the footprints left by the *Hisatsinom* as tangible markers of their covenant with the caretaker of the earth, *Masaw*, and as a cultural claim to the land. At least 180 archaeological sites in the Colorado River corridor and in the Canyons are considered by the Hopi Tribe to be ancestral homesites.

Evidence shows that sustained use of the Canyons by the *Hisatsinom* began around A.D. 700–800 (Yeatts 2013). Use increased through time with numerous small pueblo sites dotting most of the arable land in the Canyon bottom by A.D. 1000. Both the northern and southern rims of the Canyons were similarly occupied during this time period, and a trade network extended out in all directions, linking the habitants of the Canyons to the broader region. Associated with some of these pueblos were *kivas*, ceremonial structures found in every modern Hopi village and the focus for religious activities. Just as modern Hopi villages have shrines associated with them, so do these prehistoric counterparts. While people may no longer regularly deposit offerings at these shrines, they are still considered active and sacred locations. Similarly, the sites are not considered to be "abandoned" but are still viewed as serving as the homes of those who have passed on. Proper respect for and treatment of the dead are extremely important values in Hopi culture, and protection of their resting places is paramount. The Hopi people have a spiritual obligation to serve as stewards of this land and, over the years, have developed a monitoring program that evaluates Hopi values for the health on *Öngtupqa* (the Canyons) through time (Yeatts and Husinga 2012). The Hopi are concerned with the erosion caused by the operation of Glen Canyon Dam and the effect recreation has on places of cultural importance (Yeatts and Husinga 2012). Further, and as highlighted in other sections of this document, the Hopi consider plants, animals, springs, water, landforms, minerals and other geologic deposits, and the Canyons as a whole to be sacred, contributing to the overall extreme cultural importance of the place.

3.9.4 Hualapai

The Hualapai consider the Grand Canyon and Colorado River region a great cultural landscape, especially the stretch from the Little Colorado River downstream to the confluence of the Colorado with the Bill Williams River in west-central Arizona. As of 2011, 28 places along the river are periodically monitored, in addition to an emphasis on the Colorado River itself and its tributary canyons, which the Hualapai also consider TCPs (Jackson-Kelly et al. 2011). Furthermore, many of the ancestral archaeological sites along the river are cited as TCPs, as well, but are not necessarily monitored due to difficult or obscure access and the fact that they are located in fragile contexts where periodic monitoring would simply result in undesirable impacts. Monitoring activities also include the consideration of ethnobotanical resources. When considering the intricacies of the Hualapai people's historical, cultural, and spiritual relationship to the Canyon, it is very difficult and even imprudent to attempt to assign a number to quantify significant Hualapai cultural resources along the complex landscape of the Colorado River corridor. For the most part, an evaluation of the "health" of these places is essentially a holistic response to not simply a defined point on the land, but more of the spiritual well-being one feels when standing there, as if the land was expressing its own condition through the person charged with evaluating that condition. This could include the prevalence of visitors and the availability of privacy, the incidence and cause of erosion, the quality of water, or any number of other factors. The Hualapai's participation in the monitoring and assessment of cultural and natural resources throughout the Grand Canyon extends back to the early 1990s and has been a consistent presence in management decisions.

The Colorado River and its Canyons are significant spiritual and physical landmarks for the Hualapai. The Hualapai consider the river the backbone, or *Ha'yiđađa*, of the landscape and to have healing powers (NPS 2011). Today, this is symbolized by its placement in the center of the Hualapai seal (Hualapai Tribe 2013). The Hualapai worldview holds that the Colorado River provides a life connection to the Hualapai as it flows through the landscape connecting the Canyons and the riparian ecosystems that sustain the Tribe. *Ha'thi-el* (Salty Spring), a sacred spring within the Canyons, contains a petroglyph site that tells of the creation of the Hualapai and other Pai peoples (HDCR 2010).

The Hualapai have occupied and used the lands and waters lying within their ancestral territory, including their present reservation, since time immemorial. The Hualapai traditionally benefited from both hunter-gatherer and agricultural subsistence practices. Throughout the year, the people collected various plant foods that were available depending on the season, such as agave in the spring, grass seeds in summer, and piñon in the uplands in the fall. Access to these resources often involved moving camps seasonally for closer proximity. Important cultural and spiritual lessons were passed down from elder to child during these recurring seasonal rounds (HDCR 2010). Plants were important not only for food but also for medicine and for materials for making baskets, cradleboards, shelter, and other useful items.

Although permanent water sources were sometimes scarce over large areas, the Hualapai were able to establish gardens and small fields in optimal locations, including along the Colorado River. Typical crops include corn, beans, and squash, as with other Tribes in the region. Seeds were often traded with neighboring people, especially the Mojave, Havasupai, and Hopi. Near springs, small terraces were established where water could be diverted. In larger streams, they made use of alluvial terraces that flooded over during spring runoff, enriching the soil as well as providing moisture for young seedlings. Irrigation channels were sometimes used to augment runoff and create more dependable watering systems, such as along the Big Sandy River. Unique to certain locations in the western Grand Canyon and along the lower Colorado River, such as around Pearce Ferry and Willow Beach, actual floodwater farming was practiced, similar to Ak-Chin strategies practiced in southern Arizona.

Larger game animals included mule deer, bighorn sheep, and pronghorn antelope, but rabbits and other small game were also important. Game animals provided materials for shelter, clothing, tools, weapons, and ceremonial objects, in addition to being vital food sources. The Hualapai were considered excellent hunters and commonly traded hides and dried meat with their neighbors in virtually every direction, including across the river to the north. This pattern of subsistence continued for many centuries.

Although sporadic contact with European (mainly Spanish) explorers started in 1776, it was not until the mid-19th century that Hualapai people had extensive dealings with Euro-

American settlers. At first, these interactions appeared to be fairly amicable, but as the newcomers' hunger for land, minerals, water, and grass for livestock grew, trouble ensued by the mid-1860s. After a period of conflict with these intruding Euro-American miners, ranchers, and, inevitably, the U.S. Army, a truce was forged in 1868. Most Hualapai were persuaded to congregate at Camp Beale Springs near present-day Kingman, Arizona, where they maintained relatively good relations with the commanding officer, Captain Thomas Byrne (Casebier 1980). This eventually led to a number of Hualapai men joining the Army as scouts for General George Crook in 1873, during which time they performed admirably, according to Crook's own words. However, once their service was no longer required, in 1874, many of the Hualapai were removed from their homeland and forced into an internment camp at La Paz, Arizona, near the present-day town of Ehrenberg. Many Hualapai perished from malnutrition, excessive heat, and disease while interred at the camp, and those that were eventually released returned to their homeland to find it irrevocably altered by the rush of Euro-American migration. Only those that lived in the most remote and rugged canyons near the Colorado River avoided this ordeal. The Hualapai commemorate the march to La Paz, and this tragic period of their history, through an annual relay run known as the La Paz Run (HDCR 2010).

Finally, in 1883, the Hualapai Reservation was established by executive order. It comprised just a fraction of their original territory, but included 108 mi of the Colorado River country and was at least part of their ancestral homeland. Evidence of their occupancy, use, and ownership of their ancestral territory is contained in numerous and widespread archaeological sites, family and Tribal records, oral traditions, and legends, and is embedded in the names of landmarks and sacred places throughout the Canyons and surrounding areas (Reclamation 1995). The Hualapai believe they are entrusted with the responsibility of caring for the land within their ancestral homeland, both on and off the reservation, and are actively involved in preservation activities and environmental stewardship throughout the Colorado River drainage.

The Hualapai participated in the development of the 1995 EIS (Reclamation 1995) as a Cooperating Agency and as a PA signatory. At that time, a total of 18 cultural resource sites were identified within the Canyons as archaeological sites and/or traditional cultural places associated with the Tribe, although many more have been identified since then. In addition, 46 culturally significant plant species were identified within the river corridor.

Currently, the Hualapai are active members of the Adaptive Management Working Group (AMWG) and the Technical Work Group (TWG), and they participate in the monitoring and assessment of cultural and natural resources throughout the Grand Canyon, using a combination of traditional ecological and cultural knowledge and modern survey techniques (Jackson-Kelly 2008).

Hualapai monitoring programs have identified a number of issues that are negatively affecting Hualapai archaeological sites, ethnobotanical resources, and other TCPs along the Colorado River corridor. These include the disruption of riverine ecology due to fluctuating river flows resulting from Glen Canyon Dam operations, and the related increase in human activity, such as trailing and camping on beaches near ancestral sites. The dramatic increase in the number of boaters and recreationists since the early days of river running is always a matter of concern, as evidenced by occurrences of artifact piling, trail erosion, and the occasional discovery of displaced artifacts and even human remains. The long-term trend of these phenomena presents challenges in preserving the integrity and significance of fragile and nonrenewable resources.

In April of 2010, Mr. Wilfred Whatoname, Sr., the Chairman of the Hualapai Tribe, sent a letter of testimony to the Natural Resources Committee Joint Oversight Field Hearing, entitled "On the Edge: Challenges Facing Grand Canyon National Park." The letter requested assistance in the restoration of funds for monitoring of Tribal resources and reiterated the Hualapai Tribe's commitment to preserving its natural and cultural resources (Whatoname 2010). The Hualapai are also members of Native Voices on the Colorado River (NVCR undated). The Tribe is a Cooperating Agency for the preparation of this LTEMP EIS and has continued to develop, refine, and expand its program of monitoring cultural and natural resources along the river, including further implementation of traditional ecological knowledge.

3.9.5 Navajo Nation

For the Navajo Nation, or *Diné*, the Canyons downstream from Glen Canyon Dam are culturally and historically significant. The Colorado River and Little Colorado River are seen as deities, and their confluence is associated with Changing Woman, the most important Navajo traditional deity. Navajo lore includes an account of how Haash′ cheeh Zhin., or "Humpback God," created the Grand Canyon by dragging his cane from east to west, creating a great chasm to drain a flooded world (Two Bears 2012; Roberts et al. 1995). Glen Canyon, Marble Canyon, Grand Canyon, and Little Colorado Canyon are home to many Navajo deities. Oral traditions recount how these deities bestowed important ceremonial knowledge and taught the people how to use the resources found throughout the landscape (Two Bears 2012).

Ethnohistoric accounts, as well as archaeological and linguistic evidence, suggest that the Apacheans (Athabaskan-speaking ancestors of the Navajos and Apaches) entered the North American Southwest sometime between A.D. 1000 and the 1600s. During this time, the Apacheans traded and intermarried with neighboring groups, resulting in the traditional Navajo culture of today (Brugge 1983; Brown 1991). According to traditional Navajo narratives, they have always lived "among the four sacred mountains," having emerged from the four underworlds into this world at Mount Blanca (Two Bears 2012). By the mid-1800s, the Navajo were fully utilizing resources in and around the Canyons for farming, livestock grazing, plant gathering, hunting, and religious purposes (Navajo Nation 1962, undated). The Canyons also served as a place of refuge from Mexican slave raiders, other Indian Tribes, and the U.S. Army. During the 1860s, when Navajos were conquered by the U.S. Army and interned at Fort Sumner, New Mexico, many Navajos escaped to the Canyons and lived there for many years. The Canyons continued to provide protection to the Navajo and their herds of sheep, goats, and horses during the federally imposed livestock reduction program of the 1930s and 1940s. Rivers, springs, and seeps in the Canyons have provided water to people and livestock for generations. Sites and remains of historic Navajo dwellings and sweat lodges in the Canyons retain importance for the Navajo (Roberts et al. 1995).

Both the Colorado River and the Little Colorado River protect and give life to the Navajo. Offerings seeking the rivers' protection continue to be made to the Colorado River. Floodplains have provided arable land for corn fields, and the higher terraces have provided habitat for wild game such as deer and bighorn sheep, as well as important food, medicinal, and ceremonially important plants, which continue to be used today (Roberts et al. 1995).

Many mineral sources of cultural importance to the Navajo are found in the Grand Canyon, including salt, red ochre, and quartz crystals. The salt source within the Grand Canyon is personified as Salt Woman. A journey to Salt Woman consisted of following the Salt Trail down the walls of and into the Grand Canyon, stopping periodically to make offerings and perform rituals. To enter the Canyon, an individual had to be prepared mentally, physically, and spiritually, and enter the Canyon in good faith, as it was the final resting for the spirits of their ancestors (Roberts et al. 1995).

Many of the Canyon's trails and river crossings retain important cultural meanings both ritually and historically. The stories associated with the trails keep alive traditions of Navajo history. The trails led to refuge, hunting, gathering, and trade with neighboring Tribes (Roberts et al. 1995; Linford 2000).

Nihoo′ kaa Diné é bila Ashdla′ii, or the earth surface people as referred to within Navajo society, have long since been immersed in continuing and maintaining the process of the Fundamental, Natural, and Sacred laws that were bestowed within the people since the beginning of the emergence from the first world or Ni′ Hodilil (Black World). Through the passage of each world after Ni′ Hododlizh (Blue World), Ni′ Holtso (Yellow World), and Ni′ Halgagh (White World), and finally the fifth and present world, Ni′ Hodisqous (Glittering World), the Navajo people have carried the teachings and ordinance with them as they entered the present world.

The Navajo Nation views this space as a Traditional Cultural Landscape, beginning at the Animas River, into the San Juan River, into the head waters of the Green River, into the Colorado River, Lake Powell, Glen Canyon, Marble Canyon, and Grand Canyon, through the Little Colorado River, and Lake Mead, all the way into the Gulf of California and the Pacific Ocean. This Traditional Cultural Landscape includes the tributaries within the Canyon corridors, the riparian species, wildlife, fisheries, botanical, and biological entities, insects, birds, vertebrates, and invertebrates, as well as all creatures within the Canyon as culturally significant to the Navajo people. The Colorado River and the Little Colorado River have specific functions in the ceremonial sphere of the Navajo people—the river is a protector of our people.

The Navajo have participated as a Cooperating Agency in the development of NEPA documents concerned with environmental impacts on canyon resources downstream of Glen Canyon Dam. The Navajo participated in in-depth cultural studies, which have identified important archaeological, geological, botanical, and biological resources and TCPs within the Colorado River corridor, and have provided monitoring and mitigation recommendations for culturally important resources that are affiliated with the Navajo Nation. Important cultural places include trails, subsistence areas, migration places, spiritual landscapes, and archaeological sites that lie within and adjacent to GCNRA and GCNP (Thomas 1993; Roberts et al. 1995; Neal and Gilpin 2000; NPS 2005a). Currently, the Navajo are active members of the AMWG and the TWG (Reclamation 2012b).

3.9.6 Pueblo of Zuni

The Grand Canyon and the Colorado River have been sacred to the Zuni people since their emergence onto the surface of the Earth. According to the traditional narratives that describe the emergence of the Zuni people (*A:shiwi*) from Earth Mother's fourth womb, sacred items that identify the Zuni people, the *Etdo:we* (fetish bundles), were the first to emerge; the people then came out into the sunlight world at a location in the bottom of the Grand Canyon near present-day Ribbon Falls. The creation narratives also describe the Zunis' subsequent search for the center of the world, *ldiwan'a* (the Middle Place). During this search, the people moved up the Colorado River and then up the Little Colorado River, periodically stopping and settling at locations along these rivers. At the junction of the Little Colorado and the Zuni Rivers, many of the supernatural beings, or Koko, came into existence. After a long search, the Zunis located the middle of the world and settled there. The Middle Place is located in today's village of Zuni.

The Pueblo of Zuni, the *A:shiwi,* continue to maintain very strong cultural and spiritual ties to the Grand Canyon, Colorado River, and the Little Colorado River because of their origin and migration narratives.

The Zuni River, Zuni Heaven (*Ko'lu:wa/a:wa*), the Little Colorado River, the Colorado River, and the Grand Canyon have been important to Zuni culture and religion for many centuries, if not a thousand years. Zuni religious beliefs, narratives, ceremonies, and prayers are intrinsically tied to the entire ecosystem of the Grand Canyon, including the Zunis' familial relationship with birds, animals, soils, rocks, vegetation, and water. The Grand Canyon is very sacred, and the Zuni people place prayers and offerings in the Zuni River every morning and evening which are then spiritually sent to the Grand Canyon via the Zuni River's confluence with the Little Colorado River, and the Little Colorado River's confluence with the Colorado River in Grand Canyon. The Zuni people are concerned with activities that may affect the resources in this sacred place. Similarly, the Zuni people are concerned about activities that take place within the Grand Canyon that may have an impact on Zuni.

The Canyons have significant religious and cultural importance to the Zuni. Zuni 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. Each part of the Zuni universe is interconnected. Plants, animals, and colors are associated with the various cardinal directions. Minerals, clay, rocks, plants, and water are used in prayers. Prayers are accompanied by offerings of prayer sticks. The entire environment at the bottom of the Grand Canyon is sacred to the Zuni. The animals, the birds, insects, rocks, sand, minerals, plants, and water in the Grand Canyon all have special meaning to the Zuni people.

For the Zuni, traditional cultural places encompass a wide variety of cultural sites including, but not limited to, ancestral habitation sites; culturally significant archaeological/historic features; pictographs and petroglyph sites; collection areas for plants, water, and minerals; natural landmarks; prominent topographic features (e.g., mountains, buttes, and mesas); shrines; sacred sites; and pilgrimage trails and routes. All archaeological sites, including, but not restricted to, pictographs, petroglyphs, habitation areas, artifact scatters, special use areas, and other archaeological manifestations, are considered ancestral sites which imbue great cultural and religious significance to the Zuni people. For Zuni, these archaeological sites have never been abandoned but continue to maintain life and spiritual forces significant to the Zuni people. These archaeological sites are interconnected to one another by trails, and these trails connect the sites to the Zuni Pueblo. Trails often lead to shrines and offering places. Religious shrines are used by the Zuni to mark their land claim boundary, and these shrines today are considered sacred. Shrines and other sacred cultural markers act in Zuni culture as maps, charts, and other documents do in literate societies (Pandey 1995). The distribution of shrines on the landscape act as cognitive maps for the Zuni when visiting these places and play a significant role in reaffirming their cultural tradition and beliefs. Sacred shrines and offering places were used by the Zuni ancestors, the *Che:be:ya:nule:kwe* and the *Enoh:de:kwe*. Sacred shrines and offering places are often related to archaeological sites and are of great cultural and religious significance. These shrines and offering places are also imbued with life and spiritual forces. Shrines hold great significance to the Zuni and are considered sacred.

Shrines are also established at other places of significance within the Zuni cultural landscape. The Zuni people preserve and maintain these “markers,” or locations, by making regular visits or pilgrimages to deposit offerings and to ask blessings upon the land. Their location is central to the purpose of the shrines. Thus, to disturb or move the shrines would be incompatible with the essence of their location with respect to the areas and the people they protect. Second, these locations have religious significance to the Zuni people, whether or not they appear to have been used recently. Once established, they continue to provide their protection in perpetuity.

The Zunis have many named places across their cultural landscapes that are interconnected by a series of trails. Trails are important because they maintain strong and continuous connections between the heart of the Pueblo of Zuni and many culturally important distant places on the Zuni landscape. Trails are blessed before their use, and once blessed, they are blessed in perpetuity. For the Zuni, there are many prayers and offerings that are required to be made prior to a trip and during a trip, along the trail to the place of emergence and the Grand Canyon. Prayers and offerings are made at springs and shrines along the trail. The trail, the springs, and the shrine area are all sacred. The trail from Zuni to the Grand Canyon thus has a continuously important religious meaning to the Zuni people. It is sacred and will also be used in the afterlife. Once a trail is blessed, it remains blessed permanently. The Zuni people have important concerns regarding the ancient Zuni trail from their village to the bottom of the Grand Canyon.

The Pueblo of Zuni participated in the development of the 1995 EIS (Reclamation 1995) as a Cooperating Agency and a PA signatory. Currently, the Pueblo of Zuni has active representation on the AMWG and the TWG. The Zuni religious leaders, on behalf of the Pueblo of Zuni, have developed a monitoring program to identify impacts on important Zuni cultural resources in the Colorado River corridor resulting from the operation of Glen Canyon Dam. Erosion and visitor impacts (i.e., trailing, litter, vandalism, and unauthorized artifact collection or movement) have been identified as sources of impacts on archaeological sites and areas of cultural importance (Dongoske 2011a). The results of monitoring are presented directly to Reclamation and NPS.

On September 21, 2010, the Zuni Tribal Council passed resolution M70-2010-C086 which stated that the Zuni Tribe of the Zuni Indian Reservation "... asserts that the Grand Canyon, from rim-to-rim, and all specific places located therein including the confluence of the Colorado and Little Colorado Rivers, topographic and geologic features, springs, archaeological sites, mineral and plant collection areas, and any other places it so identifies as historically, culturally, or spiritually important to the Zuni Tribe within the Grand Canyon must, as a matter of the United States government's trust responsibility toward the Zuni Tribe, be assumed by all federal agencies to be eligible for the National Register of Historic Places and insists that all agencies of the United States Department of the Interior (a) accept and respect the above assertion with reference to any topographic or geologic feature, water body, or other place identified by the Zuni Tribe as historically, culturally, or spiritually important within the Grand Canyon; (b) respect Zuni tribal interests in and values ascribed by the Zuni Tribe and tribal members to such places; and (c) accept and respect that the continued mechanical removal of rainbow and brown trout at the confluence of the Colorado and Little Colorado Rivers is considered an adverse effect on a traditional cultural property that is eligible for listing on the National Register of Historic Places."

Appended to the Zuni Tribal Council Resolution was a Position Statement by the Zuni religious leaders. The Position Statement asserted that the *Newe:kwe*, *Makeyana:kwe*, *Uhuhu:kwe*, *Chikk'yali:kwe*, *Shuma:kwe*, *Halo:kwe*, *Sahniyakya*, *Shiwana:kwe*, Zuni Rain Priests, Zuni Kiva Groups, and other associated religious societies demonstrate their passionate support for the Pueblo of Zuni's cultural and religious objections (to mechanical removal of rainbow and brown trout), reflected in a letter from Zuni Governor Cooeyate to Mr. Larry Walkoviak, Regional Director, Bureau of Reclamation, dated June 30, 2010, on the past and proposed future mechanical removal management activities that consist of electroshocking and destroying thousands of rainbow trout and brown trout at the confluence of the Little Colorado River and Colorado River in the Grand Canyon. It is the Zuni religious leaders' position that all animals, including all aquatic life (e.g., native and nonnative fishes, insects, amphibians, snakes, and beavers), birds, plants, rocks, sand, minerals, and the water in the Grand Canyon are sacred, have special meaning, and a unique familial relationship to the Zuni people. The entire environment at the bottom of the Grand Canyon is sacred to the Zuni people and the Grand Canyon, including the confluence of the Little Colorado River and Colorado River, which are integrally connected to Zuni religious beliefs, ceremonies, and prayers.

The Zuni annual ceremonial activities carried out at Zuni are performed for the specific purpose to ensure adequate rainfall and prosperity for all life in the universe. The individual Zunis that are part of these respective Religious Societies pray, fast, and perform religious ceremonies not only for Zuni lands, but for all people and all lands. The ceremonies are performed as part of maintaining a balance with all parts of this interconnected universe. As a direct consequence of maintaining this balance and interconnectedness with the universe, the Zuni religious leaders believe that the past and proposed future mechanical removal activities created, and will continue to create, a counter-productive energy to the Zuni respective ceremonial efforts to ensure rainfall, prosperity for all life, and to maintain a harmonious balance among the Zuni people. The Zuni religious leaders expressed that they were especially concerned that the continuation of the mechanical removal activities proposed for the confluence of the Little Colorado and Colorado Rivers within the Grand Canyon magnifies the negative effects of this action for the Zuni people and all life. The Grand Canyon is very sacred, and the Zuni people are concerned with activities that may affect the resources in this sacred place. Similarly, the Zuni people are concerned about activities that take place within the Grand Canyon that may have an impact on the Zuni.

In summary, the Zuni River, Zuni Heaven (*Ko'fu:wa/a:wa*), the Little Colorado River, the Colorado River, and the Canyons have been important to Zuni culture and religion for many centuries. Zuni religious beliefs, narratives, ceremonies, and prayers are intrinsically tied to the entire ecosystem of the Canyons, including the Zuni's familial relationship with birds, animals, soils, rocks, vegetation, and water. The Canyons are very sacred, and the Zuni people are concerned with activities that may affect the resources in this sacred place. Similarly, the Zuni people are concerned about activities that take place within the Canyons that may have an impact on the Zuni.

3.9.7 Southern Paiute Tribes

The Southern Paiute Tribes that have ties to the region and who are most directly tied to the project area include the Kaibab Band of Paiute Indians; the Paiute Indian Tribe of Utah, which consists of five bands of Southern Paiute (Cedar Band, Indian Peaks Band, Kanosh Band, Koosharem Band, and Shivwits Band); and the San Juan Southern Paiute. The Kaibab Band of Paiute Indians and the Paiute Indian Tribe of Utah are also members of the Southern Paiute Consortium (SPC). The Kaibab Band represents the SPC in matters pertaining to Glen Canyon Dam and Colorado River management. Currently, the SPC is an active member of the AMWG and the TWG, and the San Juan Southern Paiute Tribe is a member of the AMWG (Reclamation 2012b).

The Canyons and the Colorado River have historic cultural significance as well as contemporary interest to the Southern Paiute. Traditional narratives of Paiute origin vary from band to band, but share a general central theme: "Southern Paiutes were the first inhabitants of this region and are responsible for protecting and managing this land along with the water and all that is upon and within it" (Bulletts et al. 2012).

The Southern Paiute maintain that when an undertaking is to occur in their traditional homeland, it is their divine right to understand that action and the impacts that could occur from that action (Stoffle et al. 1997). This is the reason the Kaibab Band of Paiute Indians and the Paiute Indian Tribe of Utah formed the SPC in 1993 and participate in the management of lands throughout the Colorado River drainage, through improved government-to-government interaction in the GCDAMP. The consortium participates in and conducts its own assessments of potential environmental impacts on ethnobotanical, geological, biological, and cultural resources, the results of which are provided in technical reports (Bulletts et al. 2012).

According to traditional Southern Paiute values, all plants, animals, and natural elements within that land should be respected and protected. The Southern Paiute have identified the Colorado River as one of their most powerful natural resources and consider the Colorado River corridor, as well as all natural and cultural resources within the corridor, as culturally significant features (Stoffle et al. 1995). The Southern Paiute have identified numerous archaeological sites, rock art sites, animal resources, ethnobotanical resources, traditional natural resources (soil, water, rocks, and minerals), and traditional and contemporary use areas within the Colorado River corridor that require monitoring and protection (Stoffle et al. 1994). Resources of importance continue to be monitored by the SPC on a rotating basis (Austin et al. 1999; Drye et al. 2000, 2001, 2002, 2006; Bulletts et al. 2003, 2004, 2008, 2010, 2011, 2012; Snow et al. 2007).

3.9.8 Indian Trust Assets and Trust Responsibility

The DOI acknowledges its federal trust responsibility and the importance of Indian trust assets within the proposed action area. The trust responsibility consists of the highest moral obligations that the United States must meet to ensure the protection of Tribal and individual Indian lands, assets, resources, and treaty and similarly recognized rights. Secretaries of the Interior have recognized the trust responsibility repeatedly and have strongly emphasized the importance of honoring the United States' trust responsibility to federally recognized tribes and individual Indian beneficiaries (Secretarial Order 3335; DOI 2014). Indian trust assets are legal interests in property held in trust by the U.S. Government for Indian Tribes or individuals. Examples of such resources are lands, minerals, or water rights.

The action area is bounded on the east by the Navajo Indian Reservation and on the south by the Hualapai Indian Reservation. The DOI and Reclamation have ongoing consultation with these Tribes regarding potential effects of the proposed action on their lands, resources, trust assets, and reserved rights. High-flow releases will inundate shoreline areas historically affected by seasonal floods, and analysis of effects on resources show that the proposed action is not likely to impact Indian lands, minerals, or water rights.

3.10 RECREATION, VISITOR USE, AND EXPERIENCE

This section describes the recreational and visitor-experience attributes found in the portions of GCNRA, GCNP, and LMNRA that are related to flows of the Colorado River. Recreational use is an important issue because the GCPA mandates that Glen Canyon Dam be operated in a manner that protects, mitigates adverse impacts to, and improves the values for which GCNP and GCNRA were established, including, but not limited to, natural and cultural resources and visitor use, and in a manner fully consistent with and subject to 1802(b) of the GCPA. Most of the description provided here focuses on resources and activities found in the Colorado River Ecosystem from just below Glen Canyon Dam within GCNRA to the western boundary of GCNP at RM 277. In addition, because of the potential for the alternatives to differentially affect seasonal (though not annual) reservoir levels of both Lake Powell in GCNRA and Lake Mead in LMNRA, this section also provides information on visitor use of both reservoirs and reservoir recreational facilities, principally boat launching facilities, that could be affected by the alternatives being evaluated. Recreation economics are discussed in Section 3.14 of this EIS.

3.10.1 Glen Canyon Reach of the Colorado River in Glen Canyon National Recreation Area

The Glen Canyon reach of the Colorado River is an approximately 15-mi segment of the river between Glen Canyon Dam and Lees Ferry. Recreational activities include trout fishing, motor- and human-powered boating, commercial flat-water rafting, camping, photography, hiking, interpretation of historic and cultural properties, and sight-seeing.

The Glen Canyon General Management Plan (GMP) (NPS 1979) established management zones within GCNRA. The majority of the land along the Glen Canyon reach is located within the Natural Zone and is included in the park’s wilderness recommendation. The river is managed to provide for recreation. Visitor services include facilities for camping and interpretation of resources (such as the descending sheep panel). The Navajo Indian Reservation extends along much of the east side of the river immediately adjacent to the GCNRA boundary.

3.10.1.1 Lees Ferry Recreational Fishery

The 15-mi Glen Canyon reach, upstream of Lees Ferry, supports a recreational fishery that is an important recreational and economic resource based largely on nonnative rainbow trout (Figure 3.10-1). Fish in all waters within GCNRA and GCNP are managed by the NPS, in coordination with the AZGFD and FWS. The condition of the recreational rainbow trout fishery within GCNRA can be affected by the operations of Glen Canyon Dam, which is operated by Reclamation. The Comprehensive Fisheries Management Plan (the Plan) for GCNP and GCNRA (NPS 2013e) identified the goals for this fishery (Section 1.10.3).

Dam operations and fishery management may affect the size and quality of the rainbow trout fishery and angler satisfaction. While there is a strong interest in maintaining the highly valued trout fishery in the Glen Canyon reach, there also is concern about the migration of trout to downstream areas, particularly near the confluence with the Little Colorado River, which is a key concentration area for the humpback chub, a federally listed endangered species.

The recreational fishery has evolved over time. From 1964 until 1991, the rainbow trout population of the Glen Canyon reach was sustained by annual stocking, but with the stabilization of flows by dam operations, the trout population eventually became self-sustaining, although stocking was continued through 1998. The trout population in the Glen Canyon reach has been monitored on a regular basis by the AZGFD since 1991. Key population characteristics identified

FIGURE 3.10-1 Glen Canyon Reach Rainbow Trout (Courtesy of George Andrejko, AZGFD)

from 1991 to 2009 inform an understanding of the relationships among dam operations, the trout population, and native fish populations (Makinster et al. 2011).

The trout population and accompanying angler success rate in the Lees Ferry fishery has been quite variable over the years in response to management actions, stocking, dam release regimes, and food availability. The periods from 1972 to 1978 and 1978 to 1984 were known as the fishery's Trophy Era and Quality Era, respectively (Reclamation 1995). It was during this time that the Lees Ferry fishery achieved an international reputation as the fishery producing 10- to 20-lb trout, and bag limits of 10 fish weighing a total of 40 lb were not uncommon. From 1978 to 1984, the number of large fish being taken declined, but creel census reports still showed an average weight of 2.79 lb for fish caught, and fish over 20 in. in length made up about 25% of the catch. From 1985 to 1988, fish longer than 20 in. made up less than 10% of the harvest and the percentage of 15-in. fish harvested continued to increase (Reclamation 1995). Section 3.5.3.1 presents additional discussion of the condition of the rainbow trout fishery.

An estimated total of 10,908 anglers used the trout fishery in 2014, of which 6,739 were boat anglers and 4,169 were walk-in anglers. Creel surveys conducted during 2014 found that overall angler success remained high, with 95% and 64% of the anglers catching at least one fish in the boat-fishing section upriver of Lees Ferry or walk-in section accessed at Lees Ferry, respectively. Angler satisfaction on a scale of 1 to 5 remained high for both boaters and walk-in anglers, averaging 4.55 and 4.28, respectively (Rogowski, Winters, et al. 2015). The angler catch rate generally correlates with the size of the fish population; Figure 3.10-2 shows the angler catch rate from 1977 to 2014. Catch rates peaked in 1998 and increased sharply again after 2010, with 2012–2014 having the highest catch rates on record for boat anglers. Catch rates for boat anglers have been roughly twice the rates of walk-in anglers in recent years. This has been attributed to the ability of boat anglers to access preferred trout habitat; walk-in angling catch rates are better correlated to those from electrofishing surveys (Rogowski, Winters, et al. 2015). Electrofishing data from 1991 to 2014 show that there has been a long-term trend of decreasing fish size. In the 2014 electrofishing survey conducted in the Glen Canyon reach in spring, summer, and fall months, 17% of rainbow trout collected were less than 152 mm (6 in.) in length, 58% were in the 152–305 mm (6–12 in.) range, 24% were in the 306–405 mm (12–16 in.) range, and only about 1% were in the >405 mm (>16 in.) range (Rogowski, Winters, et al. 2015).

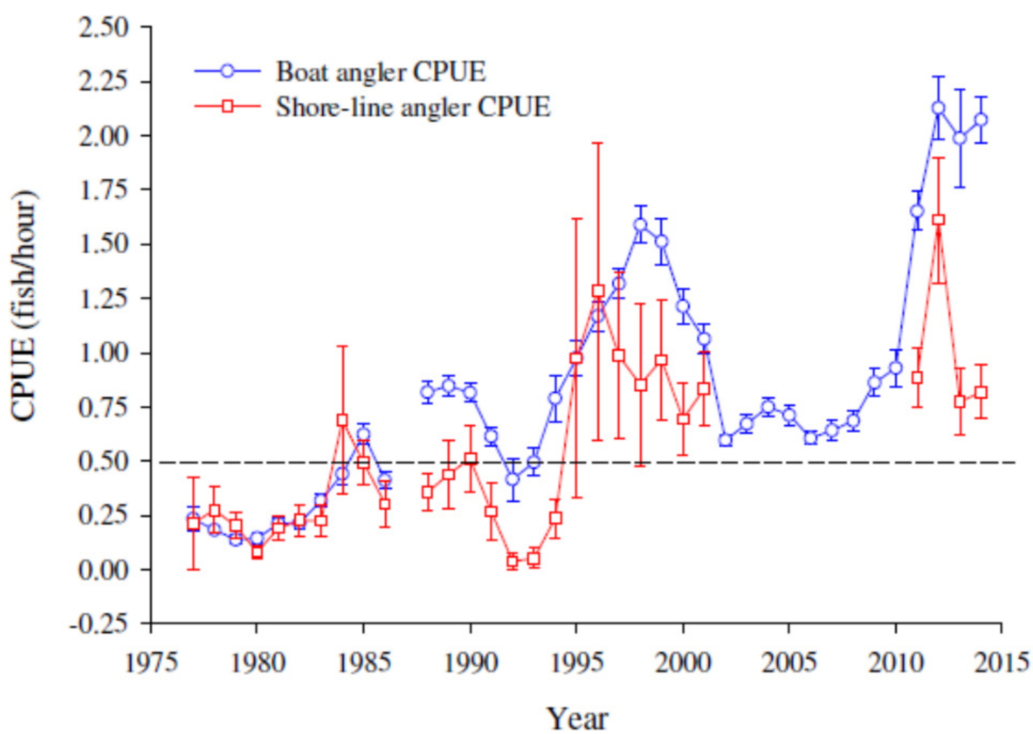

FIGURE 3.10-2 Mean Rainbow Trout Catch Per Unit Effort (CPUE, fish caught per hour) of Both Boat Anglers (blue) and Shore-Line Anglers (red) from Creel Surveys at Lees Ferry (Error bars represent 95% confidence intervals. The dashed line indicates the trigger point [0.5 fish/hour] for potential restocking of rainbow trout) (Source: Rogowski, Winters, et al. 2015)

Levels of Recreational Fishing Use

Fishing occurs year-round in the Glen Canyon reach, with the months of April and May being the peak months; however, substantial fishing use occurs from March through October in most years (Figure 3.10-3). Most fishing in the Glen Canyon reach is done from boats or is facilitated by boating access to gravel bars and riffles in the river upstream from the NPS Lees Ferry launching facility (Anderson, M. 2012). Fly fishermen fish both from boats and by wading bars, riffles, and along the shore, depending on river flow levels; spin fishermen more typically fish from boats. The availability of gravel bars for wading depends on river flow, with most bars being inundated at 15,000–16,000 cfs (Lovett 2013). There also is significant fishing use by walk-in anglers along the approximately 1.2 mi of shoreline between the Paria River confluence with the Colorado River and just upstream of the launch facility. A significant number of anglers also access the Colorado River below the Paria River confluence on Paria Beach, farther

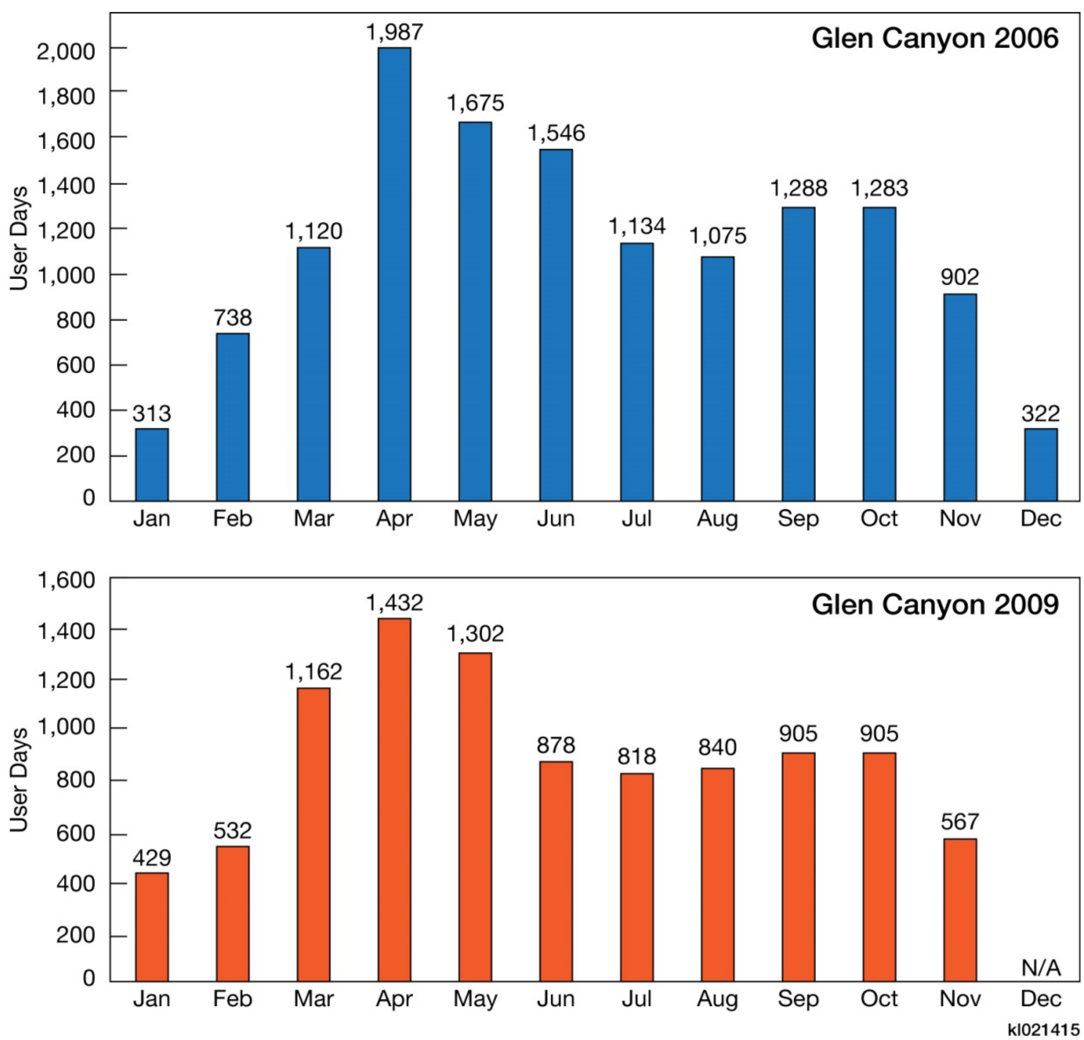

FIGURE 3.10-3 Fishing User Days by Month in the Glen Canyon Reach for 2006 (top) and 2009 (bottom) (User days for December 2009 were unavailable.) (Source: Reclamation 2011d)

downriver via a system of trails and across the river on Navajo Nation land. Power boaters can access almost the entire river upstream of the launch facility with only a small safety area below the dam being closed to access.

The AZGFD estimates that total fishing use in the Glen Canyon reach in 2011 was 87,000 hr (15,818 angler days)[10] (Anderson, M. 2012). It is estimated that 70,000 hr (12,727 angler days) of angling effort were expended by boating anglers and 17,000 hr (3,091 angler days) were expended by walk-in anglers. Angler use days peaked at 52,000 in 1983 (Figure 3.10-4), but eventually dropped to an average of about 3,400 angler days per year from the mid-1990s to 2009.

Based on AZGFD survey data, commercial guided fishing operations provided services for about 50% of the boating-based fishing use in the Glen Canyon reach in 2011 (Anderson, M. 2012). In that year, there were five NPS-authorized commercial fishing guide operations in the Glen Canyon area that provided boats and guide services in the Glen Canyon reach (Blaise 2012). The AZGFD surveys did not identify any walk-in fishing use being supported by commercial guides. NPS requires guide services to obtain a commercial use authorization to operate in GCNRA; guide services are also required to report the number of anglers they serve. The total reported number of commercial clients for the five commercial fish

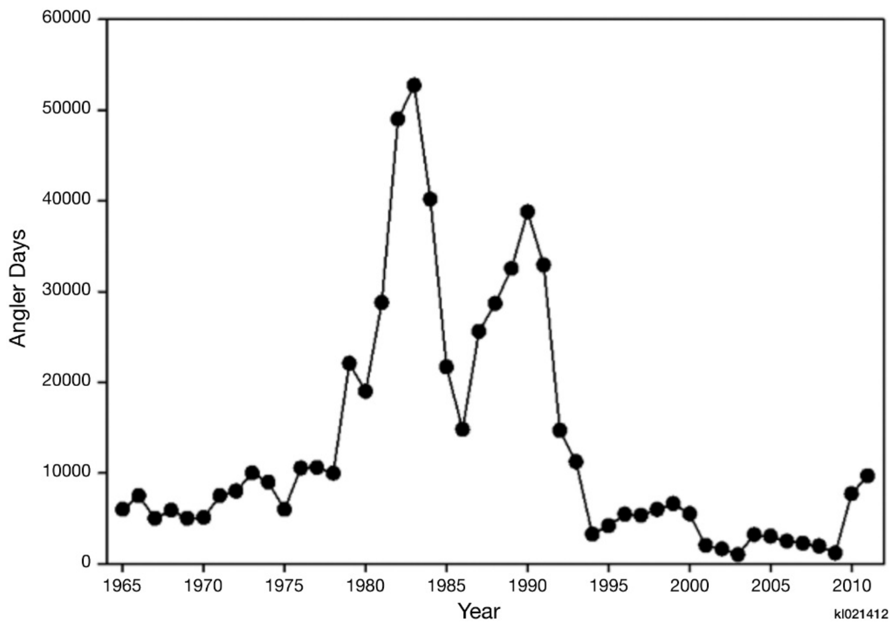

FIGURE 3.10-4 Angler Days in the Glen Canyon Reach from 1965 through 2011 (Source: AZGFD 2012)

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10 The methodology for calculating angler days depends on the assumed duration of an angler day. The computations here are based on the AZGFD statewide standard of 5.5 hr per trip, but it is understood that if other durations were used, the number of angler days would be somewhat different.

guiding operations in the 4 years beginning in 2009 was 2,652, 2,665, 2,731, and 3,210, respectively (Blaise 2012; Seay 2013). Historical levels as high as 4,000 clients per year reported for a single operator provide some perspective on the current level of commercial use (Gunn 2012).

Important Attributes of Fishing in the Glen Canyon Reach, and Angler Satisfaction

The quality of the fishing experience in the Glen Canyon reach has been studied to help understand what characteristics of fishing in the area are most important to participants. A study was conducted by Bishop (Bishop et al. 1987), during the period when dam operations resulted in large and rapid fluctuations in water flows, and shortly thereafter, when the trout fishery was regularly producing large fish. Stewart et al. (2000), in another study, identified the flow regimes preferred by anglers. Although the two studies were completed under very different operating criteria, anglers in both studies identified a marked preference for flows in the 8,000 to 15,000 cfs range. The Bishop et al. (1987) study further identified a preference for steady, non-fluctuating flows. In the Stewart et al. (2000) study, fluctuating flows were not identified as an issue. Because fluctuations had been reduced to MLFF levels by the time of the study, attitudes toward higher levels of fluctuations could not be investigated. In both studies, anglers showed a clear dislike of flows below 3,000 to 5,000 cfs.

Another attribute of fishing in the Glen Canyon reach affects fishermen who wade and fish from the shore and gravel bars. High water levels, as well as rapid changes in water levels, directly affect the safety of wading fishermen due to the potential for being swept away by the river current. The 1995 Glen Canyon Dam EIS (Reclamation 1995) included a reference to three drownings that were possibly related to river stage or stage change and noted that high flows (30,000 cfs or more) reduced the safety of wading in the river. After the adoption of the MLFF operating protocol in 1996, ramping rates were restricted, which has likely reduced the level of this risk, as has the reduction of normal high flows to 25,000 cfs.

3.10.1.2 Day-Rafting, Boating, and Camping in the Glen Canyon Reach

The 15-mi Glen Canyon reach supports several recreational activities in addition to fishing, including river floating, camping, and recreational boating. In calendar year 2012, the NPS estimated that 210,627 recreation users visited the area (NPS 2014d). About 25% of the annual visitors accessed the Glen Canyon reach via the pontoon-raft concession that departs from near the dam and travels to Lees Ferry.

The NPS facilities at Lees Ferry consist of launch ramp, campground, restroom, and interpretive facilities, as well as hiking trails. Upstream of the Lees Ferry launching facility, there are six designated, boat-accessible-only, camping areas.

An NPS launching facility is the main access both for trips going downstream through the Grand Canyon and for fishermen and other boaters heading upstream into the Glen Canyon reach. Other facilities nearby interpret the human history and existing historic structures associated with the historic Lees Ferry crossing. Aside from the courtesy dock located next to the launch ramp, facilities in this area are not directly affected by river fluctuations.

Camping in the Glen Canyon reach is allowed in six designated areas. These areas are located on sediment terraces and beaches. Figure 3.10-5 shows the general location of the six designated campsite areas; Figure 3.10-6 illustrates the affected shoreline environment in the GCNRA area.

In addition to recreational power boating, the NPS authorizes one concessionaire, Colorado River Discovery (CRD), to provide a variety of river services in the Glen Canyon reach. The most popular of these is a half-day guided trip that originates at the dam; most CRD trips are motorized pontoon rafts; however nonmotorized full-day trips are also offered.

The most popular trips are run twice a day during the main part of the recreation season. The rafts have a maximum capacity of 22 people (Figure 3.10-7). At the end of the trip, passengers are transported by bus from Lees Ferry back to Page. The passenger numbers served by CRD are shown in Table 3.10-1. The trips generally originate in Page, Arizona, at the company's rafting headquarters. The company provides transportation to the launch site, which involves traveling through a 2-mi-long tunnel that provides access to the river near the base of the dam. CRD also offers a "backhaul" service that transports private canoes/kayaks upstream from Lees Ferry into the Glen Canyon reach.

HFEs create operational issues for the rafting concessionaire, including cessation of operations for a period of days and the need to move mooring docks and rafts or to relocate operations to the Lees Ferry launch site, which is a less economically desirable location.

Although the concessionaire does not operate during an HFE, the departure/mooring docks for the day-rafting operation are located just below the dam, and HFEs in excess of power-plant capacity of 31,500 cfs require that the concessionaire's rafts either be removed from the river or relocated because of turbulence caused by the discharge from river bypass tubes. The concessionaire also must remove boarding steps that allow passengers to get from the dock to the boats. With 21 boats, this is a major amount of work that disrupts business operations.

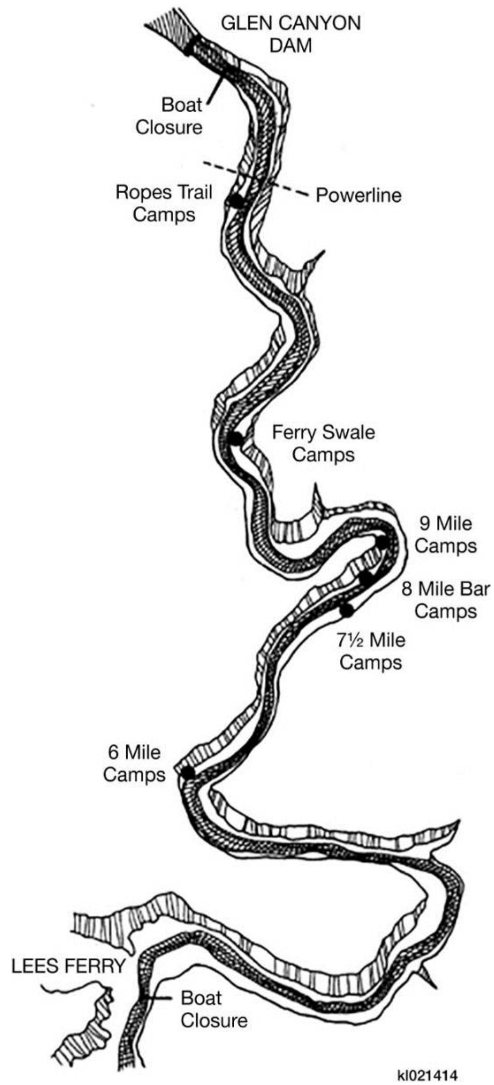

FIGURE 3.10-5 Designated Campsite Areas in the Glen Canyon Reach (GCNRA 2014)

FIGURE 3.10-6 Shoreline Environment with Steep Erosion Banks at Glen Canyon Reach Ferry Swale Campsite (courtesy of GCNRA)

FIGURE 3.10-7 Pontoon Raft Operated by Colorado River Discovery

TABLE 3.10-1 Colorado River Discovery Commercial Rafting Passengers 2009–2013

Month	2009	2010	2011	2012	2013[a]
January	0	0	0	0	0
February	159	8	19	48	100
March	2,211	2,131	1,922	2,163	2,416
April	5,256	4,599	4,533	4,801	3,914
May	6,346	6,629	6,831	7,438	6,684
June	9,333	9,905	9,444	10,372	8,880
July	9,256	9,887	9,389	9,515	8,661
August	7,866	7,367	7,050	7,773	6,479
September	5,415	6,287	6,001	6,300	5,245
October	3,825	3,824	3,978	4,363	1,311
November	735	687	458	535	562
December	0	0	0	0	8
Totals	50,402	51,324	49,625	53,308	44,260

[a] The 2013 passenger counts were affected by the closure of AZ Highway 89 in February 2013.

Source: Blaise (2014).

During the 2012 HFE event, the concessionaire indicated that the business was disrupted for 2 days before and after the HFE, as well as during the HFE.

In cases of extended high flows (such as 1983–1984), rafting operations have been relocated to the Lees Ferry launch site where they continued limited and modified operations. These operations require the rafts to travel upriver against heavy current with a reduced passenger load. In this scenario, the rafts travel upriver through a portion of the canyon using an outboard motor before floating back down to the starting point (Grim 2012). During high-flow events (other than scheduled HFEs), docking at Lees Ferry is more difficult than normal because the dock is actually in the river channel, as opposed to being out of the main current. Departing from Lees Ferry rather than the dam keeps the business functional to some degree, but the economics of this type of operation are unfavorable compared to normal operations.

River fluctuations were identified as an issue for both anglers and white-water boaters in previous studies (Bishop et al. 1987; Stewart et al. 2000). However, both studies found that daily river level fluctuations had no impact on the satisfaction level for day-rafting clients.

HFEs create steep banks in some portions of the river that make access from boats to the upper sediment terraces more difficult, as shown above in Figure 3.10-6 (Grim 2012; Hughes 2014a). Eventually most steep areas are eroded by use, restoring easy access to the terraces, but in some locations, the banks have been steepened to such a degree that visitor access is adversely affected. The six designated recreation sites located on these sediment terraces are shown above in Figure 3.10-5.

3.10.2 The Colorado River in Grand Canyon National Park

GCNP is a world-renowned recreational destination that was designated as a World Heritage Site in 1979. The 1,217,261-ac park contains 1,143,918 ac proposed for wilderness designation, including 10,919 ac of potential wilderness along the Colorado River corridor. Annual visitation to the park has exceeded 4 million visitors since 1992, and 5.5 million visitors were recorded in 2015. Most visitors focus on the developed facilities on the South Rim of the canyon, where the majority of the visitor services, facilities and administrative offices are located.

While GCNP is a destination for millions of visitors, the focus of this EIS is on the Colorado River corridor, which constitutes a small percentage of the acreage of the park and small portions of both Glen Canyon and Lake Mead National Recreation Areas. The CRMP, completed in 2006 (NPS 2006b), set goals for managing visitor use and protecting resources along the river corridor. The CRMP established a visitor capacity based on the number, size, and distribution of campsites; natural and cultural resource conditions; and visitor experience. The NPS established a capacity of 60 trips at one time, which is managed through daily launch limits, group size, and trip length. The CRMP also established a 6.5-month no-motors season to provide enhanced wilderness opportunities. The CRMP outlines a Research, Monitoring, and Mitigation Program that manages resources in the river corridor within an adaptive management framework (NPS 2006c).

A whitewater trip through all or part of the Grand Canyon is a rich and complex recreational experience, valued for the sights and sounds of the canyon, the whitewater, and superb opportunities for varied recreational experiences. Recreational river use in the Grand Canyon expanded from 150 people per year in 1955 to 16,500 in 1972 and to the 2006 CRMP levels of about 24,657 visitors per year.

Visitor use is measured in user days (e.g., one person on the river for a day), and is managed to offer a variety of trip types throughout the year. Trips are conducted using a variety of types and sizes of boats and rafts; group sizes can range up to 32 people (including guides); trip lengths range up to 25 days; trips can be run by commercial companies or by private individuals; and there are various means of joining trips, including launching from Lees Ferry, hiking into or out of the canyon to join or leave a trip at Phantom Ranch, and limited access by vehicle and helicopter (commercial use only) to join trips in the western portion of the Grand Canyon.

Commercial river trips are offered from April through October, and noncommercial trips occur year round. Peak use occurs in May through September, as shown in Figure 3.10-8.

Most Grand Canyon river trips begin at Lees Ferry (RM 0) and take out at Diamond Creek (RM 226) or at Pearce Ferry (RM 280) in LMNRA. When Lake Mead water levels were higher prior to the onset of drought in 2000, trips also regularly ended at South Cove (RM 295) on Lake Mead. Prior to the drought, reservoir travel began at Separation Canyon, and many trips either motored or were towed by jet boats that came upriver from Lake Mead to their take-out points at Pearce Ferry or South Cove.

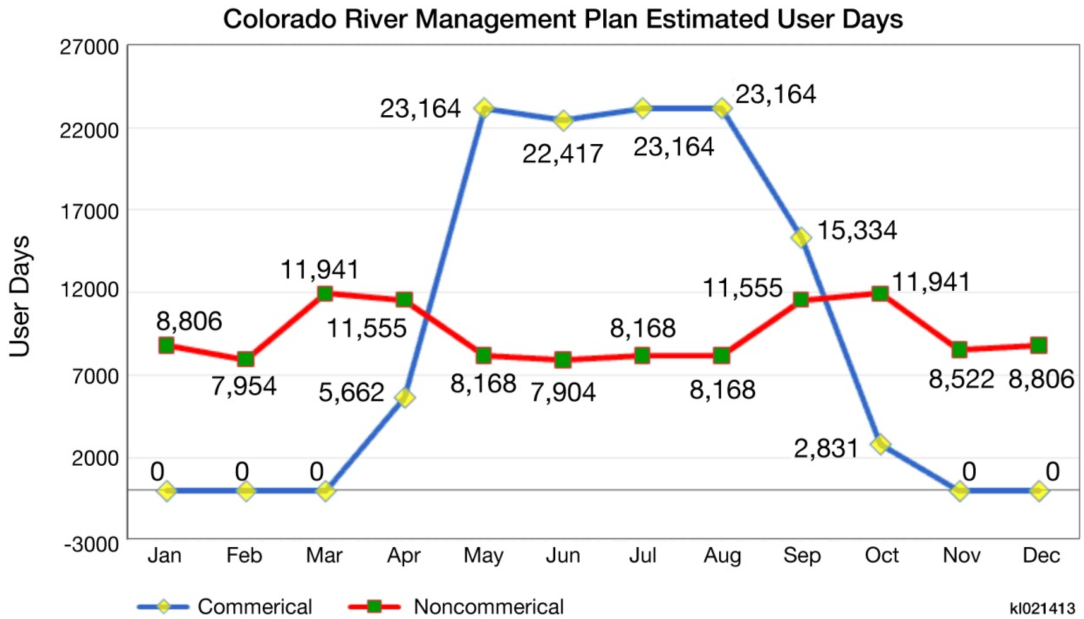

FIGURE 3.10-8 Boating in Grand Canyon, Anticipated Annual Use by Month (Source: Reclamation 2011b)

The Lower Gorge of the Grand Canyon is defined as the 51-mi section of river below Diamond Creek (RM 226) to Pearce Ferry (RM 280). Recreational use of the Lower Gorge is described in the CRMP and is managed by the NPS and the Hualapai Tribe, whose reservation is on the south side of the river (located approximately between RM 164.5 and RM 273).

Types and levels of recreational use in the Lower Gorge vary greatly from those above Diamond Creek, primarily due to road and boat access to the river by way of the Hualapai Reservation at Diamond Creek and to the influence of Lake Mead. In addition to river trips that launch from Lees Ferry and continue into the Lower Gorge, the NPS permits noncommercial (private) and educational trips launching from Diamond Creek. Also, the Hualapai Tribe operates its own river program that provides commercial trips beginning at Diamond Creek and other sites on Tribal lands.

Most trips spend fewer than three nights total in the Lower Gorge, although it is possible to spend more if boaters are interested in reservoir travel or off-river hiking. Backcountry permits are required to camp off the river in GCNP, and Hualapai Tribal permits are required for activities on the reservation, including hiking, camping, and conducting research.

3.10.2.1 Campsites in Grand Canyon National Park

River-accessed campsites within GCNP are a memorable aspect of any recreational experience along the river. The number of available campsites and the amount of campsite area at any particular time are affected by river flow (i.e., fewer campsites are available at higher flows, and vice versa). Because of their singular importance in supporting river use, there have been numerous campsite inventories over the years; NPS reported in the CRMP that there are more than 200 regularly used camping beaches in the GCNP planning area. The number and usability of campsites vary from year to year based on several factors, including flow regimes; vegetation changes; erosion from tributary flooding, wind, or recreation use; or closure of sites to protect sensitive resources (NPS 2005a). An updated campsite inventory conducted by the NPS in 2011, identified and classified, by capacity, 235 campsites between Lees Ferry and Diamond Creek.

Preferred beach characteristics for both camping and stops for lunch include a strong preference for shade, larger rather than smaller beaches, and the availability of hiking opportunities (Stewart et al. 2000). “Campable area” is the term used to describe the area of a beach where people set up camp, moor boats, cook, and sleep. The criteria used to define campable area include a smooth substrate, preferably sand, with no more than 8 degrees of slope, and with little or no vegetation (Kaplinski et al. 2010).

Campsites are further classified as being located in either critical or noncritical reaches of the river. A critical reach is any contiguous stretch of river in which the number of available campsites is limited because of geomorphic setting (e.g., narrowed canyon width), high demand for nearby attraction sites, or other logistical factors (e.g., exchange points). Noncritical reaches are those stretches in which campsites are relatively plentiful, resulting in little competition for most sites (Kearsley and Warren 1993).

Campsites vary in size and not all can accommodate the maximum group of 32 described in the CRMP. Researchers, using campsite inventories, have developed three general categories: small camps (1 to 12 people); medium camps (13 to 24 people); and large camps (25 or more people) (NPS 2005a). The results of five campsite inventories conducted between 1973 and 2011 are shown in Figure 3.10-9.

The highest number of camps (particularly large camps) recorded was documented during the inventory conducted immediately following the 1983 flood. By contrast, the 1991 inventory shows 75% fewer large camps than in 1983, while the 2003 inventory shows an even further reduction (NPS 2006b). Compared to 1973, there was about a third as many large camps and a third fewer total camps in 2003 (NPS 2005b). The loss of the large campsites is especially problematic, given the number of large commercial trips during the summer season. The loss increases the potential for groups to camp in close proximity to one another, especially in the critical reaches. This loss led the NPS to reduce group size as identified in the CRMP.

The most important finding regarding campsites in the Grand Canyon is that they are becoming smaller and less abundant. A synthesis of geomorphic data on sandbars below Glen Canyon Dam reported a 25% reduction in the sandbar area within the 87-mi reach from Lees Ferry to Bright Angel Creek between 1984 and 2000 (Schmidt et al. 2004). A study completed in 2010 summarizing detailed topographic campsite monitoring of a sample of 38 sites in GCNP showed that the total amount of high-elevation campsite area above the elevation of 25,000 cfs flow decreased 56% between 1998 and 2006. Figure 3.10-10 shows the described trend for high-elevation campsite area. The primary factors identified in campsite loss

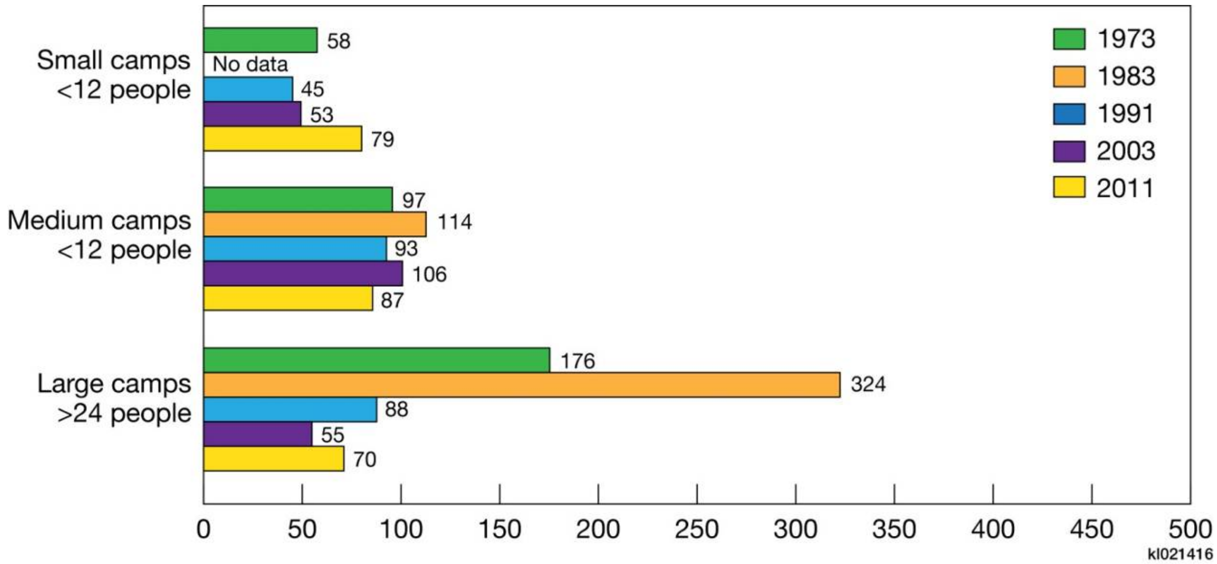

FIGURE 3.10-9 Change in Camp Size over Time in the Lees Ferry to Diamond Creek Reach of GCNP (Sources: NPS 2005a; Jalbert 2014)

were riparian vegetation growth and sandbar erosion. These losses happened in spite of a temporary increase of 29% in campsite area between the inventories in 2003 and 2005 that was related to both the 2000 summer low steady flow experiment and the 2004 HFE (Kaplinski et al. 2010). The diminishing availability of campable area, particularly in some of the narrower reaches of the river corridor, is an important issue for national park managers and recreational river runners.

The 2010 Kaplinski et al. study agreed with the findings of Kearsley and Warren (1993) that campsite area in critical reaches decreased primarily due to erosion, and in noncritical reaches, due to increased vegetative cover. Figure 3.10-11 plots the loss of high-elevation campsite area in critical and non-critical reaches.

Over the long term, eddy-sandbar size can only be increased if (1) adequate sediments are available for deposition, (2) high-flow deposition is substantial, (3) high flows occur frequently, and (4) erosion that occurs between high flows is less than the deposition. Thus, the net effect of high flows in building eddy sandbars results from the magnitude and the frequency of high flows and the deposition they cause. Erosion ensues rapidly after each high flow, and the rate of erosion declines thereafter but persists. The longer the time period between HFEs, the more erosion occurs (Melis 2011).

High flows similar in magnitude to those that occurred during the HFEs of 1996, 2004, 2008, 2012, 2013, and 2014 effectively mobilize accumulated fine sand delivered by tributaries downstream from Glen Canyon Dam and rebuild eddy sandbars in Marble and Grand Canyons. Grams et al. (2010) reported that more erosion occurs when total flow is large (excluding HFEs). Fluctuating flows under normal dam operations between HFEs can erode sandbars and campsites.

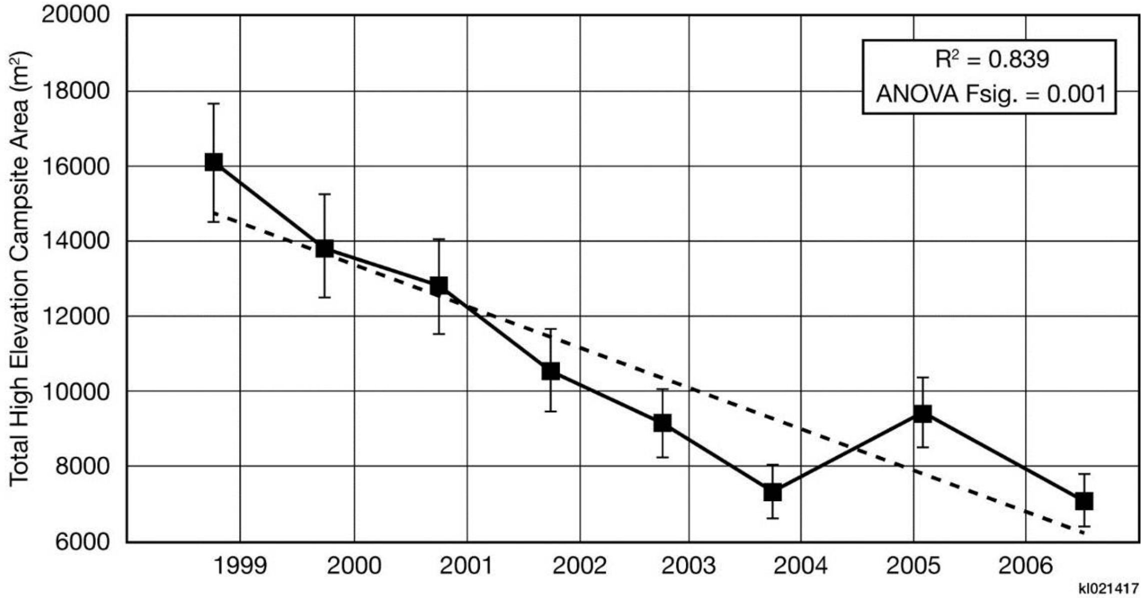

FIGURE 3.10-10 Total High-Elevation Campsite Area for Each Survey between 1998 and 2006 (with 10% uncertainty bands; the dashed line shows the linear regression fit) (Source: Kaplinski et al. 2010)

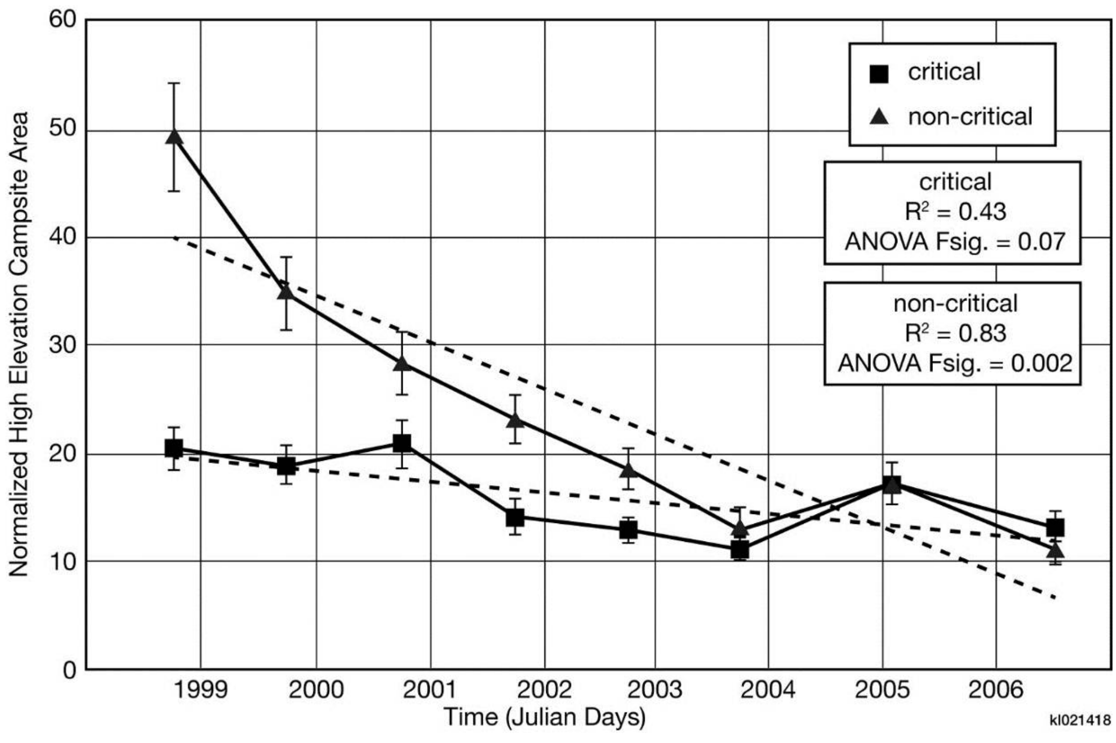

FIGURE 3.10-11 High-Elevation Campsite Area in Critical and Noncritical Reaches between 1998 and 2006 (with 10% uncertainty bands; the dashed lines show the linear regression fit) (Source: Kaplinski et al. 2010)

3.10.2.2 River Flow and Fluctuation

The effect of river flows on recreation in the Grand Canyon has been the subject of studies on the Colorado River for many years that have utilized information from river guides and river trip participants to understand what attributes of river trips are important and how they can be affected by variable river flows (Bishop et al. 1987; Hall and Shelby 2000; Shelby et al. 1992; Stewart et al. 2000; Roberts and Bieri 2001; Ralston 2011). The operation of Glen Canyon Dam commenced in 1963, and the flow regime of the river was first modified in 1991 to address issues that were affecting downstream resources (Reclamation 1995). Principal among these changes was a change in the maximum level of daily river fluctuations from 30,500 cfs to 5,000 cfs, 6,000 cfs, or 8,000 cfs, depending on the scheduled monthly release volumes.

Participants on Grand Canyon river trips have consistently identified several flow-related attributes as being important to their overall trip satisfaction; these include the presence of large rapids, being the only camping group at a beach, and having large beaches for camping (Bishop et al. 1987; Stewart et al. 2000). Large rapids are a function of higher flows. Bishop et al. (1987) found a strong preference among boaters for flows in the range of 25,000–35,000 cfs, a flow range that has been less common since 1996. Flows in this range provided the further benefit that passengers were less likely to be required to walk around rapids. Conversely, higher flows were identified as a potential contributor to crowding at campsites and attractions (Bishop et al. 1987).

The Bishop study (Bishop et al. 1987) further evaluated whitewater boater's preferences with respect to levels of daily flow fluctuations. The study, which was conducted at a time when very large fluctuations were common, identified fluctuations in excess of 10,000 cfs as being noticeable and perceived as less natural to canyon visitors. High fluctuations, ranging from 3,000 to 25,000 cfs/day, were also noted as contributing to issues related to selection of campsites, time allowed at attractions, mooring and tending of boats, transiting major rapids, and trip scheduling. Although such high levels of daily fluctuations are greater than under any LTEMP alternatives, river guides in the Bishop study were also asked to evaluate fluctuation levels that happen to overlap with the alternatives. River guides reported that tolerable fluctuations increased with increasing average daily flow, as shown in Table 3.10-2 (adapted from Bishop et al. 1987), and that the ability to run a whitewater raft trip was particularly sensitive to flow fluctuations when daily flows were low. Based on interviews with guides, the authors concluded that the identified "tolerable" fluctuation ranges were more of a "wish" in the eyes of the guides than specifically "tolerable," as identified on survey forms, and noted that guides stated that predictability in fluctuations is a key factor (Bishop et al. 1987).

Shelby et al. (1992) documented that with daily fluctuations of 9,000–10,000 cfs, boatmen reported problems with boats "left hanging" on beaches by receding water levels. By the time of the Stewart et al. (2000) study, daily fluctuations had been reduced by the MLFF operating regime (capped at 8,000 cfs). Stewart et al. (2000) indicated that "the negative effects of fluctuating flows on recreational use were not substantial problems," but also recorded that "user attitudes and preferences regarding constant flows" had not changed since the 1987 Bishop study.

TABLE 3.10-2 Tolerable Daily Flow Fluctuations Reported by Commercial and Private Trip Leaders

River Flow (cfs)	Tolerable Within-Day Fluctuation (cfs)[a]
5,000–9,000	2,400–3,400
9,000–16,000	3,900–4,800
16,000–32,000	6,400–7,200
32,000 and up	7,900–9,800

[a] Range of mean daily tolerable fluctuations reported by commercial motor guides, commercial oar guides, and private trip leaders who had experienced fluctuations of 15,000 cfs in the Grand Canyon.

Source: Bishop et al. (1987).

It is clear from numerous studies that river flow and management regimes affect whitewater rafting experiences (Bishop et al. 1987; Shelby et al. 1992; Stewart et al. 2000; Ralston 2011). There is general agreement that flows in the 20,000 to 25,000 cfs range are considered to be near optimum for all types of whitewater trips (commercial oar and motor trips and private trips); there is also general agreement that flows of less than about 10,000 cfs are considered to be marginal, while flows of less than 5,000 cfs are considered to be highly unsatisfactory (Bishop et al. 1987; Stewart et al. 2000).

Time Off of the River

A large array of attraction sites, short to long hikes, and campsites are parts of the experience of most river trips through GCNP. There are more than 100 attraction sites available along the river that can be incorporated into a trip, depending on the time available. Most river trips are run on a planned schedule, but longer trips (in number of days) tend to have more flexibility than shorter trips (Roberts and Bieri 2001).

For a river trip of a given distance, river flow rate affects the time available for off-river activities. River flow affects boat speeds, even for motor trips, which affects distance traveled per unit of time. Roberts and Bieri (2001), in their study of the effects of the low steady summer flow experiment of 2000, documented that at a normal flow of 19,000 cfs, river trips spend approximately 7 hr “off river” engaged in activities such as hiking and visiting attraction sites, while during an 8,000-cfs low-flow study, groups spent only about 3.5 hr in these activities. Bishop et al. (1987) recorded that guides indicated that at around 30,000 cfs, additional attraction sites could be included into itineraries. Interestingly, Roberts and Bieri (2001) documented that although substantially less time was available for attraction stops at low flows, the average number of stops stayed near to the norm for average flows. The explanation for this appears to be that some attractions are simply “must see,” and a shorter amount of time was allotted for each attraction rather than dropping a site. It was also recorded that some sites become more preferred at lower flows because the activities at those sites require less time to complete. These observations confirmed findings regarding flow impacts on river trips of previous studies (Bishop et al. 1987; Shelby et al. 1992; Stewart et al. 2000).

Studies have also documented that river flows can affect the choice of campsites, how late campsites are reached, how early trips need to break camp, how much or little boatmen are required to row or run motors to keep a trip on schedule, and how many layover days can be taken. Bishop et al. (1987) and Stewart et al. (2000) speculated that the optimum flow level for a Colorado River trip is in the 20,000–25,000 cfs range because of the flexibility that flow offers in accommodating the various competing needs of these trips.

During low-flow periods, in addition to reducing the amount of time at attraction sites, river guides may ask their group to break camp early or they may arrive at camp later in the day than under normal flows. This reduces the amount of camp time, which can also reduce overall trip satisfaction because of the reduced opportunity to explore the areas around camp, to participate in camp activities, or to simply relax.

Having a wilderness experience is one of the top five attributes sought by whitewater boaters (Bishop et al. 1987; Stewart et al. 2000). River flows can have effects on the wilderness experience in at least two ways. The extent that flows limit or reduce the amount of time visitors can spend enjoying the off-river activities affects this aspect of their wilderness experience. In addition, low flows require more motor use during motor-powered river trips (Bishop et al. 1987; Stewart et al. 2000) to maintain schedules. This introduces an additional noise component to the boaters and to the surrounding environment that detracts from the wilderness experience.

Whitewater Boating Experience

One of the attributes desired by participants in river trips is the opportunity to experience big rapids with large waves and a roller-coaster-type ride (Bishop et al. 1987; Stewart et al. 2000). The condition of rapids is related to the flow, with low levels tending to reduce the size of the rapids and the quality of the ride, while high flows tend to wash out smaller rapids. The perception of the quality of rapids is important to an individual's river experience; most related studies were conducted prior to implementation of MLFF and generally identify flow levels of 20,000 to 25,000 cfs as being the optimum "ride" for most participants (Bishop et al. 1987; Shelby et al. 1992; Stewart et al. 2000). Walking around rapids has been identified as one of the attributes that negatively affects the perception of river trips (Bishop et al. 1987; Stewart et al. 2000). Under reduced normal high-flow levels, having participants walk around rapids now is more likely to be related to lower flows.

Availability of Campsites

Higher flows result in reduced campsite area, which can lead to campsites being pushed into more sensitive riparian and old high-water zones. They can also result in more competition for campsites, especially in the critical reaches. Reduced campsite availability can further lead to camps being located more closely together, adversely affecting a sense of solitude and the wilderness experience. In addition, higher flow fluctuations, such as those greater than an 8,000-cfs daily range, affect the ability to both moor boats with less need to attend to them during the night and to access campsites from the river level (Bishop et al. 1987). Current fluctuation levels under MLFF have reduced but not eliminated this issue compared to previous operations (Stewart et al. 2000).

3.10.2.3 Hualapai Tribe Recreation Program

The Hualapai Tribe has implemented a comprehensive recreation services program utilizing Tribal lands that border the Colorado River in the Grand Canyon to generate income for the Tribe. The Tribe, through its Grand Canyon Resort Corporation, manages several businesses that provide recreation services, including a river rafting company. Hualapai River Runners (HRRs) is the only Tribally owned and operated river rafting company on the river. HRR offers commercial motorized day trips from the Diamond Creek and Quartermaster areas on motorized 22-ft pontoon boats. Under a Memorandum of Understanding between the Hualapai Tribe and the NPS, HRR trips are subject to operational standards required of all NPS river concessionaires.

HRR currently offers two types of river trips: (1) short 15-minute boat rides above and below the Quartermaster area (RM 260); this services people who have purchased a tour package that generally originates in Las Vegas, in which passengers are ferried to the launch site by helicopter; and (2) 1-day whitewater raft trips that put in at Diamond Creek and take out at Pearce Ferry. Both types of trips also occur during HFEs (Havatone 2013).

The Tribe authorizes the use of helicopter landing pads (on Reservation lands) both above and below Diamond Creek. The pad near Whitmore (RM 187) is used to exchange passengers from commercial river trips. The helicopter pads at RM 261 are used for day trips that do not involve on-river activities. Helicopter pads at RM 262 and RM 263 are leased to helicopter companies serving HRR river trips, pontoon trips, and trips not involving on-river activities. Noncommercial river rafting passengers do not exchange at these pads.

The landing at Diamond Creek is a major access point to the river and is a prime take-out location for NPS-permitted river trips originating at Lees Ferry. Approximately 85% of noncommercial river rafting trips and a large percentage of commercial trips end at Diamond Creek (NPS 2006b). Diamond Creek is also the starting point for Hualapai Tribe commercial trips through the lower Grand Canyon and for a few noncommercial trips. The Hualapai Tribe maintains the Diamond Creek road and charges a fee for tourists and river runners entering or exiting the river via this road.

The Hualapai Tribe has articulated concerns over the operation of Glen Canyon Dam generally and the effects of HFEs specifically (Havatone 2013). This is addressed in Section 4.10.2.7.

3.10.3 Recreation Use on Lake Mead and Lake Powell

Both Lake Mead and Lake Powell are major destinations for boaters, fishermen, and campers. Drought in the Southwest has been having a major impact on both reservoirs since 2000 and water levels are continuing to decline.

3.10.3.1 Lake Mead National Recreation Area

Lake Mead resulted from the construction of Hoover Dam (once known as Boulder Dam) in 1932. It is the largest reservoir in the United States and at an elevation of 1,221.4 ft AMSL—the elevation of the top of the spillway gates—the reservoir covers 158,500 ac at an elevation of 1221.4 ft. The reservoir extends approximately 110 mi upstream toward the Grand Canyon and about 35 mi up the Virgin River. The elevation of Lake Mead on March 1, 2014, was 1107.74 ft AMSL (Reclamation 2014a). On average, visitors at Lake Mead total about 6 million annually.

Because of the ongoing drought conditions affecting operations at LMNRA, in October 2005, NPS completed a GMP Amendment for Low Water Conditions and a FONSI (NPS 2005b) that identified the strategy for low-water operations. This amendment articulated the intent to maintain boat-launch capacities established in the original GMP of 1986 and a subsequent amendment in 2003, by either extending or relocating existing launch ramps and marinas to be functional down to an elevation of 1,050-ft AMSL. This amendment reflects the current management direction for low-water operations, and it assumes that NPS and concessionaires will continue to modify launching and marina facilities as necessary and possible, given time and budget to continue providing visitor services.

3.10.3.2 Lake Powell, Glen Canyon National Recreation Area

Reclamation completed construction of Glen Canyon Dam in 1963; Lake Powell, which was created by the dam, is the second largest reservoir in the United States. The total capacity of the reservoir is 27 million ac-ft, and it stretches for 186 mi. At full-pool elevation, 3,700 ft, the reservoir has a surface area of 161,390 ac (NPS 2014e). Lake Powell is subject to the same regional drought conditions as Lake Mead, and the elevation of Lake Powell on March 1, 2014, was 3,575.59 ft AMSL (Reclamation 2014a). Annual visitation varies and has been approximately 2 million visitors annually over the past 10 years.

3.10.4 Park Operations and Management

Related to recreation in GCNRA and GCNP is the level of park staffing needed to support recreation and resource protection. The level of staffing affects the ability of the park units to provide appropriate park infrastructure and services to support river and backcountry operations and address visitor experience, and the administrative use of the Colorado River within GCNRA and GCNP. Issues related to park management and operations were raised in public and internal scoping. Some of these issues have been addressed at GCNP by other management documents such as the CRMP (NPS 2006b) and the GCNP General Management Plan (NPS 1995). However, some issues specific to Glen Canyon Dam operations are appropriate for considering within the scope of this EIS. Changes in releases from Glen Canyon Dam may affect the number of personnel, level of funding, and staff time needed to adequately maintain park resources. For example, HFEs require increased staffing resources to notify boaters in Glen and Grand Canyons of high flow releases. In addition, NPS management related to changes in dam operations includes planning, coordination with other agencies, concessionaires, and stakeholders, as well as resource monitoring and visitor safety. Park management and operations may also be affected by non-flow actions.

The Superintendent of each park is ultimately responsible for park management and operations. In 2014, GCNP employed 512 employees (of which 313 are permanent) to manage operations, including visitor services and facilities, resource management and preservation, planning and environmental compliance, emergency medical services, law enforcement, search and rescue operations, fire operations, air operations, facilities management and maintenance, and administrative functions. Similarly, GCNRA employed 214 employees to manage areas including Lake Powell, surrounding lands, and the 15-mi stretch of Glen Canyon below the dam. These resources include a historic district, a campground, and designated campsites along the river with bathrooms and fire pits.

Park divisions with river-related responsibilities include facilities management, visitor and resource protection (permits, inner canyon and river rangers, emergency medical services, and search and rescue operations), concessions management (contracts, commercial use authorizations), interpretation and resource education (signage, information, and interpretation), science and resource management (resource protection, inventory, monitoring, research, and research permitting), and the Office of Planning and Compliance (environmental analysis). River recreational and administrative use is currently managed in accordance with the CRMP (NPS 2006b), the GCNP General Management Plan (NPS 1995), the GCNRA General Management Plan (NPS 1979), and applicable NPS laws, policies, and regulations.

3.11 WILDERNESS

There is proposed wilderness in GCNRA and GCNP that is managed as wilderness pursuant to NPS policy as discussed below. The wilderness proposals within GCNRA and GCNP do not address the Glen Canyon Dam or dam operations. Nothing in this EIS modifies the wilderness proposals in any manner.

This section is included in the EIS primarily to address activities conducted or permitted by the NPS (including research as part of the Glen Canyon Dam Adaptive Management Program [GCDAMP]). Approximately 94% of GCNP, or 1,143,918 ac, qualifies as Wilderness as described in the 1964 Wilderness Act and NPS *Management Policies 2006* (NPS 2006d). Grand Canyon Wilderness complements other Designated and Proposed Wilderness Areas north of the Grand Canyon on other NPS, Bureau of Land Management (BLM), and U.S. Forest Service (USFS) lands. Approximately 51% of Glen Canyon, or 588,855 ac, was proposed for wilderness designation. This includes 6,180 ac in the Paria unit of the Glen Canyon proposed wilderness.

3.11.1 Law and Policy

The Wilderness Act of 1964 required the Secretaries of Agriculture and the Interior to evaluate land under their jurisdiction for possible wilderness classification. Section 4 of the Wilderness Act describes authorized uses of wilderness areas; subsection 4(a) declares, with specific legislative references, that the Wilderness Act shall be supplemental to the purposes for which the national forests, parks, and refuges have been established. Subsection 4(b) states, in part:

> Except as otherwise provided in this Act, each agency administering any area designated as wilderness shall be responsible for preserving the wilderness character of the area and shall so administer such area for such other purposes for which it may have been established as also to preserve its wilderness character. Thus, except for specified provisions in the legislation, wilderness areas shall be devoted to recreational, scenic, scientific, educational, conservation, and historical uses.

Subsection 4(c) prohibits certain uses (unless specifically provided elsewhere in the Act) that are inconsistent with wilderness preservation. With the exception of the minimum actions needed for administrative duties and emergency health and safety procedures, the Act prohibits temporary roads, motor vehicle use, motorized equipment or motorboats, landing of aircraft, mechanical transport, structures, and installations.

Section 4 also addresses special provisions for certain wilderness uses. Subsection 4(d)(1) states, in part:

> Within wilderness areas designated by this Act the use of aircraft or motorboats, where these uses have already become established, may be permitted to continue. These uses are subject to such restrictions as the administering federal official deems desirable. Subsection 4(d)(5) permits the performance of commercial services within wilderness to the extent necessary for activities which are proper for realizing the recreational or other wilderness purposes of this act.

In addition, NPS Management Policies 2006 (NPS 2006d) includes the following:

> The National Park Service will take no action that would diminish the wilderness suitability of an area possessing wilderness characteristics until the legislative process of wilderness designation has been completed. Until that time, management decision pertaining to lands qualifying as wilderness will be made in expectation of eventual wilderness designation. This policy also applies to potential wilderness, requiring it to be managed as wilderness to the extent that existing non-conforming conditions allow. The National Park Service will seek to

remove from potential wilderness the temporary, non-conforming conditions that preclude wilderness designation.

NPS will manage proposed wilderness in GCNP and GCNRA in accordance with NPS Management Policies and the Wilderness Act of 1964. This area includes the 277-mi section of the Colorado River within the boundaries of GCNP and portions of the Lees Ferry District, including a 15-mi section of the river downstream of the dam in GCNRA. The Final EIS for the GCNP Colorado River Management Plan (NPS 2005a) clarifies that recreational motorized use does not preclude possible wilderness designation because such use is a temporary or transient disturbance of wilderness values and does not permanently impact wilderness resources. The 2006 CRMP established a 6.5-month no-motor season to enhance opportunities for a wilderness experience (NPS 2006b).

NPS policy requires that its wilderness management decisions be consistent with a minimum requirement concept that evaluates the potential disruptions of wilderness character and resources. The minimum requirement concept applies to all administrative activities, including research and monitoring. Research trips of NPS, USGS, and other agencies are subject to the minimum requirement policy.

3.11.2 Defining Wilderness Character

According to GCNP's GMP, areas proposed for wilderness offer visitors opportunities for solitude and primitive recreation. An important provision in the GMP states:

> The management of these areas should preserve the wilderness values and character. Non-wilderness undeveloped areas should continue to serve primarily as primitive thresholds to wilderness. Visitors traveling through the canyon on the Colorado River should have the opportunity for a variety of personal outdoor experiences, ranging from solitary to social. Visitors should be able to continue to experience the river corridor with as little influence from the modern world as possible. The river experience should help visitors to intimately relate to the majesty of the canyon (NPS 1995).

Subsection 2(c) of the Wilderness Act defines wilderness as follows:

> A wilderness, in contrast with those areas where man and his works dominate the landscape, is hereby recognized as an area where the earth and its community of life are untrammeled by man, where man himself is a visitor who does not remain.

The same subsection 2(c) further defines wilderness as having the following characteristics:

- Undeveloped land retaining its primeval character in influence without permanent improvements or human habitation

- Generally appears to have been affected primarily by the forces of nature, with the imprint of man's work substantially unnoticeable

- Has outstanding opportunities for solitude or primitive and unconfined type of recreation

- May contain ecological, geological, scientific, educational, scenic, or historical value

This last quality, recognizing ecological, geological, scientific, educational, scenic, or historical value, is of particular importance when describing the Colorado River and the greater Grand Canyon. To the Fort Mojave Tribe, Havasupai Tribe, Hopi Tribe, Hualapai Tribe, Navajo Nation, Pueblo of Zuni, Southern Paiute Tribes, and other American Indian Tribes, the canyon and river represent significant cultural, educational, and historical places that are central to their cultural identity.

Wilderness character is defined in NPS Wilderness Stewardship Reference Manual 41 as, "The combination of biophysical, experiential, and symbolic ideals that distinguishes Wilderness from other lands. The five qualities of Wilderness Character are Untrammeled, Undeveloped, Natural, Solitude or a Primitive and Unconfined Type of Recreation, and Other Features of Value."

All designated wilderness areas, regardless of size, location, or any other feature, are unified by the statutory definition. These four qualities of wilderness are as follows:

1. **Untrammeled**—wilderness is essentially unhindered and free from modern human control or manipulation. This quality pertains to actions that manipulate or control ecological systems.

2. **Natural**—wilderness ecological systems are substantially free from the effects of modern civilization. In the context of managing visitor use on the Colorado River, this quality pertains to the intended and unintended human-caused effects on natural and cultural resources conditions.

3. **Undeveloped**—wilderness is essentially without permanent improvements or modern human occupation. This quality pertains to the presence and development level of trails, campsites, structures, and facilities within the river corridor and areas visited by river users.

4. **Outstanding opportunities for solitude or a primitive and unconfined type of recreation**—wilderness provides outstanding opportunities for people to experience solitude or primitive and unconfined recreation, including the values of inspiration and physical and mental challenge. This quality pertains to visitor opportunities to experience a primitive setting that may include solitude and adventure.

The fifth quality articulated in the definition of wilderness character above is defined as follows:

5. **Other features of scientific, educational, scenic, or historical value**—attributes not required of or found in every wilderness that reflect a wilderness' specific wilderness character, and is based on the Wilderness Act's Section 2(c) that states a wilderness "may also contain ecological, geological, or other features of scientific, educational, scenic, or historical value."

This component captures important wilderness elements not covered in the other four Wilderness Character qualities such as cultural or paleontological resources. The three NPS units within the project area protect important cultural histories, significant traditional cultural resources, and extensive archeological records important to preserving the Wilderness Character of the area. The relationship between these qualities and impacts related to Glen Canyon Dam operations are important components of these analyses and will be further discussed in Chapter 4.

3.12 VISUAL RESOURCES

Visual resources refer to all objects (man-made and natural, moving and stationary) and features (e.g., landforms, night skies, and water bodies) that are visible on a landscape. These resources add to or detract from the scenic quality of the landscape; that is, the visual appeal of the landscape. Visual impacts can be defined as changes to scenic attributes of the landscape brought about by the introduction of visual contrasts and the associated changes in the human visual experience of the landscape. A visual impact can be perceived by an individual or group as either positive or negative, depending on a variety of factors relating to personal circumstances (e.g., personal experience, aesthetic sensitivity, or the activity in which the viewer is engaged) or to viewing circumstances (e.g., viewing distance, time of day, or weather/seasonal conditions).

Visual resources are not only important to visitor enjoyment of GCNRA, GCNP, and LMNRA, they are important to American Indian communities who once resided in and/or visit the area for subsistence or ceremonial purposes. Conservation of visual resources is part of the GCPA of 1992 and an important component of the federal management activities for these areas. Scenic resources found within GCNRA, GCNP, and LMNRA and on Hualapai and Navajo reservations include colorful and unique geological formations; complex geology; sleek canyon walls; towering cliffs, buttes, and mesas; rivers, lakes, and streams; barren deserts; and unique prehistoric and historic cultural sites. The scenic resources of these areas are experienced in a number of ways. The Canyons have a significant place in the traditional cosmology of the indigenous communities of the Southwest. American Indian communities may visually experience the Canyons quite differently than recreational users who experience the Canyons not only during recreational activities but also while gathering natural resources or performing religious ceremonies. Water-based recreational activities such as boating, kayaking, swimming, and fishing allow individuals to view the varied landscapes of the Colorado River, Grand and

Glen Canyons, Lake Powell, and Lake Mead from almost anywhere on the water. Stewart et al. (2000) found that the more valued aspects of a river rafting trip include simply being in a natural setting, having the opportunity to stop in scenic places, and being able to view flora, fauna, and geology. Terrestrial activities such as hiking and camping along the shores of Lake Powell, Lake Mead, and the Colorado River offer spectacular views, as do designated scenic overlooks accessible via boat, car, or hiking trail. For many Tribes, trails that enter the Canyons are sacred and the scenic setting along these trails plays an important part in the travel and ceremonial experience.

Vegetation also plays an important role in the scenic experience along the Colorado River and in Glen Canyon. Vegetation increases the visual interest of many places by adding variety in color and texture and is also a visual cue for Tribes in determining the health of the ecosystem. For example, sandbars and marshes along the river may contain stands of native vegetation which are important for many Tribal communities. For recreational visitors, native vegetation adds variety in color, texture, and form in contrast to the river and surrounding canyon walls, as well as affording the viewer a chance to see native plant life. Stands of nonnative tamarisk that occur along the river are visual evidence of a nonnative plant species. In addition, nonnative plants may have a different texture than native vegetation, and therefore create visual contrast. A full discussion of plant communities can be found in Section 3.6.

Hanging gardens are a unique feature formed when springwater flows through cracks in sandstone and seeps out through canyon walls, allowing plants to grow vertically along the walls and on the canyon floor below (Woods et al. 2001). Where visible to visitors, hanging gardens add visual interest through color and texture contrasts with the surrounding bare rock, and they are visually important to Tribes for various reasons.

3.12.1 Glen Canyon National Recreation Area

The deep, 15-mi long, narrow gorge below the dam provides a glimpse of the high canyon walls, ancient rock art, and a vestige of the riparian and beach terrace environments that were a daily experience for American Indians and first recorded in John Wesley Powell's Colorado River expedition in 1869, providing stark contrast to the impounded canyons of Lake Powell. Portions of this stretch of river are classified as either Class I or Class II scenic areas and are managed as a Natural Zone (NPS 1979). At GCNRA, the Natural Zone is managed for its outstanding scenic resources and relatively undisturbed areas that remain isolated and remote from human activities. Class I scenic areas have outstanding scenic qualities such as "intricately carved landscapes, unique canyons, and unique geological structures," and Class II scenic areas have a "single property of superior quality or a diversity of form and color." This stretch of river also includes unique historic and prehistoric sites such as Lees Ferry and Lonely Dell Ranch (NRHP 1997) and the 9-mi Descending Sheep Panel, as well as features such as Paria Beach, the Glen Canyon Dam, and the popular hiking and photographic destination Horseshoe Bend, an "awe-inspiring bend in the Colorado River" where the rocks and river change color throughout the day (NPS 2007; Hughes 2014b). Examples of these resources are shown in Figures 3.12-1 and 3.12–2. Downstream of the dam, HFEs and fluctuations in daily

FIGURE 3.12-1 Glen Canyon Viewed from the Colorado River

FIGURE 3.12-2 Horseshoe Bend (Photo credit: Massimo Tava)

flow can alter the size and shape of sandbars and scour and erode vegetation along the banks of the river, causing changes in landscape forms, lines, colors, and textures.

3.12.2 Grand Canyon and the Colorado River

Conserving the Grand Canyon's scenic resources is an important part of GCNP management goals. The Colorado River falls within GCNP's Natural Zone which is managed to conserve natural resources and ecological processes while providing for their use by the public, using management techniques that have no adverse effect on scenic quality and natural processes (NPS 1995). Segments of the Colorado River and its tributaries are eligible for Wild and Scenic River status, although an official determination has not yet been made (NPS 1995). The park's Foundation Statement identified the scenic landscape as a primary interpretive theme and further identified "Scenic Qualities and Values" as components of the fundamental resource "Preserving Visitor Experiences in an Outstanding Natural Landscape" (NPS 2010a). In recognition of its outstanding visual landscapes and its biological and cultural significance, the Grand Canyon was designated as a World Heritage Site in 1979 (UNESCO 2012).

The Colorado River flows for 277 mi through the Grand Canyon. As it flows through the canyon, the river offers spectacular views of complex geology, hardened lava flows, waterfalls, sandy beaches, sheer cliffs, towering buttes, hidden caves, and side canyons (NPS 2013l; Belknap and Belknap-Evans 2012).

The Colorado River can be seen from many viewpoints accessible along the rims and inner canyon hiking trails. These vantage points offer spectacular panoramas of the Colorado River as it winds through the Grand Canyon. Of the nearly 5 million annual visitors to the Grand Canyon, most view the Colorado River from the rim. Scenic overlooks on the South Rim along the Hermit Rim Road and Arizona State Route 64 include Mohave, Pima, Hopi, Moran, Lipan, and Desert Viewpoints. North Rim overlooks along the scenic road include Point Imperial, Walhalla Overlook, and Cape Royal. The view from the Toroweap Point overlook is one of the most photographed views of the Colorado River (Belknap and Belknap-Evans 2012; Kaiser 2010; Martin 2010; NPS 2015d; Balsom 2014).

A river trip through the Grand Canyon provides spectacular views of scenic resources along the Colorado River (Figures 3.12-3 and 3.12-4). These include unique cultural sites such as the granaries at Nankoweap (Figure 3.12-4) and Phantom Ranch; exceptionally scenic side canyons and tributaries such as the confluence with the Little Colorado River, Havasu Canyon (Figure 3.12-5), Deer Creek Narrows, Blacktail Canyon, Kanab Creek, and Diamond Creek; and distinctive and colorful geological features caverns, alcoves, grottos, and chasms that range in color from brown, reddish-brown, and orange to light tans and yellows to grays and purples. Redwall Cavern, Elves' Chasm, Vasey's Paradise (Figure 3.12-6), Silver Grotto, Whitmore Wash, Unkar Delta, and Lava Falls are among the most popular scenic geological formations along the river (Belknap and Belknap-Evans 2012; Kaiser 2010; Martin and Whitis 2008).

Campsites are located along the river's edge on sandy beaches or on ledges and alcoves above the high-water mark. Campsites offer the viewer a chance to see native plant and animal

FIGURE 3.12-3 Typical View of the Colorado River and Grand Canyon Afforded Recreationists on a River Trip

FIGURE 3.12-4 Colorado River and Granaries at Nankoweap (Photo credit: Mark Lellouch, NPS)

FIGURE 3.12-5 Entrance to Havasu Canyon (Photo credit: Erin Whitaker, NPS)

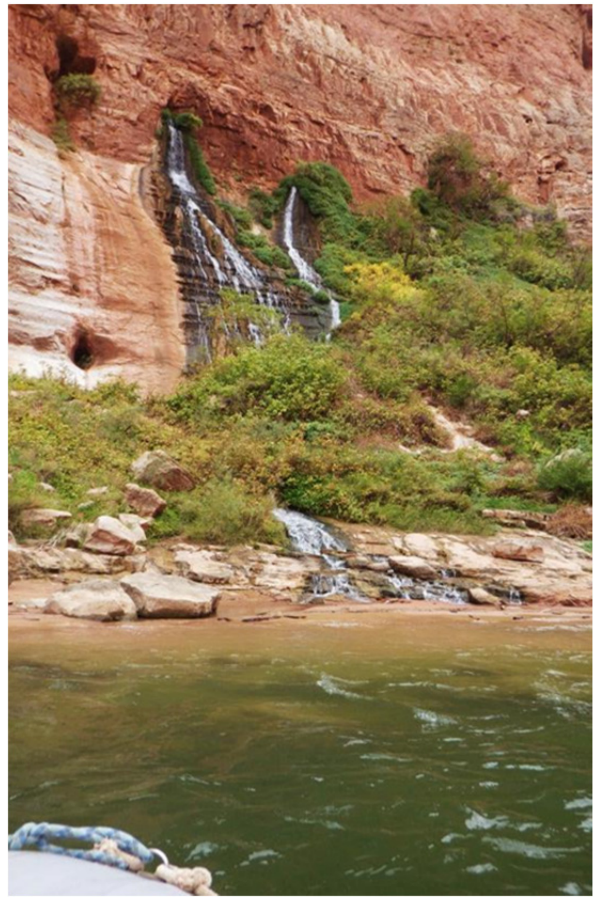

FIGURE 3.12-6 Vasey's Paradise

life, in addition to offering views of the Colorado River and surrounding landscape. Many trails are accessible only from these campsites and lead visitors to scenic vantage points of the Grand Canyon and Colorado River (NPS 2010a). See Section 3.11 for a more detailed description of campsites.

Dam operations may contribute to effects on visual resources along the Colorado River in the Grand Canyon. Prior to construction of Glen Canyon Dam, the banks of the Colorado River consisted primarily of open sandy beaches and bare talus slopes with native riparian vegetation established above the elevation of annual scouring flows within the Grand Canyon. These beaches and vegetation were depleted and replenished as the Colorado River picked up and deposited debris during seasonal floods (USGS 2007; NPS 2013i). Currently, the size and shape of beaches along the river can change frequently with changing river flows and water levels. Much of the sediment that would otherwise move through the canyon is now trapped behind the dam, and regular seasonal flooding does not occur. Because of this, the river lacks the sediment it needs to build up beaches and sandbars, and the beaches sometimes disappear altogether (NPS 2013i). In addition, beaches that are more stable are no longer scoured by occasional flooding, which allows vegetation, including nonnative species such as tamarisk, to take hold and spread (GCMRC 2011). The changes to the size and shape of beaches and the amount and types of riparian vegetation create visual contrasts that may affect visitors' scenic experiences.

Prior to construction of Glen Canyon Dam, the Colorado River carried such a large sediment load that it ran a reddish-brown color throughout the canyon. Now, the river downstream from the dam is relatively clear and green in color. During high releases or after large tributary inputs of suspended sediment, water becomes much more reddish-brown; this effect is ephemeral, however, and water quickly returns to a bluish-green color (NPS 2013g; USGS 2007). Calcium carbonate banding resulting from deposition of minerals at the water edge is also visible in some areas along the Colorado River, typically where the river bank consists of bare rock walls, rocky slopes, or boulders. The changes in water color, depth, and texture may affect the scenic experience of river runners.

3.12.3 Lake Mead National Recreation Area

LMNRA is managed for general recreational purposes to enhance visitor use, while recognizing the importance of and preserving its scenic, historic, and scientific resources (NPS 2002c). Pearce Ferry, located in the northeastern end of the park, serves as the boundary between the Grand Canyon and Lake Mead and marks the final destination for rafting trips down the lower Grand Canyon area. This area is mostly managed as a rural natural setting, where man-made features are present, but natural landscape is predominant.

Scenic resources within LMNRA include Lake Mead itself and the low, rocky, volcanic hills; steep canyons; and colorful rock formations that surround the reservoir. The surrounding landscape ranges in color from light tans and yellows to bright reds and browns, and contrasts sharply with the striking blue waters of Lake Mead and the bluish-green waters of the Colorado River.

Sediment deltas resulting from sediment transported through the Grand Canyon have built up in the headwaters of Lake Mead near Peace Ferry (Reclamation 2007a) and Iceberg Canyon (NPS 2015c), areas that are considered rural natural settings. Sediment deltas contribute to changes in form, line, color, and texture that can affect the overall scenic experience of water recreationists and may interfere with management objectives that include the protection of natural-appearing landscapes and pristine views.

3.13 HYDROPOWER

This section describes power operations and power marketing as they relate to Glen Canyon Dam and the Glen Canyon Powerplant. A description of the seven-state socioeconomic environment in which power from the powerplant is marketed is provided in Section 3.14.

The operation of Glen Canyon Dam and Powerplant directly and indirectly influences the downstream physical environment and aquatic and riparian habitats. For example, the frequency and magnitude of daily fluctuations (for the purposes of following electrical loads and maximizing the value of hydropower) directly affect sediment transport and deposition downstream, directly or indirectly affect aquatic and riparian habitats, affect the recreational environment (beach areas) and use patterns, and indirectly affect air emissions and water consumption for the region.

Power generation from the dam also financially affects the U.S. Department of Energy's (DOE's) Western Area Power Administration (WAPA) customers. When generation from the powerplant is significantly reduced or not timed to match hourly load patterns and WAPA is unable to fulfill its contractual obligations from existing Salt Lake City Area Integrated Projects (SLCA/IP) resources, WAPA must purchase power from other market sources to meet any contractual obligations. Those alternate sources are typically derived from power-generation sources fueled by natural gas, coal, oil, nuclear, and to a much lesser degree, solar and wind. Each power-generation source has its own characteristic air emissions, water consumption, and economic impacts. In the event customer contractual allocations are reduced, the customers would be required to replace that capacity and energy from an alternate source through a purchase or build-out of new generation.

All of the potential impacts noted above are influenced by hourly, daily, monthly, and annual patterns and variations in how water is released from Glen Canyon Dam to produce electricity, and how those releases are typically timed to enhance the value of power generation. Ramp rates (i.e., the rate, in cfs/hr, at which dam releases rise or fall, referred to hereafter as up-ramp rates and down-ramp rates, respectively), flow rates (in cfs), maximum and minimum daily flows (cfs), daily/monthly release volumes (ac-ft), and reservoir elevation (head) are all factors that influence the extent of impacts of dam operations on electrical power customers, downstream environmental resources, Tribal cultural sites, recreational users, and WAPA's repayment obligations and the ability to fund CRSP operations and important environmental programs in the Upper Basin.

3.13.1 Power Operations

Power operations are the physical operations of a large electrical power system, including hydropower generation, and control (operational flexibility, scheduling, load/generation following, regulation, reserves, and transmission).

3.13.1.1 Hydropower Generation

The Glen Canyon Powerplant has eight generators with a maximum combined capacity of 1,320 MW when the reservoir elevation is 3,700 ft AMSL. The maximum combined discharge (water release) capacity of the eight turbines is approximately 31,500 cfs. Under the current operating regime of MLFF adopted in the 1996 ROD (Reclamation 1996), the maximum release is limited to 25,000 cfs, except in extreme hydrologic or emergency conditions or under approved experimental actions (i.e., HFE protocol). This maximum release restriction limits Glen Canyon Dam power generation capacity to approximately 1,000 MW at a reservoir level of

3,700 ft AMSL, which is 76% of potential usable capacity without restriction. The generators require a minimum Lake Powell elevation of 3,490 ft AMSL to operate. At this elevation, the maximum capacity of the Glen Canyon Powerplant is reduced to approximately 630 MW. Prior to 1991, annual gross generation ranged from a minimum of 1.1 million MWh to a maximum of 8.8 million MWh, with an average of 4.4 million MWh. With the Interim Flows decision in 1990, generation between 1991 and 1996 ranged between 3.6 million MWh and 5.5 million MWh, averaging 4.1 million MWh, and with the adoption of the current operating regime (MLFF), generation from 1997 to 2015 has ranged between 3.1 million MWh and 6.7 million MWh, with an average of 4.2 million MWh (Reclamation 2014b). Since the implementation of MLFF, between 1997 and 2005, the average annual cost incurred from operational restrictions ranged from $38 million to $50 million (Veselka et al. 2010).

Releases that bypass the generators (such as in the case of HFEs) do not generate power, and therefore have no power system economic value. Turbines are operating at maximum capacity during HFEs, which does generate more power than the normal operations; however, there are marketing challenges due to the short-term nature of this generation during the HFE.

Glen Canyon Dam and Powerplant is the largest facility in the CRSP, which also includes other power facilities (e.g., Aspinall Unit [Blue Mesa, Crystal, and Morrow Point dams] in Colorado, and Flaming Gorge Dam in Utah). The power produced at these facilities, which includes both capacity and energy[11] generated at Glen Canyon Dam and other CRSP facilities, is marketed by WAPA. Net winter and summer energy (adding purchases to the combined powerplant resources and subtracting losses and project use) marketed by WAPA is currently 2,558 and 2,394 GWh, respectively, while net winter and summer capacity (subtracting project-use loads, system losses, control area regulation needs, firm-load reserves, and scheduled-outage-assistance-loads from generating capability) are 1,404 MW and 1,318 MW, respectively. Seasonal variation is due to differences in typical reservoir elevations and project-use loads (Reclamation 1995).

To coordinate electric power rate-setting and marketing efforts and ensure the timely repayment of federal project construction and irrigation assistance debt, the Colorado River Storage, Collbran, and Rio Grande Projects were administratively integrated in 1987 into the Salt Lake City Area Integrated Projects (SLCA/IP), which is part of an interconnected generation and transmission system that includes federal, public, and private power generating facilities (Reclamation 1995).

3.13.1.2 Basin Fund

The Upper Colorado River Basin Fund (Basin Fund) was established under Section 5 of CRSPA. CRSPA "authorized a separate fund in the Treasury of the United States to be known as

[11] Energy (typically measured in MWh) is electricity generated and/or used over time; capacity (typically measured in MW) is total powerplant generation capability.

the Upper Colorado River Basin Fund [...] for carrying out provisions of this Act other than Section 8." Money appropriated for construction of CRSP facilities, except recreation and fish and wildlife facilities constructed under Section 8, is transferred to the Basin Fund from the General Fund of the Treasury. Revenues derived from operation of the CRSP and participating projects are deposited in the Basin Fund. Most of the revenues come from sales of hydroelectric power and transmission services. The Basin Fund also receives revenues from municipal and industrial water service sales, rents, salinity funds from the Lower Colorado Basin (as a pass-through for the Colorado River Basin Salinity Control Program), and miscellaneous revenues collected in connection with the operation of the CRSP and participating projects. Revenues and appropriated funds are accounted for separately in the Basin Fund.

3.13.1.3 Operational Flexibility

The operational flexibility of hydroelectric power generation allows WAPA to quickly and efficiently increase or decrease generation in response to customer demand, generating unit or transmission line outages (contingency reserves), unscheduled customer deviation from internally scheduled contracted power usage (regulation and load/generation following) within a specific metered load area known as a Balancing Authority (BA),[12] integrated power system requirements, and requests for emergency assistance from interconnected utilities. Under the water release parameters instituted on an interim basis in 1991 and permanently under the 1996 ROD following the completion of the Glen Canyon Environmental Impact Statement (Reclamation 1995), WAPA currently restricts the scheduling of customer contract allocations to 2-day-ahead prescheduling only. Ramping restrictions, imposed under the 1996 ROD operating criteria, do not allow generation at Glen Canyon Dam to adjust sufficiently each hour to match the power customer demand schedules. These ramping restrictions result in increased use of alternate generating resources to meet power customer demand schedules. Operational conditions are complicated by the frequency, season, and time of day any of these events may occur; physical and environmental operating restrictions at other CRSP generating facilities and within the interconnected electric system; and the availability and price of alternative power resources (Reclamation 1995).

Although there is considerable potential for flexibility in Glen Canyon powerplant operations, current operating criteria have placed multiple restrictions on the variability of water released from the dam, thus restricting operations at the powerplant. Prior to 1991, Reclamation operated the dam and powerplant to maintain a minimum release of 3,000 cfs in summer months, and maintained a 1,000-cfs limit minimum flow for the remainder of the year. There were no restrictions on ramp rates, and daily fluctuations were occasionally as high as 28,500 cfs in the summer months and 30,500 cfs for the rest of the year (Poch et al. 2011). Beginning in August 1991, an Interim Flows decision restricted the operation of the dam for environmental reasons, and the Interim Flows decision was used as the basis for operation until February 1997, when the February 1997 operating criteria, based on the 1996 ROD, restricted dam operational

[12] Note that in this section of the EIS, BA is used as the abbreviation for Balancing Authority. In other sections of the DEIS, BA refers to Biological Assessment.

flexibility. This operating regime, referred to as MLFF, is currently used as the basis of operations at Glen Canyon Dam and requires water release rates to be 8,000 cfs or greater between the hours of 7 a.m. and 7 p.m., and at least 5,000 cfs at night. The criteria also limit ramp rates; the maximum hourly increase (i.e., the up-ramp rate) is 4,000 cfs/hr, and the maximum hourly decrease (i.e., the down-ramp rate) is 1,500 cfs/hr. The 1996 ROD operating criteria also restricted the extent to which releases can fluctuate during a rolling 24-hour period. This change constraint varies between 5,000 cfs/day and 8,000 cfs/day, depending on the monthly volume of water releases. Daily fluctuation is limited to 5,000 cfs in months when less than 600 thousand acre-feet (kaf) is released. The fluctuation limit increases to 6,000 cfs when monthly release volumes are between 600 kaf and 800 kaf. When the monthly water release volume is 800 kaf or higher, the daily allowable fluctuation is 8,000 cfs (Reclamation 1995; Poch et al. 2011). MLFF includes emergency exception criteria.

Under MLFF, the maximum release rate for power generation is limited to 25,000 cfs. Maximum release rate exceptions are allowed if needed to avoid spills or flood releases during high runoff periods or if authorized under approved experimental action (i.e., HFE protocol). Under very wet hydrologic conditions, defined as when the average monthly release rate is greater than 25,000 cfs, the flow rate may be exceeded, but water must be released at a constant rate. Adjustments to MLFF are made to avoid spills, during flood releases, to accommodate experimental releases, and to accommodate electrical emergencies. These adjustments include maximum release rates above 25,000 cfs. Experimental releases may require release rates in excess of the capacity of the powerplant. When this situation occurs, additional water would be released through bypass tubes to achieve the desired high release rate. Bypassing water around the generators produces no energy, which can result in additional purchases of replacement power, and increases the river stage in the tailwater, which reduces elevation, thereby reducing the effective head and power conversion rates for water passing through powerplant turbines (Poch et al. 2011).

3.13.1.4 Scheduling

Power scheduling is the matching of seasonal, daily, and hourly system energy and capacity needs with available generation. At Glen Canyon Dam, power scheduling is affected by the distribution of monthly water release volumes, restrictions in water release patterns (maximum and minimum release limits, allowable daily fluctuation rates, and hourly ramp rates), availability of the eight units in the Glen Canyon Powerplant and other CRSP units (individual units are on a rotating maintenance schedule) in the system, power customer allocations, and peak and off-peak power periods. Weather and runoff forecasts, alternate resource availability, and the market price of electricity also play important roles in how the customers schedule their allocation of CRSP resources (Reclamation 1995).

Scheduling to meet power requirements generally means higher water releases in peak months when the demand for power (load) is higher (December, January, July, and August) and lower water releases when electric power demand is lower.

Prior to 1990, dispatch (the sequence in which SLCA/IP powerplants are utilized to meet the demand for electricity) from powerplants was driven primarily by market prices. A high level of operating flexibility at the SLCA/IP allowed WAPA to purchase energy during off-peak periods to meet customer demand, storing the water for later power generation during on-peak periods when prices were higher. Accordingly, WAPA was able to maximize the economic value of electricity sales from the Glen Canyon Powerplant. Since MLFF operational constraints were imposed on SLCA/IP resources, including those at Glen Canyon Dam, SLCA/IP powerplants have been dispatched independently to meet contractual obligations at the lowest possible cost, with the lowest variable operating costs generally dispatched first, and plants with higher variable operating costs brought online sequentially as electricity demand increases. Hourly differences between loads and resource production are reconciled though market purchases and sales. Within the operational restrictions of MLFF, there are many hourly release patterns and dispatch arrangements that comply with the operating criteria to provide scheduling flexibility to meet power customer demand. However, since the implementation of MLFF, between 1997 and 2005, the average annual cost incurred ranged from $38 million to $50 million, due to operational restrictions (Veselka et al. 2010).

3.13.1.5 Load/Generation Following and Regulation

To ensure interconnected system reliability, WAPA follows mandatory reliability standards enforced by the North American Electric Reliability Corporation (NERC) and the Western Electricity Coordinating Council (WECC). In addition, WAPA follows operational criteria, guidelines, and procedures set in place by the WECC and the contingency Reserve Sharing Group (RSG) applicable to each BA. Each WECC utility is located within such a load control area, and one utility within the BA serves as the BA operator. WAPA is the BA operator for the Western Area Lower Colorado Region (WALC) BA, the Western Area Colorado-Missouri Region (WACM) BA, and the Western Area Upper Great Plains West Region (WAUW) BA, and is responsible for ensuring that each load-serving utility within each BA serves its own internal load while meeting its power and reserve obligations. Operating as a BA, WAPA is the provider of last resort should a load-serving entity not be able to fulfill its obligation to the BA, and it carries all compliance responsibility for the BA function. All CRSP powerplants are within the WACM BA, and the flexibility and load/generation following capability of CRSP hydroelectric powerplants, particularly Glen Canyon Powerplant, are important in meeting NERC/WECC reliability standards and criteria.

Hydropower generation is valuable because it can react instantaneously to changes in load or unanticipated changes in generation resources within the BA. This ability to respond to rapidly changing load conditions is called load and/or generation following regulation. As a BA operator, WAPA utilizes its hydrogeneration resources, and hydropower is typically used to balance instantaneous changes to loads and/or generation within the metered transmission and generation BA system. By comparison, coal- and nuclear-based resources have a very slow response time, and consequently have limited load/generation following regulation capability. Load/generation following regulation capability at Glen Canyon Dam is limited to $\pm$ 40 MW and is outside the 1996 ROD operating criteria ramping restrictions.

In general, power demand increases during the daylight hours as residences, commercial establishments, agriculture, and industrial electrical demands increase. Under normal conditions, the system load pattern throughout the region is similar from Monday through Friday, but load often drops considerably on Saturday and Sunday as companies with a heavy commercial or industrial load shut down. System load also varies seasonally with increases in the conditions load in December, January, July, and August, and lower demand for power in the remaining months (Reclamation 1995).

Implementation of the 1996 ROD operating criteria has reduced the ability of power generation at Glen Canyon Dam to follow hourly changes in customer load. Prior to the 1990s, power generation from CRSP powerplants, including Glen Canyon Dam, was driven primarily to meet daily and seasonal power demands. A high level of operating flexibility at these federal facilities allowed power generation to closely follow on- and off-peak electrical loads which made these federal facilities valuable assets in developing the economies of the Western United States. For example, during the 1978 energy crisis, Glen Canyon Dam was operated under an executive order that required federal agencies to exercise their authorities to increase domestic energy production and reduce U.S dependence on foreign oil. Accordingly, WAPA was able to increase the economic value of electricity deliveries to its electrical customers using generation at Glen Canyon Dam and its other facilities in the CRSP system to meet this directive. Beginning in the 1990s, however, operations at each of the CRSP powerplants (Glen Canyon Dam in 1996, Flaming Gorge Dam in 2005, and the Aspinall Unit in 2012) have been restricted for environmental reasons. Although WAPA continues to dispatch these units to maximize load-following capabilities within the constraints each unit operates under, these restrictions have substantially reduced the usable generation capacity of these facilities to meet the daily and seasonal energy needs of its customers.

In addition to load/generation-following and regulation responsibilities, dispatchers follow other practices that are specific to Glen Canyon Dam Powerplant operations. These practices fall within MLFF constraints but are not ROD requirements and may be altered or abandoned by WAPA at any time. One practice involves reducing generation at Glen Canyon Dam to the same minimum level every night during low-price, off-peak hours. WAPA also avoids large changes to total daily water volume releases when they occur over successive days. This increases the efficiency of producing and marketing power at the dam and reduces downstream environmental impacts. In addition, weekend releases are generally not less than 85% of the average weekday release and, during the summer season, one cycle of raising and lowering Glen Canyon Dam Powerplant output, increasing to a maximum of two cycles during other seasons of the year as dictated by the hourly load pattern provided by customer preschedules (Poch et al. 2011).

Changes in WAPA's scheduling guidelines typically occur slowly over a period of months, not only because of the operational constraints imposed by the ROD, but also due to changing market conditions, such as persistent drought, electricity market disruptions in 2000 and 2001, and extended experimental releases that have large daily flow rate fluctuations (Poch et al. 2011).

3.13.1.6 Capacity Reserves

Each BA, or RSG utility applicable to it, is required to maintain sufficient generating capacity to continue serving its customer load, even if the BA or RSG utility loses all or part of its own largest generating unit or largest capacity transmission line. This is done to ensure electrical service reliability and uninterrupted power supply. Reserve requirements for the generation resources of the SLCA/IP are based on a formula which considers the loss of the largest single generator within the Rocky Mountain RSG and allocates a reserve quota to each member based on their relative size within the group. Total available capacity, in turn, is determined by the minimum and maximum allowable releases from these powerplants. Spinning reserves (generating units that are operating online but not generating electricity) 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. Additional offline reserves (offline idle units that are ready to begin generating electricity) can be used to replace generation shortages, but they cannot respond as quickly as spinning reserves (Reclamation 1995). SLCA/IP generation resources are located within the Rocky Mountain RSG. A portion of that generation is set aside by the Rocky Mountain RSG to be utilized during contingency reserve activation periods. Capacity for this reserve obligation is held on Glen Canyon generation resources by WAPA whenever possible. (Reserve activations and subsequent water releases through the generators are not subject to the 1996 ROD release criteria.)

3.13.1.7 Disturbances and Emergencies and Outage Assistance

In the event of a widespread sudden loss of generation resource power outage, or an imbalance in the transmission system element causing a load/resource imbalance requiring an immediate response (i.e. disturbance), NERC contingency reserve standards require that available generation capacity be utilized to return the electric generation and transmission system to normal operating conditions within load/generation balance within 10 minutes following the disturbance. Generally, emergency operations contingency reserves are needed only for periods of an hour or less, but can and frequently are activated several times a day. WAPA also has existing contractual agreements to use capacity at Glen Canyon Dam to restart traditional thermal powerplants and provide emergency shutdown power to nuclear powerplants. It is especially important for generation resources at Glen Canyon Dam to be available for safe shutdown of nuclear facilities in the area in the unlikely event of a widespread power outage. WAPA's ability to supply emergency assistance is limited by available transmission capacity and available generation capability, while the ability to deliver emergency assistance varies on an hourly basis, depending on firm load obligations and available generation from project resources. With a full reservoir and average loads, Glen Canyon Dam and Powerplant has been able to provide emergency assistance beyond its required reserves by utilizing its remaining unloaded capacity after serving load, regulation, frequency response, and contingency reserve obligations. Due to the flexibility of hydroelectric resources, the SLCA/IP has often provided scheduled outage assistance. This ability will continue into the future under all potentially selected alternatives of the LTEMP DEIS. Responding to electrical emergencies also is not subject to the 1996 ROD operating constraints.

3.13.1.8 Transmission System

The CRSP/WACM transmission system is used to transmit electricity from Glen Canyon Dam and other generating sources to customer utilities that serve end users such as municipal, residential, Tribal, irrigation district, and commercial and industrial consumers. Both hydroelectric generation and other generation resources are affected by transmission limitations when lines do not have enough capacity to transmit electricity from the point of generation to the point of demand. 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 measured flow of power on the line. NERC requires monitoring of the actual and scheduled power flow for system operation (Reclamation 1995).

3.13.2 Power Marketing

Electricity generated at Glen Canyon Dam and Powerplant and other SLCA/IP facilities in the Upper Colorado Region is marketed by WAPA under statutory criteria in the Reclamation Project Act of 1939, the Flood Control Act of 1944, CRSPA, and the Department of Energy Organization Act of 1977, along with associated marketing plans and contractual obligations. Requirements stemming from these criteria include:

- Preference in the sale of capacity and energy must be given to municipalities, public corporations, cooperatives, and other nonprofit organizations.

- Capacity and energy must be marketed at the lowest possible rates consistent with sound business practices.

- Revenues generated from capacity and energy sales must pay for power generation and transmission facility costs (including operations, maintenance, replacements, and firming purchases and emergency power) and all allocated investment costs under the CRSPA, including interest and irrigation project expenses and investment costs related to regulating water deliveries, flood control, and water storage beyond the ability of the irrigators to repay, as well as certain environmental costs as provided under the GCPA 1992.

- Projects must generate the greatest practicable amount of capacity and energy that can be sold at firm power and energy rates.

- WAPA is responsible for the construction, operation, and maintenance of transmission lines and attendant facilities.

WAPA markets wholesale CRSP power to preference entities serving approximately 5.8 million retail customers in Arizona, Colorado, Nevada, New Mexico, Utah, and Wyoming (Reclamation 2012d). Customers are small and medium-sized municipalities that operate publicly owned electrical systems; irrigation cooperatives and water conservation districts; rural electrical associations or generation and transmission co-operatives who often act as wholesalers to these associations; federal facilities such as Air Force bases, universities, and other state agencies; and Indian Tribes (Reclamation 2012d).

For WAPA's eight largest customers in 2013, the SLCA/IP provided 6.1% of energy and 4.7% of capacity requirements; the remaining 93.9% of energy and 95.3% of capacity being provided by customer utility-owned generation facilities, or purchased from investor-owned or other utility systems, as well as other federal hydropower projects marketed by WAPA. Reliance on SLCA/IP capacity and energy varies considerably among customers; Navajo Tribal Utility Authority (27.4%) and Utah Municipal Power Agency (25.7%) received more than 25% of their energy from SLCA/IP in 2009, while three utilities, Navajo Tribal Utility Authority (19.1%), Utah Municipal Power Agency (17.8%), and Deseret Generation and Transmission Cooperative (17.8%), relied on WAPA for more than 15% of their capacity (Table 3.13-1). Other utilities, such as Tri-State G&T (1,537 GWh and 235 MW), received larger energy and capacity allocations but relied on WAPA for only a small portion of their total capacity and energy requirements.

WAPA markets long-term firm capacity and energy, short-term firm capacity and energy, and non-firm energy. Firm power is capacity and energy that are guaranteed to be available to the customer. Loads are made up of firm load, non-firm sales, and interchanges out of the control area. Firm load and capacity obligations include long- and short-term firm sales, Reclamation project use loads, system losses, BA control area regulation, firm load contingency reserves, and scheduled outage assistance. Capacity is reserved to provide regulation, contingency reserves, frequency support and response, meet CRSP contractual obligations, participating project capacity, and serve Reclamation's irrigation and drainage pumping plant loads before being marketed as long-term firm capacity. WAPA's ability to make non-firm energy sales with hydrogeneration resources after all firm power obligations have been met, and there are generation resources available for marketing purposes as water release requirements dictate, depends on SLCA/IP's flexibility to take advantage of on-peak and off-peak spot energy markets (Reclamation 1995).

The majority of CRSP power is sold under long-term firm electric service contracts. If WAPA is unable to supply contracted amounts of firm capacity or energy from Reclamation hydroelectric resources, it must purchase the deficit from other (primarily non-hydropower) resources for delivery. The expense for this purchased power is shared by all SLCA/IP customers.

Non-firm sales are short-duration energy transactions that are always less than 1 year. Normally scheduled 1 day in advance, although transactions can occur hourly, they can be determined up to the hour of transaction. These non-firm sales occur when generation patterns associated with the 1996 operating criteria do not match customer load schedules and cannot be used for firm electricity deliveries. WAPA sells the excess generation on the non-firm market to accommodate release obligations. The flexibility of hydropower operations allows actual deliveries to be modified hourly, as system conditions warrant. WAPA may market non-firm energy and arrange for interchange transactions, depending on revised water release estimates. Non-firm capacity and energy are capacity and energy that are not guaranteed to be available to

TABLE 3.13-1 Energy and Capacity Characteristics of the Eight Largest WAPA Customers, 2013[a]

Customer Utility	Energy Required (GWh)	Energy from WAPA (GWh)	Percentage of Energy from WAPA	System Peak Load (MW)	WAPA Allocation (MW)	Percentage of Load from WAPA
Colorado Springs Utilities	4,968	140	2.8	908	22	2.4
Deseret Generation and Transmission Cooperative	2,497	447	17.9	391	70	17.8
Navajo Tribal Utility Authority	718	197[b]	27.4	140[b]	27	19.1
Platte River Power Authority	3,196	536	16.8	659	71	10.7
Salt River Project	32,452	290	0.9	6,663	42	0.6
Tri-State G&T	15,313	1,537	10.0	2,666	235	8.8
Utah Municipal Power Agency	1,216	312	25.7	265	47	17.8
Utah Associated Municipal Power Systems	3,884	477	12.3	943	75	8.0
All eight customers	64,243	3,937	6.1	12,635	588	4.7

[a] Data on energy requirements and system peak load are actual values for 2013, except data for Deseret Generation and Transmission Cooperative and Navajo Tribal Utility Authority, which are forecasts for 2013.

[b] Does not include allocations received by Navajo Tribal Utility Authority from WAPA on behalf of 13 other Tribal groups.

Sources: Colorado Springs Utilities (2015); Deseret Power Cooperative (2012); Navajo Tribal Utility Authority (2012); Platte River Power Authority (2015); Salt River Project (2015); Tri-State G&T (2015); Utah Municipal Power Agency (2015); Utah Associated Municipal Power Systems (2015); Osiek (2015).

the customer, and are purchased by wholesale customers that prefer non-firm energy that is less expensive than power generated at their own powerplants or by alternative supply sources. Non-firm energy is usually sold with the caveat that the sale can be stopped on short notice and the buyer must have the resources available to meet its own load. Non-firm energy is sold at a negotiated price and delivery point based on market conditions. Rates for non-firm energy only include a charge for the energy delivered, since the customer has the capacity to meet its loads if necessary. WAPA does not sell non-firm energy on a long-term basis. The price for non-firm energy is based on market conditions (Reclamation 1995).

WAPA also offers both firm and non-firm transmission service. Firm transmission service is contractually guaranteed for the term of the agreement. Non-firm transmission service is provided as available and is not guaranteed. WAPA participates in electricity transfers, 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 connects them. WAPA offers wheeling transmission service over particular CRSP transmission paths, including lines carrying power from Glen Canyon Dam. Non-firm transmission service, like non-firm power sales, can be interrupted on short notice (Reclamation 1995).

3.13.2.1 Wholesale Rates

WAPA has long-term firm electric service contracts for SLCA/IP power with 138 Tribal entities and wholesale customers (including municipal utilities, federal and state public power facilities, and rural electric cooperatives). Power rates are established in order that revenues will be sufficient to pay all costs assigned to power within required time periods. Power revenues also pay annual power operation and maintenance, purchased power, transmission service, and interest expenses on Treasury loans used to finance construction of WAPA hydropower projects, as well as irrigation assistance beyond the ability of the irrigators to repay, along with various environmental costs, including costs of the GCDAMP and the Upper Colorado River and San Juan River Endangered Fish Recovery Implementation Programs. CRSP power revenues also must contribute toward salinity control costs under the Colorado River Basin Salinity Control Act and construction costs (with interest) of CRSP participating projects, as well as certain environmental costs as provided under the GCPA. Any remaining annual revenues are used to pay off investment costs assigned to power, so that each investment can be paid within the time allowed (Reclamation 1995).

3.13.2.2 Retail Rates

Retail rates are those paid by end users (residential, commercial, and industrial customers of WAPA's wholesale customers). The retail rates charged by not-for-profit entities normally are set to cover system operation and capital costs. 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.

3.14 SOCIOECONOMICS AND ENVIRONMENTAL JUSTICE

This section provides a brief socioeconomic background for two regions of influence: a six-county region in which the majority of recreation in the Grand Canyon area occurs and a seven-state region in which power from the Glen Canyon Powerplant is marketed. Five standard measures of economic development are described in the following sections: (1) population, (2) income, (3) total employment, (4) employment by sector, and (5) unemployment. A brief description of the numbers and locations of minority and low-income populations, including Tribal populations, in an 11-county region is also provided.

3.14.1 The Six-County Region of Influence

The six-county region is composed of Coconino County and Mohave County in Arizona, and Garfield County, Kane County, San Juan County, and Washington County in Utah. Additional socioeconomic background information on these counties can be found in DOI (2012a). Clark County, Nevada, was not included in the recreational economics analysis presented here. Although it is likely that there is some recreational expenditure in Clark County associated with recreation in Lake Mead, the share of these expenditures occurring in Clark County is not known. Expenditures were assumed to occur only in the six counties included in the analysis.

3.14.1.1 Population

Table 3.14-1 presents recent and projected populations in the region and states as a whole. The population in the region stood at 511,435 in 2012, having grown at an average annual rate of 2.4% since 2000. Washington County (4.0%), Mojave County (2.3%), and Kane County (1.5%) experienced higher growth rates than the remainder of the region, with lower growth rates in Garfield County (0.6%) and San Juan County (0.3%). The population growth rate for the region (2.4%) was slightly higher than the rates for both Arizona and Utah (2.1%) between 2000 and 2012.

TABLE 3.14-1 Population in the Six-County Region

Location	2000	2012	Average Annual Growth Rate (%), 2000–2012	2020	2030
Coconino County, Arizona	116,320	136,011	1.3	144,300	154,400
Garfield County, Utah	4,735	5,095	0.6	6,063	6,821
Kane County, Utah	6,046	7,221	1.5	8,357	10,259
Mohave County, Arizona	155,032	203,334	2.3	241,000	285,600
San Juan County, Utah	14,413	14,965	0.3	15,644	15,486
Washington County, Utah	90,534	144,809	4.0	196,762	280,558
Six-County Region	386,900	511,435	2.4	612,126	753,124
Arizona	5,130,632	6,553,255	2.1	7,485,000	8,852,800
Utah	2,233,169	2,855,287	2.1	3,309,234	3,914,984

Sources: U.S. Census Bureau (2013a); Arizona Department of Administration (2013); Governor's Office of Planning and Budget (2013).

The population in the region is expected to increase to 612,126 by 2020 and 753,124 by 2030.

3.14.1.2 Income

Personal income in the region stood at $15.1 billion in 2011 and grew at an annual average rate of 3.1% over the period from 2000 to 2011 (Table 3.14-2). Personal income per capita in the region also rose over the same period at a rate of 0.6%, increasing from $27,990 to $29,842. Per-capita incomes were higher in Coconino County ($35,685) and Kane County ($32,989) in 2011 than the average for the region as a whole. The rate of growth in personal income in the region (3.1%) was higher than the rates for Arizona (2.3%) and the same as that for Utah (2.5%) as a whole.

Average per-capita incomes in 2012 in the six-county region were lower than the averages for Arizona ($36,397) and Utah ($34,738).

Median household incomes (the income level at which exactly half of all households earn more than the level, and half earn less) over the period 2008 to 2012 varied between $42,074 (in 2013 dollars) in Mohave County and $51,622 in Coconino County (U.S. Census Bureau 2013a). Median household incomes were $50,101 for Arizona and $60,576 for Utah over the same period.

3.14.1.3 Employment

In 2012, employment in the region stood at 207,673 (Table 3.14-3). Over the period from 2000 to 2012, annual average employment growth rates were higher in Washington County (3.0%) and Mohave County (1.3%) than elsewhere in the region. At 1.6%, growth rates in the region as a whole were slightly higher than the average rates for Arizona (1.2%) and Utah (1.3%).

In 2011, the service sector provided the highest percentage of employment in the region at 53.9%, followed by wholesale and retail trade (22.3%) (Table 3.14-4). Smaller employment shares were held by manufacturing (6.6%) and construction (5.6%). Within the region, county-level employment varied somewhat across sectors compared with the region as a whole. Garfield County had a higher percentage of employment in agriculture (18.7%) and services (64.4%) than the region as a whole, while manufacturing in Coconino County (8.3%), wholesale and retail trade in Mohave County (26.6%), and services in Kane County (76.2%) were more important as employment sources than in the region as a whole.

TABLE 3.14-2 Income[a] in the Six-County Region

Location	2000	2011	Average Annual Growth Rate (%), 2000–2011
Coconino County, Arizona			
Income (billions of 2013$)	3.8	4.8	2.2
Per-capita income (2013$)	32,298	35,685	0.9
Garfield County, Utah			
Income (billions of 2013$)	0.1	0.1	1.6
Per-capita income (2013$)	25,680	28,007	0.8
Kane County, Utah			
Income (billions of 2013$)	0.2	0.2	2.5
Per-capita income (2013$)	30,195	32,989	0.8
Mohave County, Arizona			
Income (billions of 2013$)	4.1	5.5	2.7
Per-capita income (2013$)	26,249	27,045	0.3
San Juan County, Utah			
Income (billions of 2013$)	0.3	0.3	2.6
Per-capita income (2013$)	17,866	23,148	2.4
Washington County, Utah			
Income (billions of 2013$)	2.4	4.1	4.8
Per-capita income (2013$)	27,019	28,915	0.6
Six-County Region			
Income (billions of 2013$)	10.8	15.1	3.1
Per-capita income (2013$)	27,990	29,842	0.6
Arizona			
Income (billions of 2013$)	183.6	235.4	2.3
Per-capita income (2013$)	35,778	36,397	0.2
Utah			
Income (billions of 2013$)	74.4	97.8	2.5
Per-capita income (2013$)	33,333	34,738	0.4

[a] Per-capita income is income per person.

Source: U.S. Department of Commerce (2013).

TABLE 3.14-3 Employment in the Six-County Region

Location	2000	2012	Average Annual Growth Rate (%), 2000–2012
Coconino County	59,739	67,052	1.0
Garfield County	2,301	2,454	0.5
Kane County	2,896	3,098	0.6
Mohave County	65,589	76,733	1.3
San Juan County	4,324	4,449	0.2
Washington County	37,771	53,887	3.0
Six-County Region	172,620	207,673	1.6
Arizona	2,404,916	2,778,579	1.2
Utah	1,097,915	1,276,249	1.3

Source: U.S. Department of Labor (2013).

3.14.1.4 Unemployment

Unemployment rates varied across the five counties in the region. Between 2000 and 2012, the average rate in San Juan County was 8.9% and 8.3% in Garfield County, with a relatively high rate of 6.8% in Mohave County (Table 3.14-5). The average rate in the region over this period was 6.4%, which was higher than the average rates for Arizona (5.2%) and Utah (4.0%). Unemployment rates were higher in 2012 than the average rates for the period from 2000 to 2012, with higher rates of 10.7% in San Juan County, 10.5% in Garfield County, and 9.9% in Mohave County. The average rates in 2012 for the region (8.6%) and for Arizona (8.3%) and Utah (5.7%) were also higher than the corresponding average rates for 2000 to 2012.

3.14.1.5 Environmental Justice

E.O. 12898, "Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations" (59 FR 7629, Feb. 11; U.S. President 1994b), formally requires federal agencies to incorporate environmental justice as part of their missions. Specifically, it directs them to address, as appropriate, any disproportionately high and adverse human health or environmental effects of their actions, programs, or policies on minority and low-income populations.

The analysis of the impacts of changes in the operation of hydropower facilities on environmental justice issues follows guidelines described in the CEQ's *Environmental Justice Guidance under the National Environmental Policy Act* (CEQ 1997). The analysis method has three parts: (1) the geographic distribution of low-income and minority populations in the

TABLE 3.14-4 Employment by Sector in 2011[a]

Employment Sector	Coconino County Employment	Coconino County % of Total	Garfield County Employment	Garfield County % of Total	Kane County Employment	Kane County % of Total	Mohave County Employment	Mohave County % of Total
Agriculture[a]	628	1.4	260	18.7	141	6.3	265	0.7
Mining	60	0.1	10	0.7	10	0.4	556	1.4
Construction	1,932	4.3	60	4.3	76	3.4	1,932	4.8
Manufacturing	3,750	8.3	60	4.3	60	2.7	2,552	6.4
Transportation and public utilities	1,658	3.7	20	1.4	70	3.1	1,551	3.9
Wholesale and retail trade	8,563	19.0	176	12.6	369	16.5	10,645	26.6
Finance, insurance, and real estate	1,628	3.6	23	1.7	70	3.1	1,724	4.3
Services	25,722	57.0	896	64.4	1,702	76.2	20,744	51.9
Other	10	0.0	0	0.0	0	0.0	12	0.0
Total	45,143		1,392		2,234		39,998	

Employment Sector	San Juan County Employment	San Juan County % of Total	Washington County Employment	Washington County % of Total	Six-County Region Employment	Six-County Region % of Total
Agriculture[a]	226	8.3	381	1.0	1,901	1.5
Mining	110	4.0	60	0.2	806	0.6
Construction	164	6.0	2,953	8.1	7,117	5.6
Manufacturing	175	6.4	1,896	5.2	8,493	6.6
Transportation and public utilities	75	2.7	2,624	7.2	5,998	4.7
Wholesale and retail trade	492	18.0	8,236	22.6	28,481	22.3
Finance, insurance, and real estate	99	3.6	1,830	5.0	5,374	4.2
Services	1,475	53.9	18,511	50.7	69,050	53.9
Other	0	0.0	1	0.0	23	0.0
Total	2,738		36,485		127,990	

[a] Agricultural employment includes 2007 data for hired farmworkers.

Sources: U.S. Census Bureau (2013c); USDA (2013).

TABLE 3.14-5 Unemployment Rates (%) in the Six-County Region

Location	Average Growth Rate (%), 2000–2012	2012
Coconino County, Arizona	6.1	8.1
Garfield County, Utah	8.3	10.5
Kane County, Utah	5.5	7.2
Mohave County, Arizona	6.8	9.9
San Juan County, Utah	8.9	10.7
Washington County, Utah	5.7	7.0
Six-County Region	6.4	8.6
Arizona	5.2	8.3
Utah	4.0	5.7

Source: U.S. Department of Labor (2013).

affected area is described; (2) an assessment is conducted to determine whether the impacts of changes in operation would produce impacts that are high and adverse; and (3) if impacts are high and adverse, a determination is made as to whether these impacts disproportionately affect minority and low-income populations.

Changes in the operation of hydropower facilities and in hydropower costs could affect environmental justice if any adverse impacts on health, environmental conditions, economics, or Tribal values resulting from operational changes are determined to be high, and if these impacts would disproportionately affect minority and low-income populations, including impacts on Tribal groups. If the analysis determines that impacts on health, environmental conditions, economics, and Tribal values are not significant, there can be no disproportionate impacts on minority and low-income populations. In the event impacts are significant, disproportionality would be determined by comparing the proximity of any high and adverse impacts with the location of low-income and minority populations, including Tribal groups.

Environmental justice impacts on Tribes could occur through impacts on Tribal values or through impacts on Tribal economics. Impacts on values could result from temporary changes in access to culturally important Tribal resources associated with dam operations, and there may be an adverse impact on Tribal values from trout management actions. In addition, Tribal economics may be affected by alternative-specific differences in impacts on recreation in Glen Canyon and Grand Canyon and in the surrounding area.

The affected environment related to environmental justice issues is the 11-county region in the vicinity of the reservoirs and river corridor, and in eastern Arizona and northwestern New Mexico, which corresponds to the area in which the majority of impacts on recreation of changes in dam operations would likely occur. A description of the geographic distribution of minority and low-income groups in the affected area was based on demographic data from the 2010 Census (U.S. Census Bureau 2013b) and the 2008–2012 American Community Survey (U.S. Census Bureau 2013a). The following definitions were used to define minority and low-income population groups:

- **Minority.** Persons are included in the minority category if they identify themselves as belonging to any of the following racial groups: (1) Hispanic, (2) Black (not of Hispanic origin) or African American, (3) American Indian or Alaska Native, (4) Asian, or (5) Native Hawaiian or Other Pacific Islander.

  Beginning with the 2000 Census, where appropriate, the census form allows individuals to designate multiple population group categories to reflect their ethnic or racial origin. In addition, persons who classify themselves as being of multiple racial origins may choose up to six racial groups as the basis of their racial origins. The term "minority" includes all persons, including those classifying themselves in multiple racial categories, except those who classify themselves as not of Hispanic origin and as White or Other Race (U.S. Census Bureau 2013b).

- **Low-Income.** Individuals who fall below the poverty line. The poverty line takes into account family size and age of individuals in the family. In 2013, for example, the poverty line for a family of five with three children below the age of 18 was $27,400. For any given family below the poverty line, all family members are considered as being below the poverty line for the purposes of analysis (U.S. Census Bureau 2013b).

The CEQ guidance states that minority or low-income populations should be identified where either (1) the minority or low-income population of the affected area exceeds 50%, or (2) the minority or low-income population percentage of the affected area is meaningfully greater than the minority population percentage in the general population or other appropriate unit of geographic analysis. The LTEMP EIS applies both criteria in using the Census Bureau data for census block groups, wherein consideration is given to the minority or low-income population in a census block group where the relevant population is either 50% or more of the total block group population, or where the relevant population is 20 percentage points higher than the state average (the reference geographic unit) for the relevant population.

The data in Table 3.14-6 show the minority and low-income composition of the total population located in the region, based on 2010 Census and 2008–2012 American Community Survey data and CEQ guidelines. Individuals identifying themselves as Hispanic or Latino are included in the table as a separate entry. However, because Hispanics can be of any race, this number also includes individuals additionally identifying themselves as being part of one or more of the population groups listed in the table.

TABLE 3.14-6 Minority and Low-Income Populations in the 11-County Area

Population Type	Apache County, Arizona	Coconino County, Arizona	Mohave County, Arizona	Navajo County, Arizona	Cibola County, New Mexico	McKinley County, New Mexico	San Juan County, New Mexico	Garfield County, Utah	Kane County, Utah	San Juan County, Utah	Washington County, Utah	11-County Region
Total population	71,518	134,421	200,186	107,449	27,213	71,492	130,044	5,172	7,125	14,746	138,115	5,730,547
White, non-Hispanic	14,568	74,231	159,378	47,181	5,857	7,384	55,254	4,740	6,639	6,474	118,282	3,555,517
Hispanic or Latino	4,113	18,166	29,569	11,571	9,934	9,473	24,776	234	263	649	13,486	1,433,977
Non-Hispanic or Latino minorities	52,837	42,024	11,239	48,697	11,422	54,635	50,014	198	223	7,623	6,347	741,051
One race	51,753	39,222	7,985	47,047	11,077	53,329	47,564	161	153	7,371	4,161	646,795
Black or African American	157	1,495	1,715	842	221	317	617	13	15	21	632	67,458
American Indian or Alaskan Native	51,360	35,610	3,793	45,551	10,680	52,402	46,321	75	103	7,308	1,460	457,112
Asian	185	1,787	2,016	542	136	542	445	61	31	35	954	87,215
Native Hawaiian or other Pacific Islander	24	138	316	68	19	17	64	10	1	5	1,022	26,839
Some other race	27	192	145	44	21	51	117	2	3	2	93	8,171
Two or more races	1,087	2,802	3,254	1,650	345	1,306	2,450	37	70	252	2,186	94,256
Total minority	56,950	60,190	40,808	60,268	21,356	64,108	74,790	432	486	8,272	19,833	2,175,028
Low-income	19,838	23,050	37,426	24,061	6,468	19,985	20,576	628	539	4,103	20,225	729,333
Percent minority	76.9	44.8	20.4	56.1	78.5	89.7	57.5	8.4	6.8	56.1	14.4	38.0
State percent minority	42.2	42.2	42.2	42.2	59.5	59.5	59.5	19.6	19.6	19.6	19.6	–[a]
Percent low-income	27.7	17.2	18.6	22.4	23.7	27.8	16.0	12.3	7.6	27.9	14.5	12.7
State percent low-income	12.4	12.4	12.4	12.4	14.9	14.9	14.9	12.1	12.1	12.1	12.1	–

[a] A dash indicates not applicable.

A large number of minority and low-income individuals are located in the 11-county area around the Glen Canyon and Grand Canyon. Within the area, 38.0% of the population is classified as minority, while 12.7% is classified as low-income. According to CEQ guidelines, however, environmental justice concerns should be evaluated where there are minority and low-income *populations*, where the number of minority and low-income *individuals* present in a geographic area are compared to a reference population (the number of minority and low-income individuals in a state, for example), rather than only on the number of minority and low-income individuals present in a geographic area. The number of minority individuals exceeds the state average by 20 percentage points or more in Apache County, Arizona; McKinley County, New Mexico; and San Juan County, Utah; and exceeds 50% of the total population in Apache County and Navajo County, Arizona; in Cibola County, McKinley County, and San Juan County, New Mexico; and in San Juan County, Utah; meaning that there are minority populations in each of these counties based on CEQ guidelines and on county-level data in the 2010 Census and 2008–2012 American Community Survey data. As the number of low-income individuals does not exceed the state average by more than 20 percentage points, or does not exceed 50% of the total population in any of the 11 counties, there are no low-income populations based on county-level data in the 11-county region.

Within each county, there are block groups with minority and low-income populations. Figures 3.14-1 and 3.14-2 show the locations of the minority and low-income population groups in the 11-county area.

A large number of block groups in the 11-county area have populations whose percentage of minority individuals is more than 20 percentage points higher than the state average. In the Arizona counties, these block groups are located in the eastern part of Coconino County on the Navajo Nation Indian Reservation and the Hopi Indian Reservation; in the western part of Coconino County, which includes the Havasupai Indian Reservation and the Hualapai Indian Reservation, which are also located in one block group in eastern Mohave County. The Navajo Nation Indian Reservation and the Hopi Indian Reservation are also located in the central and northern part of Apache County, which also contains the Fort Apache Indian Reservation in the southern part of the county. The Navajo Nation Indian Reservation is also located in the central and northern part of Navajo County, Arizona, and in the western part of San Juan County, New Mexico. In all census block groups in these areas, the number of minority individuals is higher than the state average by 20 percentage points or more. Elsewhere in New Mexico, eastern San Juan County, a large majority of McKinley County, which contains part of the Navajo Nation Indian Reservation, part of the Zuni and Ramah Navajo Indian Reservations, and parts of Cibola County, which contains parts of the Ramah Navajo Indian Reservations, and the Acoma, Canoncito and Laguna Indian Reservations, all have block groups whose percentage of minorities is more than 20 percentage points higher than the state average.

There are a number of census block groups in the 11-county area in which more than 50% of the total population is minority. These are located in the southern portion of San Juan County, Utah, which includes the Navajo Nation Indian Reservation and the Ute Mountain Indian Reservation; the western part of Cibola County, which includes the Zuni Indian Reservation; and the eastern part of the Cibola County, which includes the Acoma, Canoncito and Laguna Indian Reservations. Census block groups in Page, Winslow, and Holbrook,

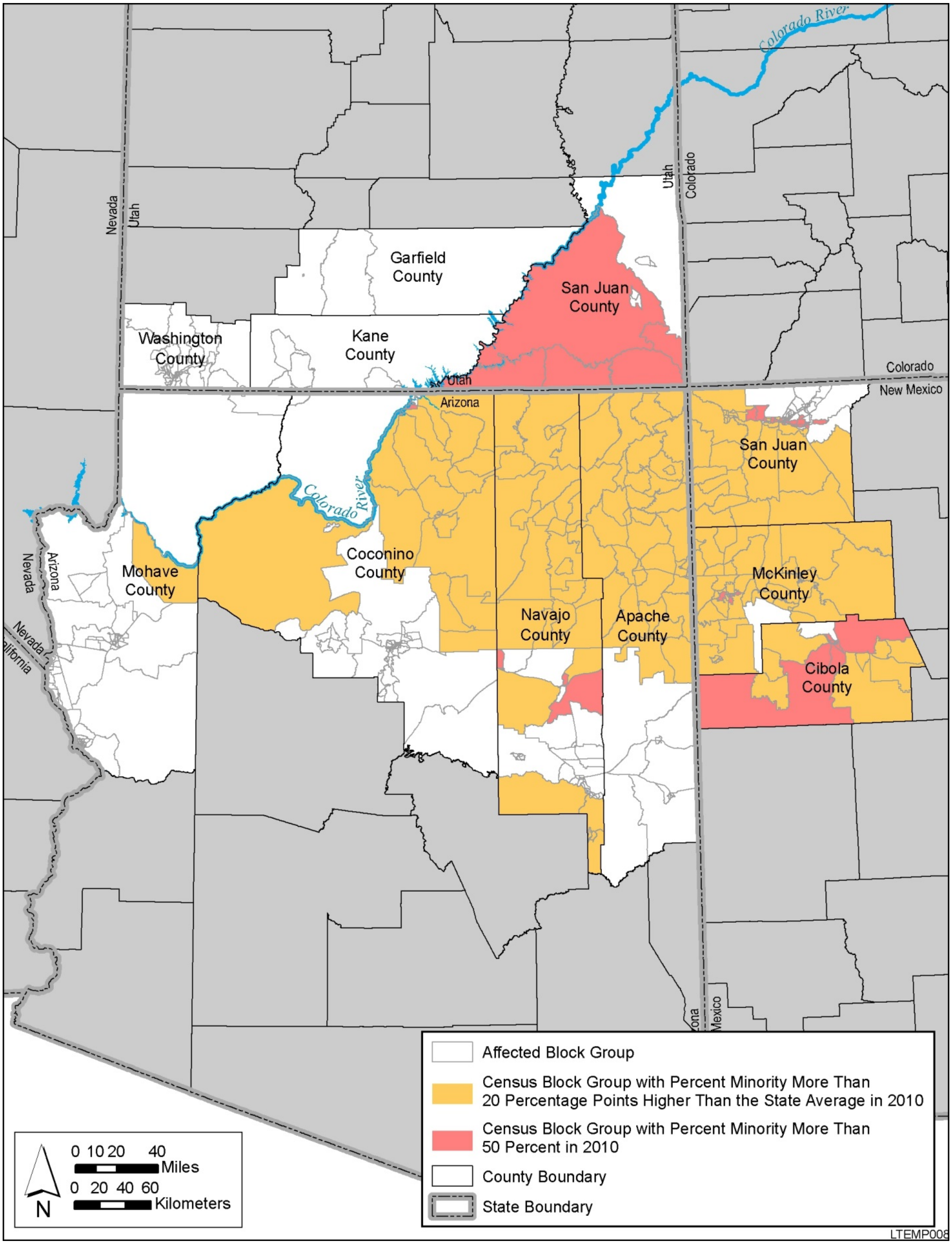

FIGURE 3.14-1 Minority Population Groups in the 11-County Area

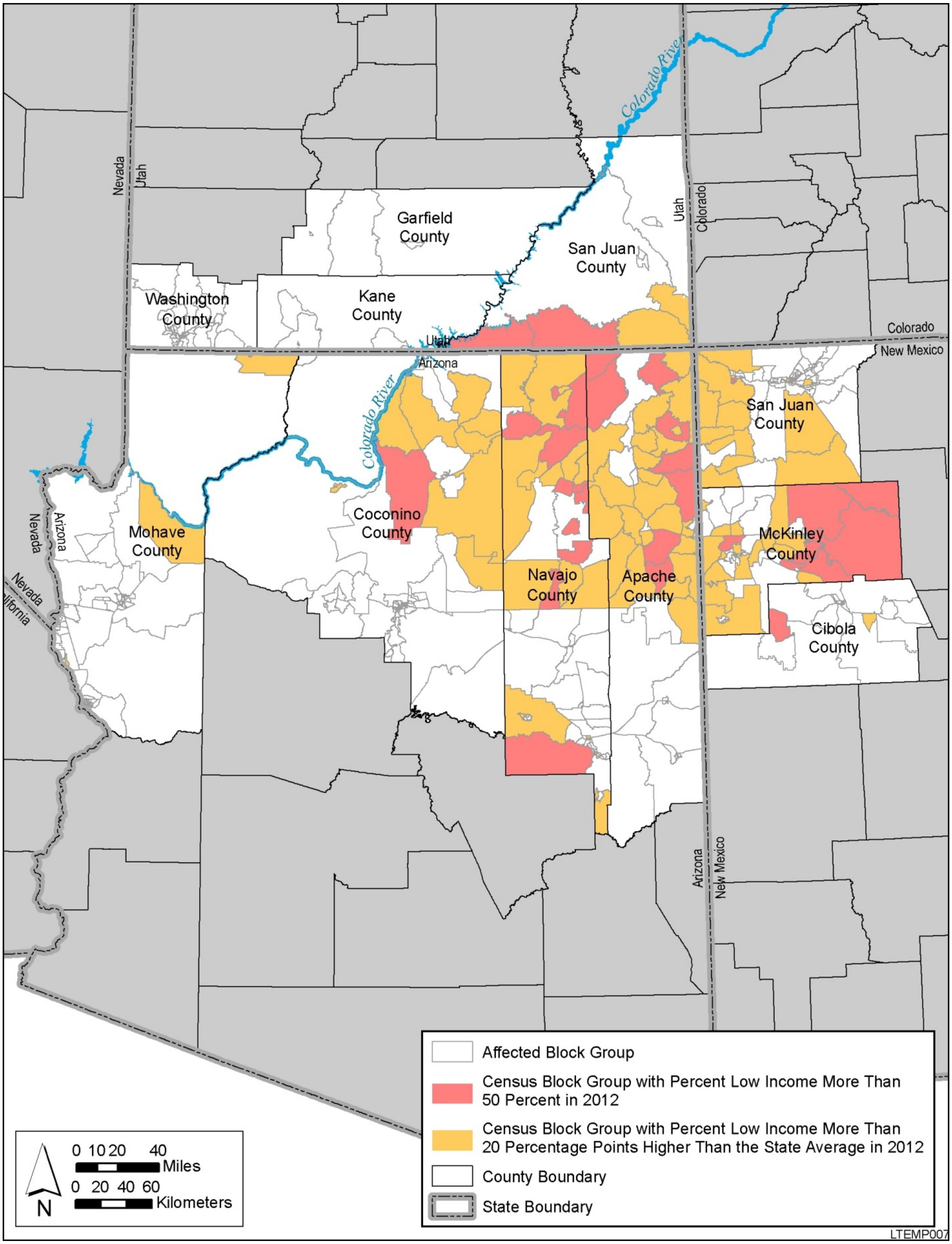

FIGURE 3.14-2 Low-Income Population Groups in the 11-County Area

Arizona, also have minority populations that are more than 50% of the total, as do census block groups in, and in the vicinity of, Farmington and Shiprock, New Mexico

There are a large number of census block groups in the 11-county area in which the percentage of low-income individuals is more than 20 percentage points higher than the state average. These are located on the Navajo Nation Indian Reservation and the Hopi Indian Reservation in Coconino County and on the Navajo Nation Indian Reservation in Navajo County, Arizona, which also contains the Fort Apache Indian Reservation; and in Apache County, Arizona, and San Juan County, New Mexico, on the Navajo Nation Indian Reservation. There are also block groups in McKinley County, New Mexico, on the Zuni Indian Reservation and in the vicinity of Gallup; in southeastern San Juan County, New Mexico; in eastern Mohave County, Arizona, on the Hualapai Indian Reservation; in southeastern and southwestern San Juan County, Utah, on the Navajo Nation Indian Reservation and the Ute Mountain Indian Reservation, where the percentage of low-income individuals is more than 20 percentage points higher than the state average.

There are also a number of census block groups in the 11-county area in which more than 50% of the total population is below the poverty level. These are located in the eastern part of Coconino County, Arizona, on the Navajo Nation Indian Reservation and Hopi Indian Reservation; in southwestern San Juan County, Utah, on the Navajo Nation Indian Reservation and the Ute Mountain Indian Reservation; in the northern parts of Navajo County and Apache County, Arizona; in southwestern Navajo County on the Fort Apache Indian Reservation; in New Mexico, in the eastern part of McKinley County, in the vicinity of Gallup, and on the Ramah Navajo Indian Reservation in Cibola County, New Mexico.

3.14.2 The Seven-State Region of Influence

This section describes current socioeconomic conditions within the seven-state region, the area in which electricity from Glen Canyon Dam is marketed, including Arizona, Colorado, Nebraska, Nevada, New Mexico, Utah, and Wyoming.

3.14.2.1 Population

Total population in the seven-state region was 21.9 million people in 2012, an increase from 17.7 million in 2000 (Table 3.14-7). Population in the region is concentrated in Arizona and Colorado, which, at 11.7 million people, had almost 54% of the total regional population in 2012.

Population in the seven-state study area grew at an annual average rate of 1.8% from 2000 to 2012. Growth within the region was uneven over the period, with higher than average annual growth rates in Nevada (2.7%), Arizona (2.1%), and Utah (2.1%). Growth rates in Colorado (1.6%) were closer to the average for the region, with lower than average rates in Wyoming (1.3%), New Mexico (1.1%), and Nebraska (0.7%).

TABLE 3.14-7 Population in the Seven-State Region of Influence

State	2000	2012	Annual Growth Rate (%), 2000–2012	2020	2030
Arizona	5,130,632	6,553,255	2.1	7,485,000	8,852,800
Colorado	4,301,261	5,187,582	1.6	5,915,922	6,888,181
Nebraska	1,711,263	1,855,525	0.7	1,940,114	2,054,752
Nevada	1,998,257	2,798,931	2.7	2,959,641	3,222,107
New Mexico	1,819,046	2,085,538	1.1	2,351,724	2,613,332
Utah	2,233,169	2,855,287	2.1	3,309,234	3,914,984
Wyoming	493,782	576,412	1.3	622,360	668,830
Total	17,687,410	21,872,530	1.8	24,583,995	28,214,986

Sources: U.S. Census Bureau (2013a); Arizona Department of Administration (2013); Colorado Department of Local Affairs (2013); Nebraska Department of Economic Development (2013); Nevada State Demographer's Office (2013); University of New Mexico (2013); Governor's Office of Planning and Budget (2013); Wyoming Department of Administration and Information (2013).

The regional population is projected to reach 24.6 million in 2020 and 28.2 million 2030.

3.14.2.2 Income

Arizona and Colorado generated almost 55% of the income in the seven-state region, together producing almost $469 billion in 2011 (Table 3.14-8). Personal income grew at an annual average rate of 2.0% over the period from 2000 to 2011, with higher than average growth rates in Wyoming (3.4%), New Mexico (2.5%), Utah (2.5%), and Arizona (2.3%). Income per capita rose slightly over the same period at a rate of 0.2%, resulting in an increase from $38,640 to $39,509. Per capita incomes were higher in 2011 in Wyoming ($49,676), Colorado ($45,628), and Nebraska ($43,973) than the average for the region as a whole.

Median household incomes (the income level at which exactly half of all households earn more than the level, and half earn less) over the period from 2008 to 2012 varied between $45,542 in New Mexico and $59,096 in Colorado (U.S. Census Bureau 2013a). Median household income in the United States was $53,832 over the same period.

TABLE 3.14-8 Income in the Seven-State Region of Influence

State	2000	2011	Average Annual Growth Rate (%), 2000–2011
Arizona			
Income (billions of 2013$)	183.6	235.4	2.3
Per-capita income (2013$)	35,778	36,397	0.2
Colorado			
Income (billions of 2013$)	198.9	233.4	1.5
Per-capita income (2013$)	46,252	45,628	–0.1
Nebraska			
Income (billions of 2013$)	66.3	81.0	1.8
Per-capita income (2013$)	38,735	43,973	1.2
Nevada			
Income (billions of 2013$)	84.6	104.3	1.9
Per-capita income (2013$)	42,337	38,328	-0.9
New Mexico			
Income (billions of 2013$)	56.0	73.6	2.5
Per-capita income (2013$)	30,808	35,410	1.3
Utah			
Income (billions of 2013$)	74.4	97.8	2.5
Per-capita income (2013$)	33,333	34,738	0.4
Wyoming			
Income (billions of 2013$)	19.6	28.2	3.4
Per-capita income (2013$)	39,626	49,676	2.1
Total			
Income (billions of 2013$)	683.4	853.7	2.0
Per-capita income (2013$)	38,640	39,509	0.2

Source: U.S. Department of Commerce (2013).

3.14.2.3 Employment

In 2012, more than 53% (5.3 million) of all employment in the seven-state power marketing service territory (9.9 million) was concentrated in Arizona and Colorado (Table 3.14-9). Employment in Utah was 1.3 million and 1.2 million in Nevada, the remaining states supporting 2.1 million jobs. Over the period from 2000 to 2012, annual employment growth rates were higher in Nevada (1.6%) and Utah (1.3%) than elsewhere in the seven-state study area, with rates in Colorado (0.8%), New Mexico (0.6%), and Nebraska (0.5%) lower than the average rate of 1.0%.

In 2011, the service sector provided the highest percentage of employment in the seven-state region at almost 56%, followed by wholesale and retail trade (17.5%) (Table 3.14-10). Smaller employment shares were held by finance, insurance, and real estate (6.9%), and both construction and manufacturing (6.7%). Within the region, the distribution of employment across sectors varied somewhat compared to the region as a whole. Nebraska (5.7%) and Wyoming (4.6%) have a higher percentage of employment in agriculture than the region as a whole (2.2%), and these states have lower shares of employment in services compared with the region as a whole. Service sector employment in Nevada (62.9%) and Colorado (58.6%) is higher than in the region as a whole. Nebraska (10.8%) and Utah (10.2%) have larger than average shares of manufacturing sector employment, while mining is a more significant employer in Wyoming (12.4%) than elsewhere in the region.

TABLE 3.14-9 Employment in the Seven-State Region of Influence

State	2000	2012	Average Annual Growth Rate (%), 2000–2012
Arizona	2,404,916	2,778,579	1.2
Colorado	2,300,192	2,523,535	0.8
Nebraska	923,198	980,668	0.5
Nevada	1,015,221	1,226,408	1.6
New Mexico	810,024	871,299	0.6
Utah	1,097,915	1,276,249	1.3
Wyoming	256,685	289,621	1.0
Total	8,808,151	9,946,359	1.0

Source: U.S. Department of Labor (2013).

TABLE 3.14-10 Employment by Sector in 2011 in the Seven-State Region of Influence[a]

	Arizona		Colorado		Nebraska		Nevada	
Sector	Employment	% of Total	Employment	% of Total	Employment	% of Total	Employment	% of Total
Agriculture[a]	30,113	1.4	40,673	2.0	48,061	5.7	4,603	0.5
Mining	11,160	0.5	25,006	1.2	963	0.1	11,484	1.1
Construction	116,992	5.5	115,615	5.7	37,196	4.4	50,140	5.0
Manufacturing	137,532	6.4	117,810	5.9	91,190	10.8	39,277	3.9
Transportation and public utilities	87,613	4.1	68,901	3.4	38,583	4.6	48,147	4.8
Wholesale and retail trade	398,228	18.6	332,919	16.6	146,784	17.4	163,369	16.3
Finance, insurance, and real estate	168,747	7.9	132,273	6.6	68,097	8.1	57,788	5.7
Services	1,186,730	55.5	1,177,687	58.6	413,514	49.0	632,580	62.9
Other	175	0.0	375	0.0	60	0,0	175	0.0
Total	2,137,315		2,011,186		844,678		1,005,038	

	New Mexico		Utah		Wyoming		Total	
Sector	Employment	% of Total	Employment	% of Total	Employment	% of Total	Employment	% of Total
Agriculture[a]	23,426	3.8	20,175	1.9	10,029	4.6	177,080	2.2
Mining	16,643	2.7	10,755	1.0	27,001	12.4	103,012	1.3
Construction	39,441	6.4	56,030	5.3	17,350	8.0	432,764	5.5
Manufacturing	27,434	4.4	106,865	10.2	9,644	4.4	529,752	6.7
Transportation and public utilities	21,385	3.4	50,294	4.8	13,861	6.4	328,784	4.2
Wholesale and retail trade	115,071	18.5	187,284	17.9	37,926	17.4	1,381,581	17.5
Finance, insurance, and real estate	31,848	5.1	76,448	7.3	10,925	5.0	546,126	6.9
Services	345,254	55.6	540,136	51.5	92,500	42.4	4,388,401	55.6
Other	62	0.0	60	0.0	75	0.0	982	0.0
Total	620,564		1,048,851		218,211		7,885,843	

[a] Agricultural employment includes 2007 data for hired farmworkers.

Sources: U.S. Census Bureau (2013c); USDA (2013).

3.14.2.4 Unemployment

Between 2000 and 2011, average unemployment rates have varied across the seven-state region, from 7.7% in Nevada and 6.5% in Arizona to lower rates elsewhere in the region, particularly in Nebraska (3.8%) (Table 3.14-11). The average rate in the region over this period was 6.2%. Rates were higher in 2012 than average rates for the period from 2000 to 2011, unemployment standing at 11.1% in Nevada and 8.3% in Arizona, with lower rates in the other five states; the average rate for the region as a whole (7.6%) was also higher during this period than the corresponding average rate for 2000 to 2011.

3.14.2.5 Environmental Justice

The data in Table 3.14-12 show the minority and low-income composition of total population located in the seven-state region based on 2010 Census and 2008–2012 American Community Survey data and CEQ guidelines. Individuals identifying themselves as Hispanic or Latino are included in the table as a separate entry. However, because Hispanics can be of any race, this number also includes individuals also identifying themselves as being part of one or more of the population groups listed in the table.

TABLE 3.14-11 Unemployment in the Seven-State Region of Influence[a]

State	Average Rate (%), 2000–2011	2012 (%)
Arizona	6.5	8.3
Colorado	6.0	8.0
Nebraska	3.8	3.9
Nevada	7.7	11.1
New Mexico	5.7	6.9
Utah	5.0	5.7
Wyoming	4.5	5.4
Total	6.2	7.6

Source: U.S. Department of Labor (2013).

TABLE 3.14-12 State Minority and Low-Income Populations, 2010

Category	Arizona	Colorado	Nebraska	Nevada	New Mexico	Utah	Wyoming	Region Total
Total population	6,392,017	5,029,196	1,826,341	2,700,551	2,059,179	2,763,885	563,626	21,334,795
White, Non-Hispanic	3,695,647	3,520,793	1,499,753	1,462,081	833,810	2,221,719	483,874	13,717,677
Hispanic or Latino	1,895,149	1,038,687	167,405	716,501	953,403	358,340	50,231	5,179,716
Non-Hispanic or Latino minorities	801,221	469,716	159,183	521,969	271,966	183,826	29,521	2,437,402
One race	686,590	368,869	130,757	442,837	242,131	134,841	21,216	2,027,241
Black or African American	239,101	188,778	80,959	208,058	35,462	25,951	4,351	782,660
American Indian or Alaska Native	257,426	31,244	14,797	23,536	175,368	27,081	11,784	541,236
Asian	170,509	135,564	31,919	191,047	26,305	54,176	4,279	613,799
Native Hawaiian or other Pacific Islander	10,959	5,661	966	15,456	1,246	23,909	365	58,562
Some other race	8,595	7,622	2,116	4,740	3,750	3,724	437	30,984
Two or more races	114,631	100,847	28,426	79,132	29,835	48,985	8,305	410,161
Total minority	2,696,370	1,508,403	326,588	1,238,470	1,225,369	542,166	79,752	7,617,118
Low-income	1,094,249	659,786	229,923	398,027	413,851	359,242	61,577	3,216,655
Percent minority	42.2	30.0	17.9	45.9	59.5	19.6	14.1	35.7
U.S. Percent	35.3	35.3	35.3	35.3	35.3	35.3	35.3	35.3
Percent low-income	17.4	13.4	12.9	14.9	20.4	13.2	11.2	15.1
U.S. percent	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8

Sources: U.S. Census Bureau (2013a,b).

A large number of minority and low-income individuals are located in the seven-state region in which electricity from Glen Canyon dam is marketed. In the region as whole, 35.7% of the population is classified as minority, while 15.1% is classified as low-income. According to CEQ guidelines, however, environmental justice concerns should be evaluated where there are minority and low-income *populations*, where the number of minority and low-income *individuals* present in a geographic area are compared to a reference population (the number of minority and low-income individuals in the nation, for example), rather than only on the number of minority and low-income individuals present in a geographic area. The number of minority or low-income individuals in the seven-state region does not exceed the respective national averages by 20 percentage points or more, and does not exceed 50% of the total population in the area, meaning that for the region as a whole, there are no minority or low-income populations based on CEQ guidelines and on 2010 Census and 2008–2012 American Community Survey data. However, within one state in the region, New Mexico, 59.5% of the total population is minority, meaning that according to 2010 Census and 2008–2012 American Community Survey data, there is a minority population in the state.

Although there are no minority populations in any of the seven states, except for New Mexico, and no low-income populations, there are a large number of Native American individuals in the seven-state area, many of whom reside on Tribal Reservations. Section 3.9 provides more information on the location and Tribal population associated with Reservations. Many of these individuals are low-income in status.

Tribal members receive a significant portion of their electricity from WAPA, which currently targets an allocation of 65% of total Tribal electrical use to the 57 Tribes or Tribal entities currently receiving an allocation of power from the SLCA/IP system, which includes power from Glen Canyon Dam. Nine of these Tribes operate electric utilities and receive power directly from WAPA, while the remaining 48 Tribes can often benefit from cheaper federal hydropower through “benefit crediting” arrangements with SLCA/IP customers or other electric utilities. Benefit credits are provided to a Tribe by the utility that serves the area in which the Tribe is located in lieu of direct electric service by WAPA, and are intended to be the financial equivalent of a direct allocation. When the SLCA/IP rate is lower than the rate charged for electrical power by the utility, the difference between the two rates is paid to each Tribe by subtracting the amount of the benefit credit, pro-rated by the amount of electricity consumed, from the monthly electric bill.

3.14.3 Non-Use Value

Non-use values are economic values that may be placed on the status of the natural or physical environment by non-users, or individuals who may never visit or otherwise use a natural resource that might still be affected by changes in its status or quality, who may assign a non-use or passive-use economic value to a resource.

Welsh et al. (1995) estimated the willingness to pay to improve native vegetation, native fishes, game fish, river recreation, and cultural sites in Glen Canyon National Recreation Area and Grand Canyon National Park. Value estimates varied between $17.74 and $26.91 for a U.S. household, and between $29.05 and $38.02 for a western U.S. household.

Understanding non-market values affected by proposed operational changes at Glen Canyon Dam, for both recreational use and environmental non-use values, has been the topic of considerable prior investigations (e.g., Bishop et al. 1987; Welsh et al. 1995). These studies have been important in bringing non-market values into consideration for managing the resources of the Colorado River Basin (Harpman et al. 1995; Loomis et al. 2005). In that regard, two additional studies (Loomis 2014; Jones et al. 2016) have been conducted regarding non-market values.

Loomis (2014) concluded that there is a theoretical basis for non-market values associated with hydropower and water. He used the example of how people can place value on maintaining the ranching and farming way of life associated with western rural communities as irrigated agriculture landscapes are correlated with open space. In addition, people may place value on the existence and well-being of farming communities. Indirect empirical support for altruism toward farmers is cited in Loomis (2014). Non-market values associated with hydropower and water resources may also exist to the extent hydropower and developed water assist in the maintenance of Tribal values and social well-being.

3.15 AIR QUALITY

Air quality is primarily affected by air emission sources, both natural (e.g., wildfires and windblown dust) and man-made (e.g., power generation from fossil fuel–fired plants, such as the nearby Navajo Generating Station, and potentially other plants in the 11-state area, as well as onroad and offroad mobile sources such as vehicles).

Changes in operations at Glen Canyon Dam can create either more or less hydroelectricity at certain times of the day to meet regional electricity demand. If less electricity is available at Glen Canyon Dam, demand must be met by other means, which may include powerplants fueled by fossil fuels (including coal, oil, and gas turbine plants) and nuclear, other hydroelectric, wind, and solar energy sources, or by demand-side management. Changes in the operation of Glen Canyon Dam, therefore, may indirectly affect air quality by potentially changing the degree to which electricity demand is met within the region, with either non-emission hydropower, wind, or solar powerplants, or emission-producing powerplants, such as fossil fuel–fired powerplants that can directly affect air quality and related resources. These air quality changes can also affect greenhouse gas (GHG) emissions that can influence climate change. Local and regional GHG information is presented here, while climate change is discussed in Section 3.16.

3.15.1 Local Air Quality

The Clean Air Act (CAA), as amended (42 USC 7401) established Prevention of Significant Deterioration (PSD) provisions for use in protecting the nation's air quality and visibility. The PSD provisions apply to new or modified major stationary sources and are designed to keep an attainment area in continued compliance with the National Ambient Air Quality Standards (NAAQS). Major stationary sources are industrial-type facilities and include powerplants and manufacturing facilities that emit more than 100 tons per year of a regulated pollutant. No major stationary sources are being proposed for construction or modification by the proposed federal action; therefore the statutory provisions specific to PSD are not applicable. However, there are criteria pollutants for which thresholds for increases in pollution concentrations have been established. These include sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and particulate matter (PM), which are often analyzed. The PSD standards are most stringent in Class I areas and are progressively less stringent in the Class II and Class III areas (Table 3.15-1). GCNRA and LMNRA are designated as Class II areas, while GCNP is designated as a Class I area.

Table 3.15-2 presents criteria pollutant and volatile organic compound (VOC) emission totals in 2011 for Coconino and Mohave Counties (EPA 2013a), which encompass the GCNP. The data represent 13 source categories (e.g., fuel combustion by power generation and industry, highway vehicles, off-highway vehicles, and miscellaneous sources). Miscellaneous sources, including prescribed/structural fires, wildfires, fugitive dust, and agricultural production, account for a predominant portion of the two-county totals of PM with an aerodynamic diameter less than or equal to 2.5 μm ($PM_{2.5}$), particulate matter with an aerodynamic diameter less than or equal to 10 μm (PM_{10}), and SO_2. In addition, miscellaneous sources are primary contributors to carbon monoxide (CO) and VOC emissions, which account for more than 50% of their respective total emissions. Highway vehicles are primary contributors to total NO_x emissions and secondary contributors to total CO emissions. Off-highway vehicles are secondary contributors to total NO_x and VOC emissions. In these counties, fuel combustion and industrial activities are minor contributors to any criteria pollutant and VOC emissions.

TABLE 3.15-1 Clean Air Act Prevention of Significant Deterioration Designations

Designation	Definition
Class I Area	Visibility is protected more stringently than under the NAAQS; includes national parks, wilderness areas, monuments, and other areas of special national and cultural significance.
Class II Area	Moderate change is allowed, but stringent air quality constraints are nevertheless desired.
Class III Area	Substantial industrial or other growth is allowed, and increases in concentration up to the national standards would be considered insignificant.

TABLE 3.15-2 Criteria Pollutant and VOC Emissions in Counties Encompassing Grand Canyon National Park and for the Navajo Generating Station, 2011

	Annual Emissions (10^3 tons)[a]					
County/Facility	CO	NO_x	VOCs	$PM_{2.5}$	PM_{10}	SO_2
Coconino	117.41	14.24	26.17	8.98	17.76	0.67
Mohave	48.77	12.79	10.97	2.55	12.65	0.13
Two-county total	166.19	27.03	37.13	11.52	30.41	0.80
Navajo Generating Station[b]	1.96	19.84	0.03	2.83	4.11	4.64

[a] CO = carbon monoxide; NO_x = nitrogen oxides; $PM_{2.5}$ = particulate matter with an aerodynamic diameter of ≤ 2.5 μm; PM_{10} = particulate matter with an aerodynamic diameter of ≤ 10 μm; SO_2 = sulfur dioxide; and VOC = volatile organic compound.

[b] The 2,250-MW coal-fired powerplant is located on the Navajo Indian Reservation near Page, Arizona, which is within Coconino County. Emissions from the Navajo Generating Station are not included in Coconino County emission totals.

Source: EPA (2013a).

Data on emissions from Tribal lands in Coconino and Mohave Counties are hard to find because the emission data are given in total emissions for Tribal lands which straddle many counties and even many states. One important point source within the area is the Navajo Generating Station, a 2,250-MW coal-fired powerplant located on the Navajo Indian Reservation near Page, Arizona (within Coconino County). NO_x emissions from this powerplant are about three-fourths of the two-county emissions combined, while SO_2 emissions are much larger (Table 3.15-2). There are three natural gas–fired powerplants in southwestern Mohave County but none in Coconino County.

3.15.2 Regional Air Quality

Changes in operations at Glen Canyon Dam can affect regional air quality if these changes result in corresponding increases or decreases in power generation at other facilities in the Western Interconnection grid. Under the CAA, the U.S. Environmental Protection Agency (EPA) has established the NAAQS for six criteria pollutants considered harmful to public health and the environment (40 CFR Part 50): SO_2, NO_2, CO, ozone (O_3), $PM_{2.5}$, PM_{10}, and lead (Pb) (EPA 2015a). Each state in this 11-state area can have its own State Ambient Air Quality Standards (SAAQS) for criteria pollutants. If a state has no standard corresponding to one of the NAAQS or a standard less stringent than NAAQS, the NAAQS apply. In addition, any state can establish standards for pollutants other than criteria pollutants. Several states have adopted standards for additional pollutants: visibility-reducing particles, sulfates, hydrogen sulfide (H_2S), and vinyl chloride for California; fluorides for Idaho; H_2S, settled PM, and fluoride in forage for Montana;

H_2S for Nevada; total suspended particulates, H_2S, and total reduced sulfur for New Mexico; particle fallout for Oregon; radionuclides and fluorides for Washington; and H_2S, suspended sulfates, fluorides, and odors for Wyoming.

Parts of the 11-state area have not yet attained the NAAQS for SO_2, 8-hour O_3, $PM_{2.5}$, PM_{10}, and Pb, as shown in Figure 3.15-1 (EPA 2015b). Currently, there are no nonattainment areas for NO_2 and CO in the United States, and thus in the 11-state area. Except for Washington, each state has one or more nonattainment areas. Arizona has nonattainment areas for all five air pollutants, while California and Montana have nonattainment areas for four air pollutants. In contrast, Washington has no nonattainment areas. Utah has nonattainment areas for three air pollutants. Three states (Idaho, Oregon, and Wyoming) have nonattainment areas for two air pollutants, while three states (Colorado, Nevada, and New Mexico) have nonattainment areas for one air pollutant. Nonattainment areas are mostly located in urban areas, except for the rural environment of the Upper Green River Basin in southwestern Wyoming, due to high wintertime ozone.

There are many regional air pollution problems such as O_3, acid deposition, and visibility degradation in the western United States. Ozone issues are most prevalent around urban centers, with the exception of elevated wintertime O_3 at higher elevations near oil and gas fields in Utah, Wyoming, and Colorado, where snow cover is prevalent. Impacts of acid deposition have been observed in the Desert Southwest, where excess nitrogen deposition facilitates invasion of nonnative grass species that compete with native plant species and increase fire risk due to increased biomass fuel loading. Acid deposition may also affect high-elevation lakes where excess nitrogen deposition can alter aquatic species composition. Visibility impairment is a widespread and pervasive problem throughout the country, and, in particular, in many national parks and wilderness areas where the CAA specifically requires visibility protection.

Visibility degradation is caused by cumulative emissions of air pollutants from a myriad of sources scattered over a wide geographical area. In general, the primary cause of visibility degradation is the scattering and absorption of light by fine particles, with a secondary contribution provided by gases. In general, visibility conditions in the western United States are substantially better than those in the eastern United States because of the higher pollutant loads and humidity levels in the East (EPA 2006). The typical visual range (defined as the farthest distance at which a large black object can be seen and recognized against the background sky) in most of the western United States is about 60 to 90 mi, while that in most of the eastern United States is about 15 to 30 mi. Most visibility degradation is associated with combustion-related sources, while fugitive dust sources contribute to some extent. In particular, smaller particles such as $PM_{2.5}$ scatter light more efficiently, which includes ammonium sulfate, ammonium nitrate, particulate organic matter, light-absorbing carbon (or soot), mineral fine soil, and sea salt. Ammonium sulfate and ammonium nitrate are formed by chemical reactions in the atmosphere that include emissions of SO_2 and NO_x, respectively. Particulate organic matter (POM) can be emitted directly from vegetation or can form in the atmosphere from a variety of gaseous organic compounds. At the GCNP, POM has the greatest impact on visibility, followed by ammonium sulfate (Hand et al. 2011).

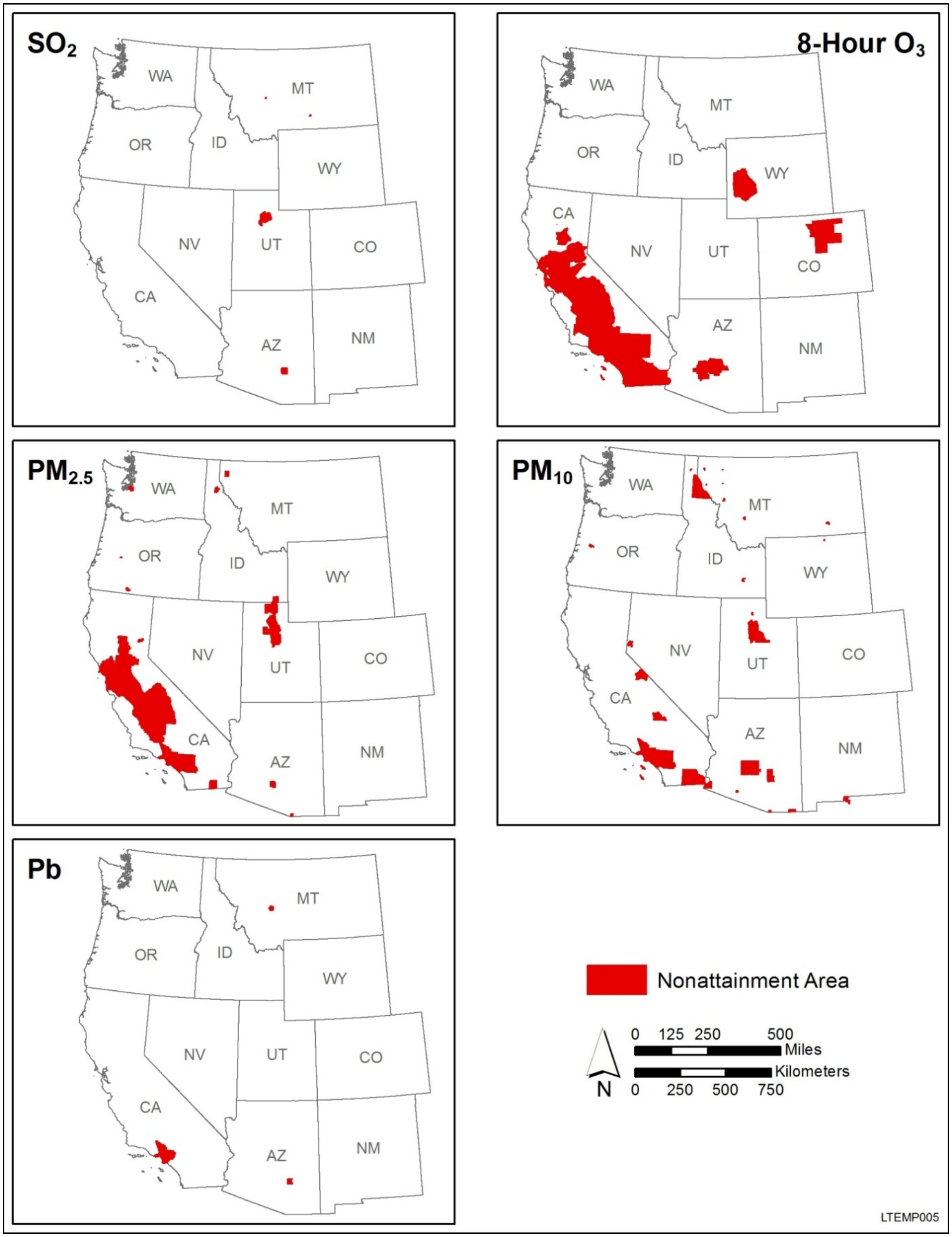

FIGURE 3.15-1 Nonattainment Areas for SO_2, 8-Hour O_3, $PM_{2.5}$, PM_{10}, and Pb in the 11-State Area (Note that currently there are no nonattainment areas for NO_2 and CO in the United States and thus in the 11-state area.) (Source: EPA 2015b)

Visibility was singled out for particular emphasis in the CAA Amendments (CAAA) of 1977. Visibility in a Class I area is protected under two sections of the CAAA. Section 165 provides for the PSD program (described in Section 3.15.2) for new sources. Section 169(A), for older sources, describes requirements for both reasonably attributable single sources and regional haze, which address multiple sources. Federal land managers have a particular responsibility to protect visibility in Class I areas. There are 158 mandatory federal Class I areas in the United States, and those in the 11-state area are illustrated in Figure 3.15-2 (EPA 2013b).

In 1999, the EPA issued the final Regional Haze Rule (64 FR 35714, July 1, 1999) which sets a national visibility goal for preventing future and remedying existing impairment to visibility in Class I areas. The rule is designed to reduce visibility impairment from existing sources and limit visibility impairment from new sources. States with Class I areas or states affecting visibility in Class I areas must revise their state implementation plans, prepare emission-reduction strategies to reduce regional haze, and establish glide paths for each Class I area. States are required to periodically review whether they are making reasonable progress toward meeting the goal of achieving natural conditions by 2064. Wildfires and windblown dust storms can significantly degrade visibility at Class I areas in the 11-state area. Emissions of SO_2 and NO_x from fossil fuel combustion are the major man-made causes of visibility impairment; these emissions have been substantially reduced in the 11-state area in the past decade in response to state and federal requirements (ARS 2013).

3.15.3 Regional Air Emissions

Table 3.15-3 presents statewide criteria pollutants and VOC emissions for the 11-state area within the Western Interconnection in 2011 (EPA 2013a). As discussed in Section 3.15.2, emission data are given in 13 source categories. Overall, miscellaneous sources are primary contributors to CO, $PM_{2.5}$, PM_{10}, and VOCs for the 11-state totals. Highway vehicles and fuel combustion for electricity generation are primary contributors to NO_x and SO_2, which account for about 45% and 41% of the 11-state total emissions, respectively. Among the 11 states in the region, all criteria pollutants and VOC emissions, except PM_{10} and SO_2, are highest in California. PM_{10} emissions are highest in New Mexico. SO_2 emissions are highest in Wyoming, which burns large quantities of fossil fuel (notably coal) for power generation and industrial activities. Total criteria pollutant and VOC emissions combined are highest in California followed by Arizona, and lowest in Nevada.

Table 3.15-3 also shows total statewide gross[13] GHG emissions on a consumption basis in terms of carbon dioxide equivalent (CO_2e).[14] GHG emissions for California are the highest at 453.1 million metric tons (MMt) (499.5 million tons) CO_2e, followed by Colorado, while those

[13] Excluding GHG emissions removed due to forestry and other land uses.

[14] The carbon dioxide equivalent is a measure used to compare the emissions from various GHGs on the basis of their global warming potential (GWP), which is defined as the ratio of heat trapped by one unit mass of the GHG to that of one unit mass of CO_2 over a specific time period. For example, GWP is 21 for CH_4, 310 for N_2O, and 23,900 for SF_6. Accordingly, CO_2e emissions are estimated by multiplying the mass of a gas by the GWP.

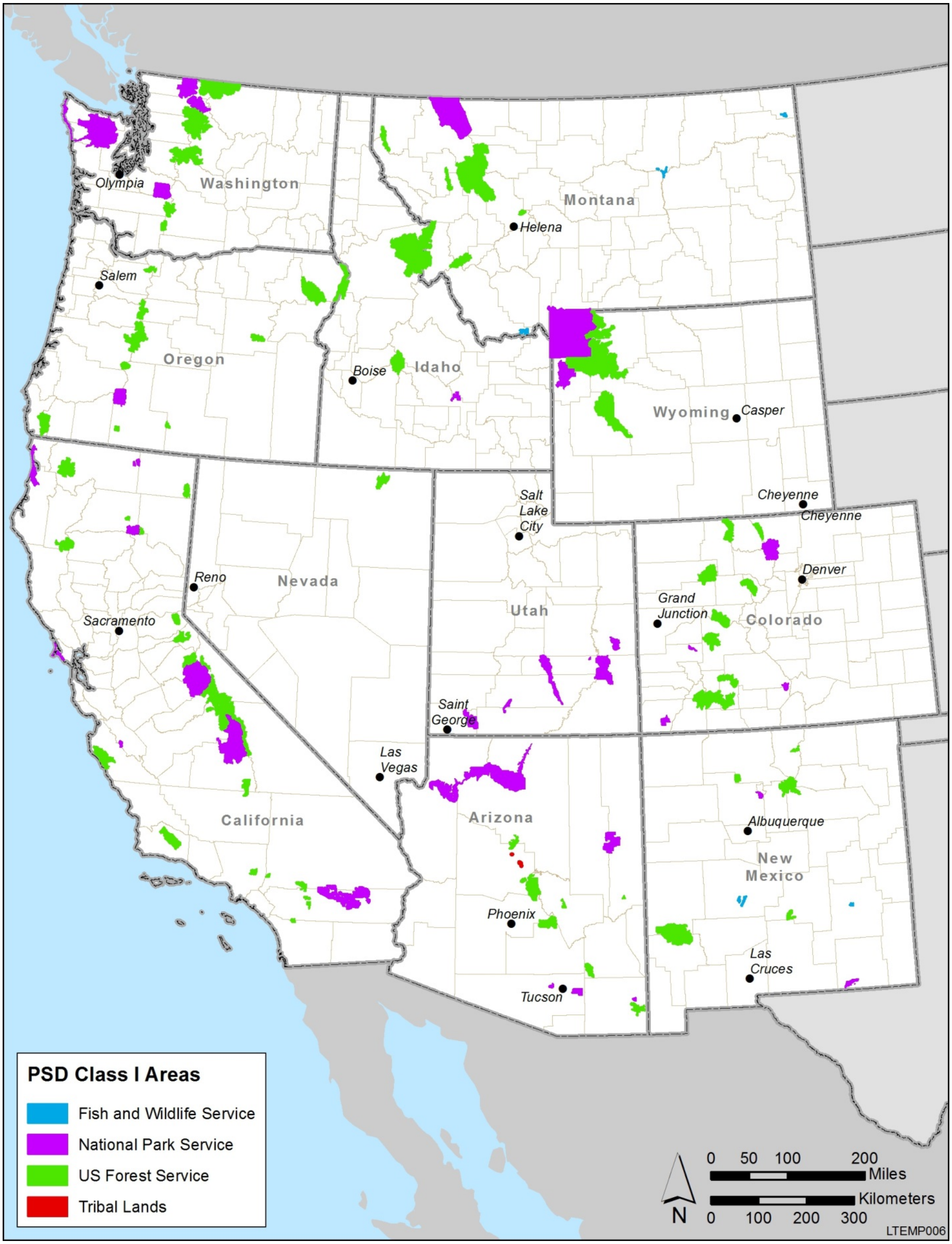

FIGURE 3.15-2 PSD Class I Areas in the 11-State Affected Area (Source: EPA 2013b)

TABLE 3.15-3 Criteria Pollutant and VOC Emissions for 2011, and GHG Emissions for 2010, over the 11-State Affected Area within the Western Interconnection

	Annual Emissions (10^3 tons; million metric tons for CO_2e)[a]						
State	CO	NO_x	VOCs	$PM_{2.5}$	PM_{10}	SO_2	CO_2e[b]
Arizona	2,357	251	508	178	405	77	116.6
California	3,674	736	836	208	475	36	453.1
Colorado	1,340	282	500	103	332	57	129.3
Idaho	1,111	98	258	116	431	14	39.6
Montana	1,321	119	342	141	437	29	38.5
Nevada	509	99	87	37	169	13	58.1
New Mexico	1,392	208	440	180	916	30	77.5
Oregon	2,285	161	495	183	372	30	74.7
Utah	595	185	241	39	184	28	75.7
Washington	1,648	278	307	92	249	30	103.0
Wyoming	1,106	196	296	130	483	80	60.3
11-State Total	17,338	2,614	4,311	1,407	4,454	425	1,226.4

[a] CO = carbon monoxide; CO_2e = carbon dioxide equivalent; NO_x = nitrogen oxides; $PM_{2.5}$ = particulate matter with an aerodynamic diameter of ≤2.5 μm; PM_{10} = particulate matter with an aerodynamic diameter of ≤10 μm; SO_2 = sulfur dioxide; and VOC = volatile organic compound.

[b] Total gross emissions on the consumption basis. To convert from metric ton to ton, multiply by 1.1023.

Sources: ADEQ (2006b); ARB (2014); Bailie et al. (2006), Bailie, Roe, et al. (2007); Bailie, Strait, et al. (2007); CCS (2007); EPA (2013a); NDEP (2008); ODEQ, ODOE, and ODOT (2013); Roe et al. (2007); Strait et al. (2007, 2008).

for Montana are the lowest at 38.5 MMt (42.4 million tons) CO_2e. Wyoming also produces a relatively large amount of CO_2e, but about one-third of the state's CO_2e emissions result from the production of electricity that is exported out of state. Total emissions from the 11-state area are about 1,226.4 MMt (1,351.9 million tons) CO_2e. This equates to about 18.0% of total GHG emissions in the United States during 2010, at 6,810.3 MMt (7,507.0 million tons) CO_2e (EPA 2013c).

3.16 CLIMATE CHANGE

Climate change may affect resources that are also affected by LTEMP alternatives. As explained in the air quality discussion (Section 3.15), changes in operations at Glen Canyon Dam have the potential to alter emissions from other sources of electricity, sources that can produce more GHGs than hydroelectric power. Glen Canyon dam reduces CO_2 emissions by about 1.4 to 3.5 MMt (1.5–3.9 million tons) in an average year (EPA 2014a; Reclamation 2015), which equates to about 0.11 to 0.29% of 11-state total emission. Climate change is also predicted to affect climate and hydrology in the region, which could affect resources in the project area.

As discussed above, dam operations can affect air quality, including the concentration of GHGs in the atmosphere. GHGs are transparent to incoming short-wave radiation from the sun but opaque to outgoing long-wave (infrared) radiation from the earth's surface. The net effect over time is a trapping of absorbed radiation and a tendency to warm the earth's atmosphere, which together constitute the "greenhouse effect." The principal GHGs that enter the atmosphere due to human activities, including fossil fuel power generation, include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and fluorinated gases such as hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). Some GHGs such as CO_2, CH_4, and N_2O occur naturally and are emitted to the atmosphere through natural processes as well.

In the arid/semiarid western states, climate change is already having serious consequences on the region's scarce water supplies; this particularly applies to the snow that makes up most of the region's precipitation and that, when melted, provides 70% of its water. To date, decreases in snowpack, less snowfall, earlier snowmelt, more winter rain events, increased peak winter flows, and reduced summer flows have been documented (Saunders et al. 2008). Another potential effect of climate change is that more dust will be produced as vegetative cover decreases and as soils become dry (Mormon 2010). It is widely understood that impurities in snow, such as dust or soot, decrease snow albedo[15] and enhance solar radiation absorption and melt rates. Dust may shorten snow-cover duration by as much as a month (Painter et al. 2007). Earlier spring snowmelt and higher spring/summer temperatures have broad implications with regard to water resources in southwestern states that are already strapped for water, especially during the summer when peak demand is higher, and these factors also lead to increased numbers of forest fires (USGCRP 2014). It is likely that most dust on snowpack at high mountains is coming both from nearby lands where soil-disturbing activity has made the land susceptible to wind erosion and dust from the deserts of Colorado Plateau along with prevailing westerlies, and to dust from other southwestern deserts to some extent. Activities such as exploration and development of energy resources, offroad vehicle use, agriculture, and grazing serve to destabilize soils, making them more susceptible to wind erosion (Belnap et al. 2009).

In December 2012, Reclamation and agencies representing the seven Colorado River Basin States completed the Colorado River Basin Water Supply and Demand Study (Reclamation 2012e). The purpose of the Study was to define future imbalances in water supply and demand in the Basin through the year 2060, and to develop and analyze options and strategies to resolve those imbalances. The study used several different scenarios for both supply and demand to capture a range in potential future conditions. The supply conditions included the downscaled general circulation model (GCM) projected trends and variability (downscaled GCM) scenario. This scenario was developed as one plausible projection of the future based on recent studies of future changes in climate variability and climate trends, and their influence on streamflow and Basin water supply, which indicate that the climate will continue to warm, and

[15] The fraction of solar radiation reflected from an object or surface, often expressed as a percentage.

that there will be corresponding changes in regional precipitation and temperature trends beyond what has occurred historically. Comparing the median of the water supply projections against the median of the water demand projections, the long-term projected imbalance in future supply and demand is about 3.2 million ac-ft by 2060 (Figure 3.16-1).

Another key Reclamation document that provides information regarding climate change is the 2011 SECURE Water Act Report (Reclamation 2011e). It identifies climate challenges the Colorado River Basin could likely face:

- On average, Colorado River Basin temperature is projected to increase by 5 to 6°F during the 21st century, with slightly larger increases projected in the upper Colorado Basin.
- Precipitation is projected to increase by 2.1% in the upper basin while declining by 1.6% in the lower basin by 2050.
- Mean annual runoff is projected to decrease by 3.5 to 8.5% by 2050.
- Warmer conditions will likely transition snowfall to rainfall, producing more December to March runoff and less April to July runoff.

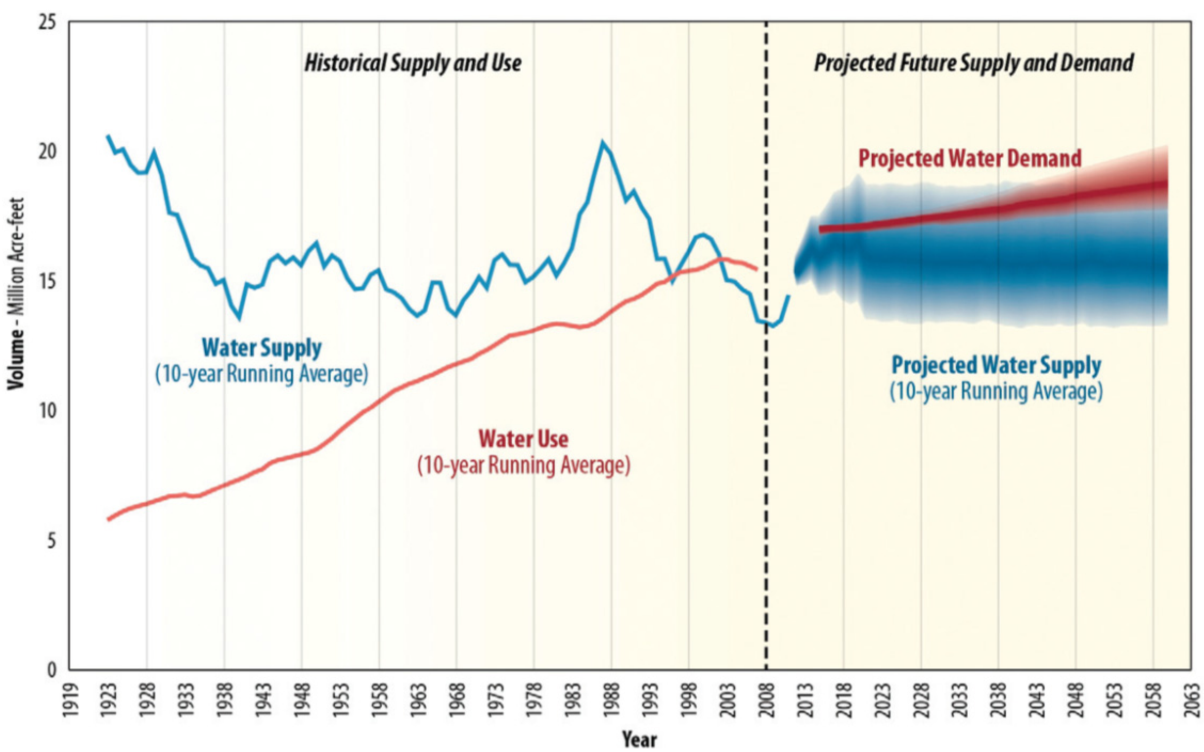

FIGURE 3.16-1 Historical Supply and Use and Projected Future Colorado River Basin Water Supply and Demand (medians of projections are indicated by the darker shading) (Source: Reclamation 2012e)

Historical and projected climate changes have potential impacts for the basin:

- Spring and early summer runoff reductions could translate to a drop in water supply for meeting irrigation demands, resulting in lower reservoir levels, which adversely impact energy production from hydropower operations at the Glen Canyon Dam.

- Increased winter runoff may require infrastructure modification or flood control rule changes to preserve flood protection, which could further reduce warm-season water supplies.

- Warmer conditions might cause changes in fisheries habitat, shifts in species geographic ranges, increased water demands for instream ecosystems and thermoelectric power production, increased power demands for municipal uses (including cooling), and increased likelihood of invasive species infestations. Endangered species issues might be exacerbated.

The extent to which climate change could affect future water supply is considered in the hydrology modeling for the proposed action and all alternatives. See Section 3.2.1 for an explanation of the methodology for hydrology modeling.

Although no studies specifically evaluate the potential effects of climate change on Lake Powell or the Colorado River between Lake Powell and Lake Mead, decreases in Lake Powell elevation and corresponding increases in temperatures of water releases from Glen Canyon Dam and in water temperature of the Colorado River downstream (as well as to tributaries of the Colorado River) are important potential effects of climate change on the project area. Projections of future supply and demand in the basin indicate that inflows into Lake Powell may decrease, and the effect of climate change is likely to exacerbate this effect (Reclamation 2012e). Climate-induced changes in inflow, evaporation, and evapotranspiration all have the potential to influence water quality. For example, increased temperatures will increase metabolic rates of aquatic biota, increasing the demand for nutrients and oxygen, and potentially changing the quality of habitat for various organisms (Wrona et al. 2006; Heino et al. 2009; Woodward et al. 2010). Increases in the water temperature of the Colorado River mainstem and its tributaries in the Grand Canyon due to climate change could expand the distribution of warmwater-adapted nonnative fishes (Eaton and Scheller 1996; Rahel and Olden 2008), which can prey on and compete with native fishes such as endangered humpback chub or disadvantaged coldwater nonnative species. Climate-change-driven warmer water temperatures across the contiguous United States are predicted to expand the distribution of existing aquatic nonnative species by providing 31% more suitable habitat for aquatic nonnative species, based upon studies that compared the thermal tolerances of 57 fish species with predictions made from climate change temperature models (Mohseni et al. 2003). Climate change also may facilitate expansion of nonnative parasites such as Asian tapeworm (Rahel et al. 2008), another threat to native fishes such as humpback chub. Cold water temperatures in the mainstem Colorado River in Marble and Grand Canyons have so far prevented these warmwater fishes and parasites from expanding their distribution in the project area. Warmer climate trends could result in warmer overall water temperatures, increasing the prevalence of these species and threating native fish populations.

Climate change effects on Lake Powell's elevation could also affect the amount of electric energy produced by the Glen Canyon Dam Powerplant over the study period, as well as the electric capacity of the Glen Canyon Dam. The hydraulic head (water pressure) on the turbines in the Glen Canyon Dam Powerplant is directly proportional to the elevation in Lake Powell. Thus, when Lake Powell's elevation drops, the amount of hydropower generated by a given release volume also decreases. Ultimately, if Lake Powell drops low enough, no power can be produced at Glen Canyon Dam (at a Lake Powell elevation of 3,490 ft).

In addition to water temperature, other aspects of water quality are also affected by Lake Powell's elevation. Dissolved oxygen concentrations in the tailwater are usually slightly below saturation but have not dropped to concentrations low enough to affect the aquatic ecosystem in the Grand Canyon. However, climate-change driven decreases in the elevation of Lake Powell could increase the chances of water that is low in DO being released from Glen Canyon Dam (Vernieu et al. 2005). Low DO in the tailwater could adversely affect the rainbow trout fishery in Glen Canyon. Similarly, an increase in water temperatures of the Colorado River driven by climate change could cause low levels of DO in Lake Mead that could adversely affect native and nonnative fish (Tietjen 2014).

Climate change could have mixed effects on sediment supply and retention in the Colorado River in the project area. For example, reduced precipitation under climate change could lower sediment input from tributaries to the mainstem of the Colorado River. In addition, higher variability in flows under climate change may require higher flows in equalization years, which could lead to a large erosive effect. Conversely, lower average flows in the Colorado River could positively affect overall sediment retention.